The market potential of micro-CHCP

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PolySMART

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PolySMART® is a project partly funded by the European Union where 32 partners collaborate in order to develop a set of technical solutions for a new market segment for poly-generation, in particular the market for small tri-generation systems.

The main objectives of operation of this combined system called “Combined heating, cooling and power (CHCP)” are the following:

- To reduce the consumption of conventional energy for cooling by use of waste heat from a co-generation system in combination with a thermally driven cooling process.
- Thereby to improve the economic viability of the entire system by an increase of the annual operation time of the CHP unit.

CHCP technology already exists on a large scale, mainly for industrial applications and some district cooling applications. The goal within PolySMART is to develop further application areas using small-scale CHCP systems in the commercial, tertiary and residential sectors.

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Why use combined heating, cooling and power systems (CHCP systems)?

The advantage of combined production of heating and power in a co-generation (or CHP) system is obvious: the waste heat which is always produced when electricity is generated using thermodynamic cycles is not rejected to the environment – like in large scale centralized power plants – but can be used. Typical use of this heat is to heat buildings or to produce domestic hot water. However, the times when use can be made of this heat are limited on certain seasons, at least if the main part of the waste heat is applied for heating buildings. Depending on the building site and building standard the heating season often lasts for only 6 months or less. But for the economic viability of CHP systems it is important that they are used as much as possible. Therefore, other uses of the waste heat are awakening more interest. One of the possible uses of waste heat during the non-heating season is cooling. The demand for summer air-conditioning of buildings in Europe is increasing due to enhanced comfort expectations, architectural trends using large glass façades and also due to climate change. Therefore, the combination of combined heat and power (CHP) and thermally driven chillers (TDC) operated with the CHP's waste heat seems to be a logical step.

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Executive summary

1. Introduction

The present study aims to assess the market potential of small scale Combined Heating Cooling and Power (CHCP) in several European countries, namely Austria, Czech Republic, Germany, Italy, Netherlands, Poland, Portugal, Spain, Sweden and Switzerland.

The study focuses on grid-connected CHCP systems which are operated only when an effective use of the engine heat can be made. Being the cooling effect generated by thermally driven chillers, the engine operation is driven by both heating and cooling demand. Electricity is either consumed locally or fed into the grid, depending on the user electric demand. Also, conventional boilers and chillers fit into the system in order to cover heating and cooling peak loads.

Moreover, the study is limited to small scale or "micro" systems. The definition of "micro" in the field of combined heat and power (CHP) is not unanimous allover the world. In the U.S. the term indicates a system lower than 5 kWe. According to Cogen Europe, a micro CHP system has less than 10 kWe and a mini CHP system goes from 10 to 100 kWe. Within the PolySMART project, the target for small size CHCP focuses on small civil applications such as small residential and service buildings (hotels, hospital and offices); considering the mentioned circumstances, the suitable CHCP size is approximately in the range of 1 to 50 kWe.

2. Heating and cooling market in Europe

The analysis initially explores the European heating and cooling market framework, as the demand of heating and cooling in the residential and service sectors and the supply of heating and cooling components for separate production of heating and cooling are the reference conditions for the diffusion of micro-CHCP.

- The Residential and Service sectors alone account for more than 50% of total heat demand in the EU 15, equal to some 2,600 TWh. Space cooling demand in the Residential and Service sectors is still little, some 30 TWh and 100 TWh respectively. This is explained by the fact that cooling saturation in the civil sector is still low: 5% in the Residential and 27% in the Service have been estimated in year 2000. However, a substantial growth in the cooling demand is forecasted: assuming 40% for Residential and 60% for Service, total Residential and Service demand should reach some 500 TWh by 2020.

- Boilers (both condensing and non condensing) are by far the most widely adopted technology for separate production (i.e. excluding district heating) of space heating and domestic hot water heating. Some 8.3 million boilers were sold in Europe in 2006, of which 2.8 were condensing and 5.5 non condensing. The adoption of condensing boilers is increasing steadily. Heat pumps are increasingly but slowly becoming accepted, with nearly 250 thousand units sold in 2006 in Europe (mainly in Sweden, Germany and France), the majority of which make use of geothermal heat exchangers.

- As for air conditioning, some 3.3 million Room Air Conditioners (RACs) and some 65 thousand Central Air Conditioning (CACs) systems were sold in West Europe in 2003. Among RACs, the single and multi split technology dominates the scene with a share of approximately 80%. Italy and Spain are the leading markets and cover together about 70% of the total. The average grow rate is 5% p.a., and about 75% of yearly sales are new installations.

3. District heating and Combined Heating and Power in Europe

- More than 5,000 district heating systems exist in the area of 32 European countries. Average annual growth rates in district heat deliveries are higher in Portugal (20%) and Netherlands (16%), although mainly due to increased industrial heat deliveries. Positive growth rates for non industrial district heating systems can be found in Italy (8%), Austria (6%) and Sweden (2%).

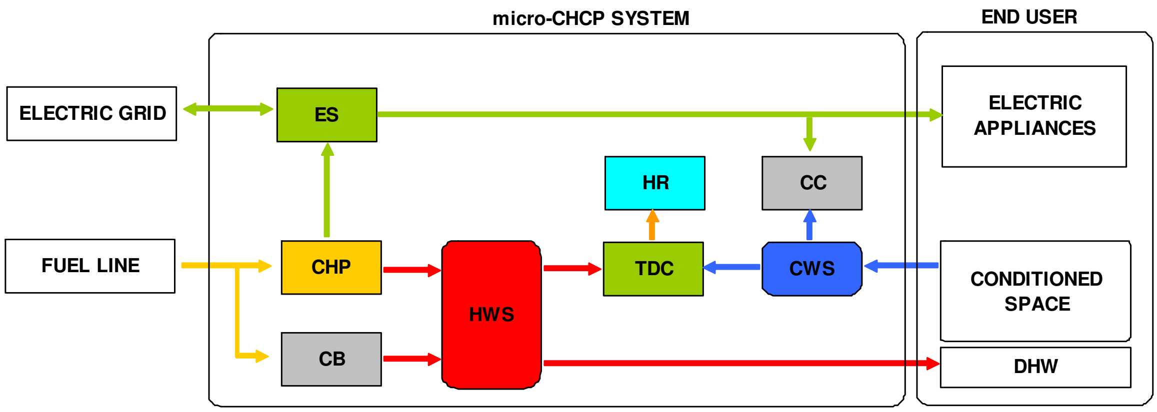
- The CHP share in heat generated for district heating systems is quite high: above 65% on average and ranging from 20% - 30% (in France, Sweden, Iceland and Norway) to 80 - 100% (in Belgium, Germany, Netherlands, Portugal and United Kingdom). A high penetration of CHP heat deliveries (> 20%) within the civil sector is estimated in the Netherlands, Czech Republic, Sweden and Poland. The main fuel used in CHP plants is natural gas, accounting for 40% of the total low heating value. Hard coal and lignite follow with 19% and 8% respectively. Renewable fuels account for only 10% of the total.

- Micro-CHP, from 1 to 50 kWe, is still in its early stage, with only a few products available on the market in Europe. Germany is the leading country with thousands of units installed in small commercial buildings, multi-family houses and single-family homes, followed by the UK, Czech Republic and Portugal. The most widely adopted technology is the 5 kWe gas engine. A few Stirling engines in the range of 2 - 9.5 kWe have also been commercialized.

- The field trial programme in the UK by the Carbon Trust's Micro-CHP Accelerator concluded that micro-CHP can achieve typical carbon savings of 15% to 20% relative to a conventional heating system using modern condensing boilers -when installed as the lead boiler in appropriate environments-. Around half of all electricity generated by such systems in the trial has been exported to the grid, so wider adoption is likely to depend on the availability of appropriate export reward tariffs. Micro-CHP should be considered as an eligible technology for policy support programmes on the condition that support is only provided for devices installed in appropriate environments.

4. Micro-CHCP technologies

A few micro cogeneration units (CHP) and thermally driven chillers (TDC) are already, or will become soon, commercially available. They constitute the basic components of a micro-CHCP system along with electric switchboard (ES), heat rejection systems (HR), conventional boilers (CB), vapor compression chillers (CC), hot water (HWS) and cold water (CWS) storages.



- When assembling a CHCP system, two major design aspects must be taken into account: driving heat temperature and engine thermal output. The CHP should be able to deliver heat at the temperature required at the TDC, i.e. usually above 80℃, and the engine thermal capacity is expected to be larger than the heat required to operate the TDC. The driving heat temperature is complicated by the fact that TDC usually works with low temperature drops between supply and return, typically 5 ℃-10 ℃, whilst CHP cooling circuits need in general higher temperature drops, i.e. 10-15℃.

- CHP prime movers include internal combustion engines, Stirling engines and micro turbines. Fuel cells are not yet considered mature for commercialization as CHP units. Gas engines present an electrical efficiency of 20% - 30% ([1]) and a total fuel efficiency of up to 90%. Minimum sizes start from 1 - 5 kWe. The Stirling engine, an external combustion motor which is very silent but is also slow to respond at load changes, shows typical electrical efficiency of only 10-15%, although total fuel efficiency can be as high as 90%. Microtrubines can have electrical efficiency as high as 30% and a total fuel efficiency of about 80%. The smallest microturbine available on the market is a 30 kW electric output engine. First costs are approximately in the range 2,000 - 4,000 €/kWe depending on technology and size.

- Thermally driven chillers include absorption LiBr water, absorption water ammonia, adsorption silica gel and adsorption zeolite chillers. Sizes larger than 20 kW cooling power are commonly available on the market. Recent developments have covered the gap in the micro scale from 2.5 to 20 kW. In absorption (water-ammonia or lithium bromide-water) chillers, the driving heat temperature is typically in the range 80 to 100 ℃ when wet cooling towers are employed for heat rejection. In adsorption (silica gel or zeolite) chillers, the driving heat temperature is typically lower, in the range 75 to 85 ℃. First costs are approximately in the range 800 - 1,500 €/kWc depending on technology and size.

5. Economic attractiveness

The potential for fossil fuel primary energy savings and financial savings has been assessed by comparing the different energy carriers utilization occurring between micro-CHCP and the separate production of heating, cooling and electricity. In order to account for the different primary energy content of energy carriers, the Primary Resource Factor (PRF) approach is used ([2]). The following analysis focuses on natural gas fired micro-CHCP.

- As the fossil fuel power plants have the least dispatching priority, the marginal power plant was assumed to have the same conversion efficiency as the country average fossil fuel generation. The electricity PRF of fossil fuel power plants has been estimated on the basis of IEA data. Including the effect of grid losses, an average of 2.66 was found for the considered countries.

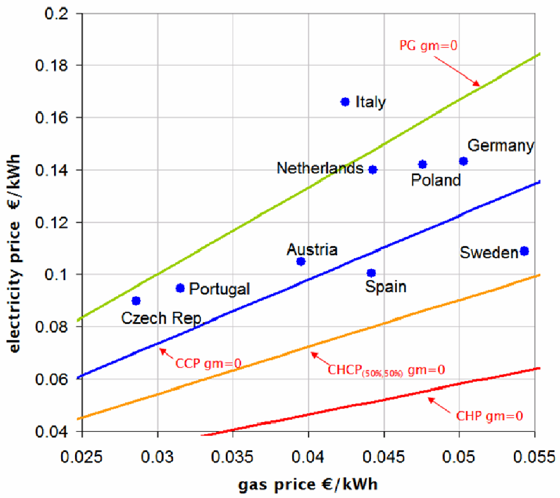
- Primary energy savings are easier to obtain in heating (combined heating and power, CHP) than in cooling mode (combined cooling and power, CCP). The most sensitive parameters are the electricity PRF and the micro-CHCP electrical efficiency. It is believed that, at the current level of grid efficiency, micro-CHCP can compete with cooling separate production only when the micro-CHP electrical efficiency is well above 25% on a low heating value basis. Moreover, TDC electrical consumption and thermal COP must not be far from the best values achievable at the present state of development. It is concluded that top performing CHCP systems have the potential to become an environmentally sound alternative to separate production.

- Financial benefits are mostly affected by the gross margin arising from the avoided purchase of self-generated electricity and fuel for heating. For a top performing CHCP

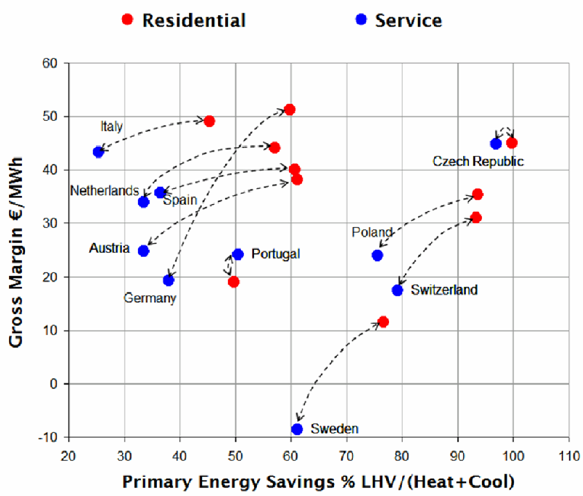
[1] Throughout the present report, efficiencies are expressed on a low heating value basis.
[2] PRF is a definition by EuroHeat & Power and represents the content of fossil fuel resource, on a low heating value basis, per unit of energy delivered at the use point.

system, the price of fuel and electricity are the key factors. In the considered countries, prices for the consumer are configured in such a way that, if a positive gross margin can be easily guaranteed in CHP mode, the same is not true in CCP mode.

- A comparative picture of the maximum achievable gross margin and primary energy savings in the Residential sector reveals that energy savings are most promising in countries like Czech Republic, Poland and Switzerland, whereas gross margin seems best in Germany and Italy. The picture for the average Service user shows, in general, a less attractive potential. Coherently, this is due to an higher cooling to heating demand ratio and to a lower price of electricity, as compared to the Residential case. However, reality might look very different, as the analysis assumed ideal conditions (e.g. reverse metering of electricity) which are not (and might not ever be) in place. Moreover, an economically sized CHCP system will not have enough capacity to cover the peak loads, thus reaching less primary energy saving than the maximum achievable: the lower the full load operation hours, the longer the payback time.



2007 energy prices Vs lines of zero gross margin in power generation (PG), cooling & power (CCP), heating & power (CHP), heating cooling and power (CHCP). Margin is positive above the lines



Primary energy saving Vs gross margin for the average residential and service user in year 2007

Gas fired micro-CHCP is one of the possible CHCP solutions. Other ways to efficiently combine heating, cooling and power production are biomass fired micro-CHCP and district heat driven TDCs.

- Biomass fired micro-CHCP can become a technically viable solution as the Stiriling engine becomes more and more reliable. The main limitation is the electrical efficiency of the CHP systems, which might not exceed 10%. However, the heat in excess might not be a problem in the eventuality of a large demand for heating and cooling. Environmentally viable, this technology can benefit from large incentives on green electricity, ranging from 0.180 to 0.195 €/kWh$_e$ on the top of the regular electricity feed-in tariff. The small agro food industry would be the ideal market for the early uptake of this technology.

- A comparative analysis of the cooling PRF in district heat driven micro-TDCs and mechanical cooling shows that district heating driven micro-TDCs might be environmentally sound in many circumstances. The key factor is the district heat PRF, which must be lower than a limiting value ranging from about 0.40 (Netherlands, Austria) to about 0.55 (Poland, Czech Republic). Such conditions might be achieved only when the district heat PRF can benefit from the internalization of the electricity produced in central CHP plants, co-firing of green fuels and waste heat delivered by industrial activities. However, concerns exist on the financial viability of the solution. The heat utilized for driving the micro-TDCs can provide little margin, as it has to compete with the cheap operating cost of conventional cooling (approximately one fourth of the electricity price).

6. Selected case studies

The economical viability is influenced by many factors, including: the effective performance of the CHCP plant (start-ups, thermal storage losses, effect of outdoor temperature); the load profile (which in turn affects full load operational hours and electricity export / import); the first costs associated to the hardware and the installation work; the variability of energy prices over the system useful life; the specific incentives applicable to CHCP (e.g., tax breaks on fuel, white certificates, capital subsidy). An overall assessment of these factors can be performed only by means of detailed computer simulations. Although maintaining a theoretical character, the investigation has provided insight on how well the market available micro-CHCP equipments cope with the energy demand and prices in different sectors.

- **Hotels in Italy** - With about 1.9 mio of beds, hotels in Italy represent a flourishing sector with a positive trend over the last few years. The 3 and 4 star categories cover the largest share: 51% and 27% respectively. Whereas large electrical capacities (> 100 kWe) are suited for 5 star hotels, micro-CHCP can cover a substantial share (> 50%) of the energy demand of small sized hotels (< 100 - 150 rooms), which constitute the majority of the hotels in the 3 star and 4 star categories. The most economical micro-CHCP is in the size range of 20 - 50 kWe, 30 - 80 kWt and 15 - 35 kWc, with a coverage of about 75% of the heating and cooling demand in small hotels (< 50 rooms) and about 50% in larger hotels. On average, total primary energy savings well above 10% can be achieved at the economic optimum. Primary energy savings in 3 star and small sized 4 star hotels are larger in the Centre-North (10-20%) than in the South (6-13%). Moreover, the payback time becomes very attractive (<5 years) only in a strong support scenario, with maximum capital subsidy in an order of 30,000 € per installation. The investment is reasonably attractive (payback < 10 years) in the moderate support (which assumes electricity reverse metering) and business as usual scenarios as well, but mainly in the 4 star business hotels located in the Centre - North, which can benefit from the higher marginality associated to the heating demand and, at the same time, can fully exploit the cooling capacity of the micro-CHCP.

- **Hospitals in Poland** - The health sector in Poland accounts for about 280,000 beds. The hospital sector is characterized with a very diversified architecture. Hospitals with less than 50 beds (50% share) and 50 to 200 beds (30% share) are predominant. A meaningful group is also that of hospitals with beds between 201 and 500 (15% share), which, in vast majority, have been built before 1950 and are characterized with a massive construction. Hospitals larger than 500 beds represent only a small share of the total. The best achievable primary energy savings vary between 5 (large hospitals) and 20% (small hospitals). Climate has very little effect on both the environmental and the financial potential. On the contrary, building construction and size is the key factor. Maximum savings are considerably higher for hospitals with number of beds between 51 and 200 (about 18 -20%). Profitability is not very attractive, with a net benefit to cost ratio slightly above 1 in the business as usual and moderate support scenario. However, profitability becomes more attractive in the strong support scenario (benefit to cost ratio about 1.8), thanks to a 40% capital subsidy on the CHP unit. Mid-size hospitals presents maximum energy savings in the range 10-13%, but they have low profitability because of their massive construction. In this type of hospital, cooling demand is so low that it does not allow to take profit from the investment in the TDC. Hospitals larger than 500 beds are not suited for micro-CHCP either, as they need large heating power (above 300 kWt) to cover a significant share of the heat demand. Therefore, the most promising applications are the small-sized hospitals, for which the most economical size is in the range of 15 - 20 kWe, 35 - 40 kWt, 10 -15 kWc. At the most economical sizing, the CHCP plant can cover about 40% of the heating demand and 10 - 15% of the cooling demand. The corresponding achievable primary energy savings are in the range 9 - 10%.

- **Residences in Spain** - The residential sector in Spain amounts to 1,900 mio m^2 of floor area, corresponding to some 23 mio dwellings. With an increase factor of 2.5 in the constructed area from 1990 to 2005, the 28 % of the stock was built in the years 1990 - 2000 and an additional 32% in the last decade. The prevision in population and economic growth, along with the need to keep down energy demand, has pushed towards the implementation of energy efficiency policies. In new and efficient buildings, heating demand ranges from 25 to 60 kWh/m^2,y and cooling demand ranges from 0 to 30 kWh/m^2,y, depending on location. Multi-storey buildings (from 4 to 8 floors) and single / two-storey buildings constitute the majority of the building stock, with approximately a share of 35% each. A very good insulated and small single family house, with a low heating and cooling demand, is not the best choice to implement a micro-CHCP system. Anyway, micro-CHCP can have sense in bad insulated single family houses, although economic subsidies should be granted in order to make the investment self-rewarding. Moreover, central heating systems are not too common among single-family houses (3 - 8 %). The picture is slightly more attractive in multi-storey buildings, with maximum primary energy savings of 28% in Vitoria, 24% in Madrid, 18% in Barcelona and 13% in Seville. However, due to the high price of natural gas for the residential users, in the absence of subsidies the financial potential is too low.

- **Offices in Germany** - The office sector in Germany is estimated in about 360 Millions m^2 of floor area, with micro-CHCP suitable for office sizes up to 16,000 m^2. Heating, cooling and electricity load profiles have been reconstructed for such office sizes, with overall building U-value (with respect to the useful area) of 1 W/m^2,K and internal gains of 52 kWh/m^2,year. Sensitivity to insulation level and internal gains was also explored. According to the building operation schemes that were assumed, resulting energy demand key figures were, on average, 74 kWh/m^2,year and 38 kWh/m^2,year for heating and cooling respectively. In order to draw the picture of future economic performance of the CHCP-systems in dependence on different energy price augmentation scenarios, the economic calculations were carried out for augmentation rates of 2%, 5% and 8% for electricity and gas, assuming augmentation rates for gas higher than the one for electricity. The results given rely on one specific µ-CHCP-system which is the best performing one. It consists of a CHP with an electrical output of 17 kWe and a thermal output of 32 kWt and a TDC with a cooling capacity of 15 kWc. The nominal total efficiency of the CHP is presumed to be 92%, the electrical efficiency 32%. Primary energy savings achieved with currently available µ CHCP systems compared to state-of-the art conventional heating boilers and compression chillers are approximately 20% of primary energy for the best performing CHCP system. On the other hand, depending on their efficiency numbers (and size matching) the application of worse performing CHCP systems can even cause an additional consumption of primary energy. Applied to average German office buildings, only micro CHCP systems with high efficient components perform well enough to achieve economical and ecological benefits. Economic viability is mainly dependant on the future electricity and fuel price ratio. Moreover, system sizing is another key aspect: economic viability is achievable if heat and cool demand coverage is less than 25%.

- **Offices in Switzerland** - Cooling loads in offices are becoming more important than heating loads, leading to increased electricity demand and peak load problems. A 2,400 m^2 office building complying with advanced building energy standards was used for the study. Heating demand amounts to 40MWh/a (16.6 kWh/m2/a), cooling demand to 46 MWh/a (19.1 kWh/m2/a) and electric demand for office appliances and lighting (non-HVAC) to 44 MWh/a (18.4 kWh/m2/a). The analysis has focused on the environmental performance only. Primary energy savings, carbon dioxide equivalent savings and savings in terms of eco-indicator points have been estimated. The latter consists of three midpoint indicators (ecosystem quality, human health and resource depletion), aggregated using equal weighting factors. The performance of the CHCP system was analyzed for different electricity mixes assuming a cogeneration unit (CGU) size of 7.5 kW power and 30 kW heating output, and compared to the reference system (gas boiler and chiller only). Primary energy demand is comparable to the reference for the Swiss mix, 12% lower for the UCTE mix and 12% higher for the Combined Cycle Power Plant. Emitted Greenhouse gas equivalents are substantially higher than for the reference with Swiss electricity mix. Considering all environmental impacts, polygeneration showed a high total impact, up to the double compared to the reference in the Swiss mix case with equally weighted endpoint indicators. This high impact is mainly due to the endpoint indicators “ecosystem quality” and “human health” whereas the indicator “resource depletion” has an attenuating effect.

7. Opportunities and barriers

In light of the presented case studies, micro-CHCP is likely to find application where the electricity demand is relatively not too low as compared to the heating and cooling demand, and the electricity base load is such that the electricity exported to the grid is limited. Moreover, suited applications must be characterized by smooth profiles of the heating and cooling demand, in order to maximize the operation hours of the micro-CHCP system with the minimum possible system capacity. Since the marginal energy and financial savings are more attractive for heating than for cooling, a convenient application should have a larger heating than cooling demand. Finally, the micro-CHCP should cover only a limited fraction -of about 50%- of the heating and cooling demand so that the investment becomes economical. As such, the micro-CHCP system must be complemented by auxiliary heaters and coolers.

- Prospective customers could be preferably found among:
  - Medium size hotels (< 200 rooms)
  - Small hospitals (< 200 beds)
  - Office buildings (< 4,000 m^2)
  - Small industries
  - Small supermarkets

  Due to emergency and safety, the possibility provided by the CHCP plant to self-generate electricity constitutes an added value for this type of customers. Medium size hotels and small hospitals are likely to constitute the ideal application field. According to statistics of the main chain hotels, micro-CHCP has the potential to find application in about 50% of the chain hotels in EU15, for a total of nearly 7,000 installations. Considering the totality of the hotel sectors, the number of suitable installations can likely increase up to 70,000. In the health sector, a reasonable estimate of hospitals suitable for micro-CHCP installations should be in a range from 4,000 to 6,000 units in the EU15.

- Applications in the households sector appear more difficult at the present stage of technology, although they can benefit from gross margins and primary energy savings larger than those in the Service and Industry sector. In single family houses, the benefit to cost ratio of micro-CHCP is seldom attractive because small units have a higher specific investment cost, a large part of the self-generated electricity is injected to the grid, the driving thermal load is discontinuous, relatively high costs must be sustained for the balance of the plant (storages, auxiliaries) and the room needed for heating and cooling storages might be a problem. In multi-family houses, the overall thermal and electric load would be such to justify the investment. However, centralized heating and cooling distribution systems are not always present in multi-family houses and the individual metering of heating, cooling and electricity for each dwelling adds complexity and investment cost.

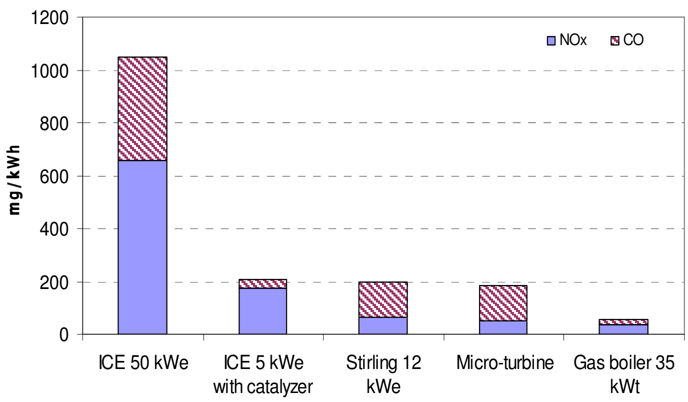
One of the main concerns about micro-CHP is the possible impact on air quality. Although micro-CHCP can provide savings of primary energy and the associated CO_2 emissions, fuel combustion generates several types of hazardous emissions. Another important aspect is the electricity market. Volatility of energy prices and enhancement in the average efficiency of fossil fuel central power generation pose concerns on the future financial savings and primary energy savings potential of micro-CHCP.

- Among the different emission sources, heating systems alone are said to contribute to the total NOx emissions of urban areas in a share variable from 20 to 40%. Consequently, the EU regulation has imposed severe restrictions on the NOx emissions of gas boilers. Nowdays, eco-labelled gas fired boilers in the range below 70 kWt have reached low NOx and CO emission levels, although some concerns exist about the effectively emitted quantity of pollutants during startups, which occur frequently when a heat storage is not installed.

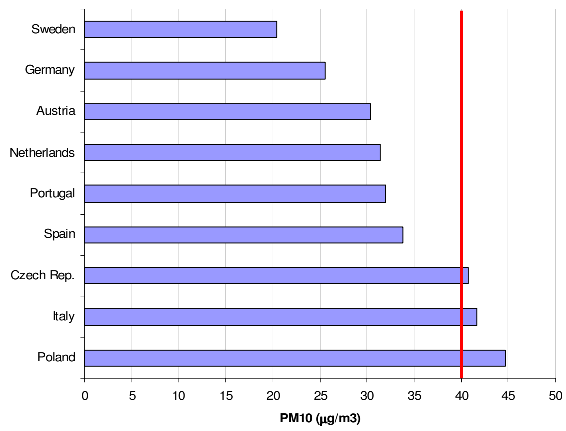
- Internal combustion engines are traditionally not the best in terms of NOx emissions, because of the high combustion temperature which is the primary cause of the NOx formation. Newly generated lean-burn engines can achieve both low NOx emissions and high efficiency by increasing the air to fuel ratio in the combustion mix. In order to bring down the flue gases CO and HC concentration, an emission control device (i.e. catalytic converter) is usually recommended.

- Stirling engines and microturbines generate NOx emissions in concentrations comparable to those of the most efficient gas boilers. However, their CO emissions can be considerably higher than those of the best gas boilers.

- The Stirling engine fuelled by solid biomass may suffer from the fine dusts problem associated to biomass combustion. Recent advances in the pellet burner technology have lead to a massive reduction of fine dusts emissions. Against fine dusts emissions of about 350 mg/kWh from the old logwood boilers, emissions from newly developed pellet burners can be as low as 30 mg/kWh. However, reasonable concerns exist on the utilization of biomass in within high density population urban areas, especially where the exposure to particulate matter is already above the limiting value set by the EU.

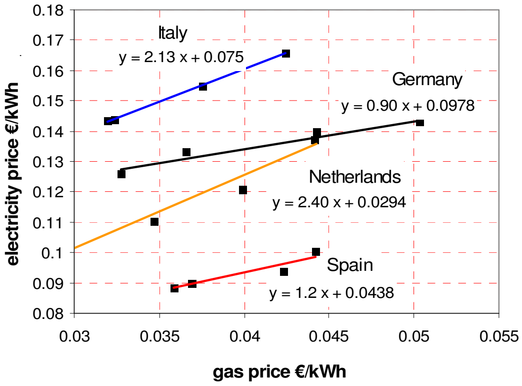


NOx and CO emissions per kWh of fuel input

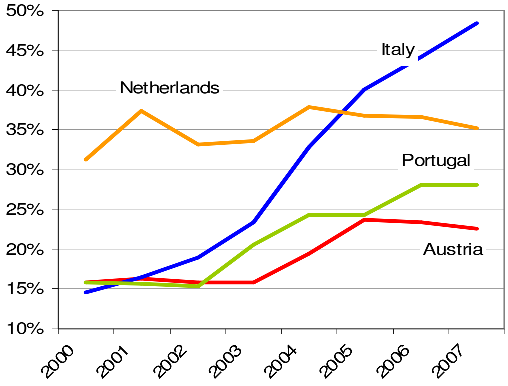


Exposure to particulate matter in year 2006 (Source: Eurostat)

- Volatility of energy prices represent a serious threat for the financial viability of micro-CHCP. Gross margin is strongly affected by the electricity price in relation to the fuel price. In the recent years, the ratio of the electricity price increase over the natural gas price increase has been very different across countries. Average electricity increase to gas increase ratios like 2.13 in Italy and 2.4 in Netherlands have contributed to the positive marginality of micro-CHCP is such countries, whereas little lower ratios like 0.9 in Germany and 1.2 in Spain have determined a loss of marginality in the recent years.



Gas price Vs electricity price in year 2004-2007 for the residenetial user (Source: Eurostat)



Trend in CCGT share over total thermal power capacity (Source: Eurostat)

- Electricity market liberalization has lead to the progressive replacement of old and less efficient power plants by new efficient CCGT power plants, as it has been the case in Italy. In the future, an increase in the fossil fuel generation efficiency would bring down the electricity PRF, thus affecting the primary energy saving potential of micro-CHCP.

The heating and cooling market in Europe

The demand of heating and cooling in the civil sector

A large amount of the total heat demand across Europe is made of low temperature heat, in the form of hot water at 80 - 100 ºC. Such low grade heat is mainly used for space heating and domestic hot water preparation in the civil sector, but also in low temperature industrial processes as washing, rinsing, and food preparation (ECOHEATCOOL, 2006). As shown in Figure 1, the Residential and Service sectors alone account for more than 50% of total heat demand in the EU 15, equal to some 2,600 TWh. Heat demand in the Industry amounts to about 1,800 TWh, of which one fourth is estimated as low temperature heat. This suggests that promoting efficient ways of delivering low temperature heat, especially in the Residential and the Service sectors, should be a top priority in the agenda of the EU carbon emissions reduction and primary energy saving policy. As compared to space heating, space cooling demand in the Residential and Service sectors is much lower, some 30 TWh and 100 TWh respectively (ECOHEATCOOL b, 2006). This is explained by the fact that cooling saturation in the civil sector is still low: 5% in the Residential and 27% in the Service have been estimated in year 2000. However, a substantial demand growth has been recorded over the past years as a consequence of the increasing need for better people comfort during the summer. Assuming cooling saturation will increase up to the current level in Japan and US, i.e. 40% for Residential and 60% for Service, total Residential and Service demand should reach some 500 TWh by 2020 (see Figure 2).

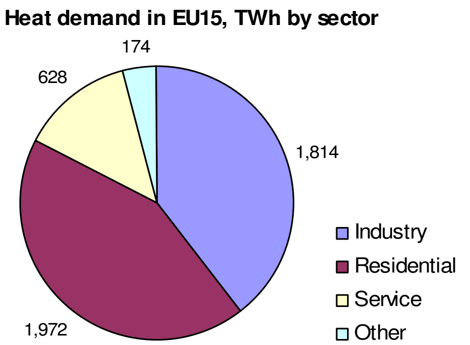


Figure 1: Total heat demand in the EU15 [TWh]

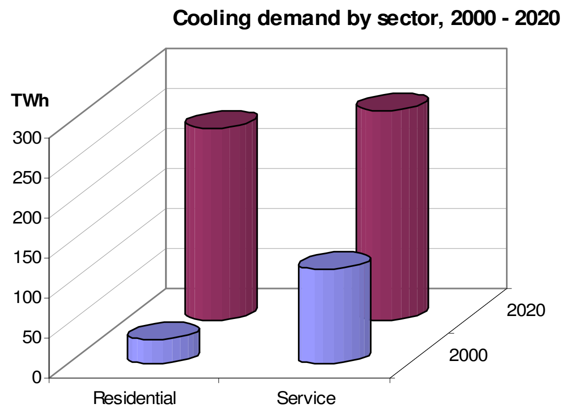


Figure 2: Cooling demand in the EU15 in Residential and Service [TWh]

Overall, Residential and Service are sectors in which energy efficiency in heating and cooling generation might play a decisive role for reaching the carbon emissions reduction and primary energy saving targets of the EU. Moreover, the concurrence of heating and cooling demand makes the residential and service sectors suitable for combined heating, cooling and power production.

The supply of heating and air-conditioning systems

Both condensing and non condensing boilers are by far the most widely adopted technology for **space heating** and **domestic hot water heating** in Europe. As reported by Bosch, 2006, some 8.3 million **boilers** were sold in Europe in 2006, of which 2.8 were **condensing** and 5.5 **non condensing** (see Figure 3). The trend over prior year shows an increase by 30 % in sales of condensing boilers and a decline by 6% in sales of non condensing boilers. With condensing technology increasingly becoming accepted as the new standard, the share of conventional boilers will likely continue to shrink. With nearly 1.5 million condensing boilers sold and less than 0.2 million non condensing boilers, the UK is the single leading market in Europe for condensing boilers. Sharp drops in conventional boilers sales were reported in

Germany and France. On the opposite, conventional boilers are still predominant in Spain and Italy. In the coming years, stable trends of + 9% p.a. for condensing and - 4% p.a. for non condensing boilers are expected.

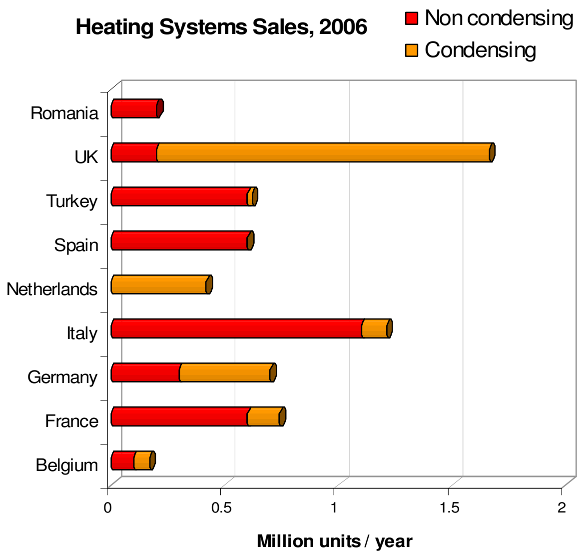


Figure 3: Boilers sales in 2006 [million units/year]

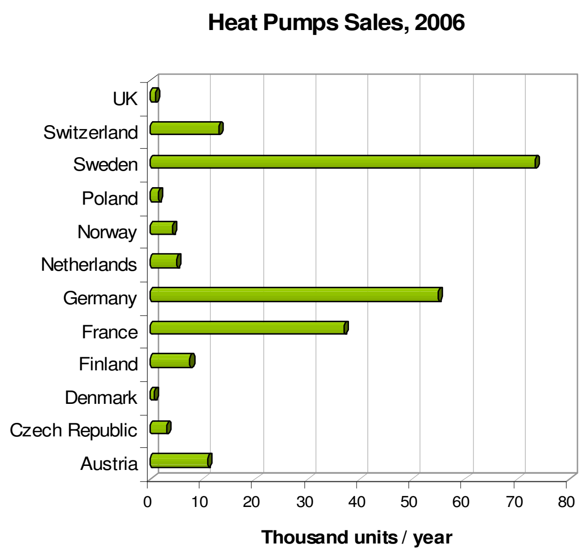


Figure 4: Heat pumps sales in 2006 [thousand units/year]

Among competing technologies, electrical **heat pumps** are increasingly but slowly becoming accepted, with nearly 250 thousand units sold in 2006 in Europe, the majority of which make use of geothermal heat exchangers. The leading markets are Sweden, with some 72 thousand units, Germany with some 54 thousand units and France with some 36 thousand units (see Figure 4).

As for **air conditioning**, some 3.3 million **Room Air Conditioners** (RACs) and some 65 thousand **Central Air Conditioning** (CACs) systems were sold in West Europe in 2003 (BSRIA, 2003)(BSRIA b, 2003).

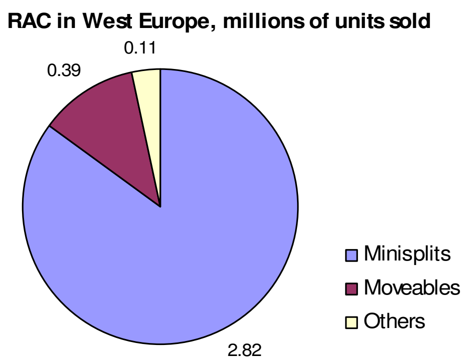


Figure 5: Room Air Conditioners sales in 2003 [million units/year]

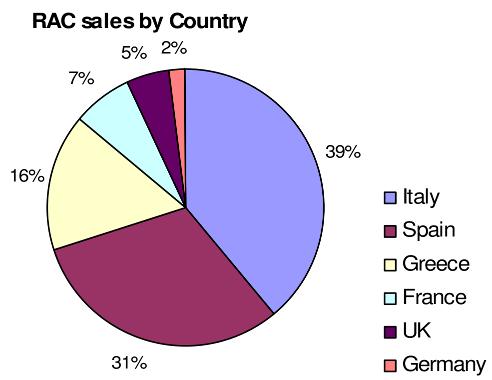


Figure 6: Room Air Conditioners sales in 2003, share by country [% of sold units]

Among RACs, the **single and multi split** technology dominates the scene with a share of approximately 80%. Italy and Spain are the leading markets and cover together about 70% of the total (see Figure 6). The average grow rate is 5% p.a., and about 75% of yearly sales are new installations.

Among CACs, **air condensed chillers** are predominant over water condensed chillers accounting for 83% of the total sales. Moreover, the market is dominated by small size chillers below 70 kW. Italy is the leading producer and controls 70% of the European market in the range of 5 to 20 kW cooling capacity. The European **air handling units** market recorded sales by 122,000 units in 2003. The largest markets are Germany (48%), the UK, Italy and Spain. The latter is the fastest growing market with a positive trend of 6.3% per year. As for the **fan coil** market, 1.3 million units were sold in 2003, but a slowdown has been recorded in the last two years, due to increased competition from split systems. However, the markets continue to benefit from a significant installed base and consequent replacement market. In particular, strong growth is expected from Greece (12.6% p.a.) as well as Spain (6.0% p.a.) and France (5.1% p.a.). 4-pipe systems are popular in Italy and the UK and control half of the European market by volume. 2-pipe systems dominate in Germany, Spain and Greece with 2-pipe + electric current particularly strong in France. In Italy there is a strong residential market of around 100,000 units. In France, Spain, Germany and Greece ceiling concealed chassis units are widely used in hotels and offices.

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CHP in the macro and micro scale

Macro CHP

Macro CHP refers to large scale (> 1 MW) combined heat and power production. There are basically two types of investors in the field: (i) autoproducers (e.g. private industries like paper, printing, chemical and oil refinery), in which the heat generated is directly used in the production process and occasionally sold to district heating utilities for distribution to the consumers; (ii) public utilities which sell heat to consumers and electricity to the public grid. Public utilities accounted in 2002 for 54 % of the total electricity generated by macro CHP plants in Europe (Danko & Lösönen, 2006). In contrast, public utilities are less efficient in heat generation, since the total share of CHP heat was about 42 % in the same year.

There are basically five types of technology in CHP generation:

- Combined cycle plants
- Gas turbines with heat recovery
- Steam backpressure turbines
- Steam condensing turbines
- Internal combustion engines

Overall, steam turbines -both backpressure and condensing- account for about 50% of the electricity generated in CHP in the EU25 (see **Figure 7**). Combined cycles account for 23%, followed by gas turbines with heat recovery (15%) and internal combustion engines (9%).

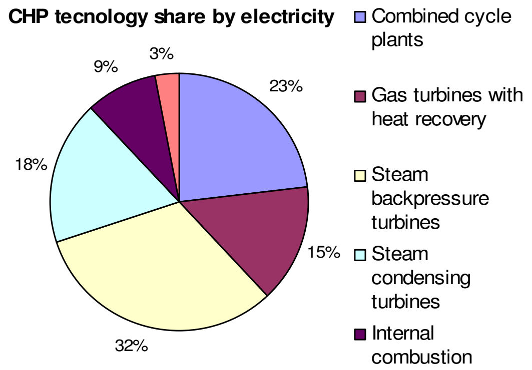

Figure 7: CHP electricity generation in the EU 25

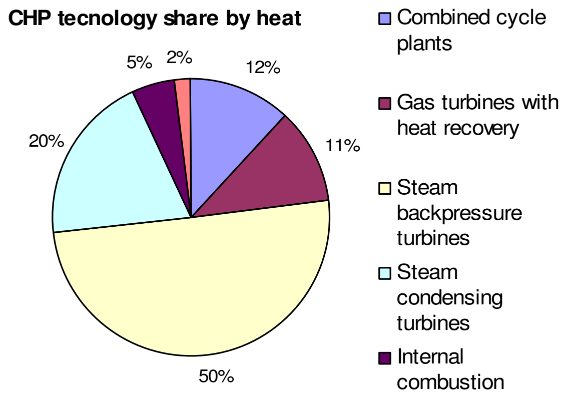

Figure 8: CHP heat generation in the EU 25

By looking at heat generation, the share by technology changes due to the different power to heat ratio. Steam backpressure accounts alone for 50% of the total heat generation in CHP, followed by steam condensing (20%), combined cycle (12%), gas turbine with heat recovery (11%) and internal combustion engines (5%).

Assuming that CHP public supply delivers most of the generated heat to the residential and service sector, it is possible to calculate the saturation of CHP in terms of share of electricity and heat in CHP public supply over total electricity and heat consumption.

CHP public supply generation was reported for year 2002 (Danko & Lösönen, 2006), while electricity and head demand in the residential and service sector was available for year 2003 (ECOHEATCOOL, 2006). The calculated penetration of heat and electricity generation in CHP is shown hereafter for some European countries (see **Figure 9** and **Figure 10**). A high penetration of CHP heat deliveries in the civil sector is estimated in Netherlands, Czech Republic, Sweden and Poland, where the heat share must be easily higher than 20%.

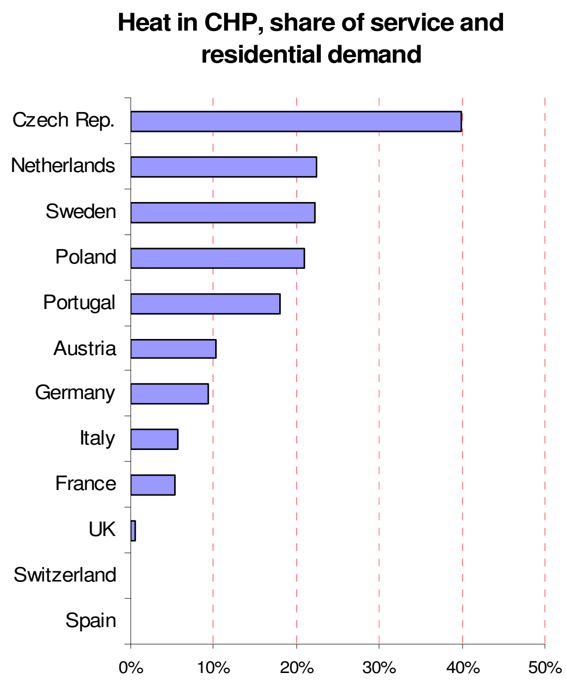

Figure 9: Penetration of CHP heat by country, residential and service sector

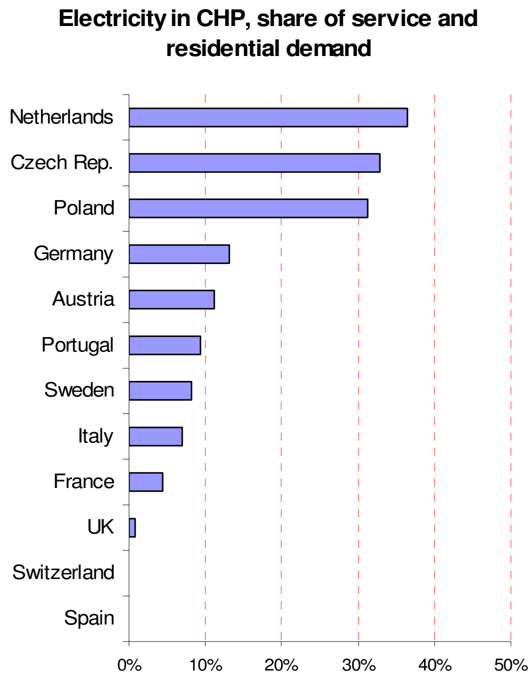

Figure 10: Penetration of CHP electricity by country, residential and service sector

The main fuel used in CHP plants is natural gas, accounting for 40% of the total low heating value. Hard coal and lignite follow with 19% and 8% respectively. Renewable fuels account for only 10% of the total. Fuel input in CHP by country is represented in **Figure 11**. Germany, Italy and Netherlands are the main consumers of natural gas, followed by UK, Spain and France. Poland relies mainly on coal, which is also representing an important share in Germany, Netherlands and Czech Republic. Lignite is used in Czech Republic and Germany, while renewable fuels, including solid waste, are well established in Sweden, France, Austria and Portugal.

One major distinction in CHP plants is between gas fired and solid fuel fired plants. High electrical efficiency and high electricity to heat ratio can be obtained in combined cycles and gas turbines, both requiring gas -mainly natural gas- as fuel. The electrical efficiency is typically between 40% and 50%. Lower efficiencies can be obtained by internal combustion engines. In contrast, CHP plants running on solid fuel such as coal, lignite and solid biomass are mainly based on back pressure steam turbines, which can achieve a lower electrical efficiency . Typically, biomass fired plants have electric efficiencies in the range of 15% - 30% depending on the boiler’s technology. Co-firing, i.e. the combination of different types of fuel, is widely adopted. Typically biomass fired plants make use of different types of biomass (e.g. bark, sawdust or cutter chips) and fossil fuels (e.g. coal or peat).

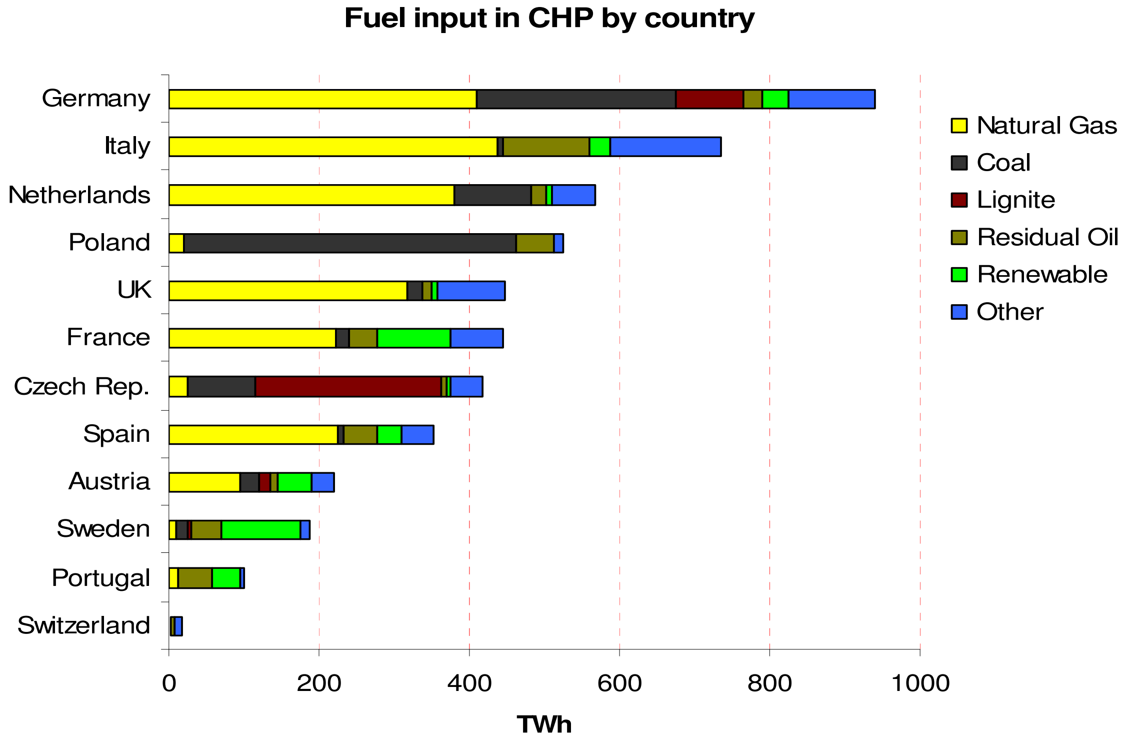

Figure 11. Fuel input in CHP by country, LHV, [TWh]

Being district heating networks the necessary distribution channel for public heat supply, their expansion is a fundamental driver for macro CHP market growth. More than 5,000 district heating systems exist in the area of 32 European countries (ECOHEATCOOL d, 2006). Statistics of district heat deliveries indicate that the CHP share in heat generated for district heating systems is quite high: above 65% on average and ranging from 20% - 30% (in France, Sweden, Iceland and Norway) to 80 - 100% (in Belgium, Germany, Netherlands, Portugal and United Kingdom).

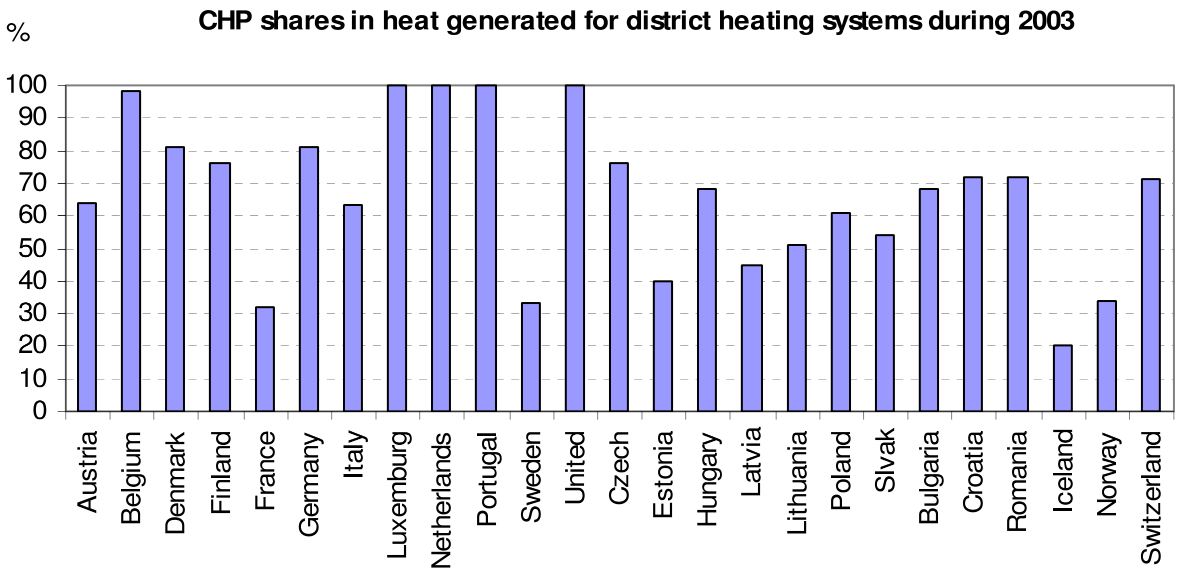

Figure 12: CHP share in heat generated for district heating systems, 2003. Source: ECOHEATCOOL d, 2006.

Average annual growth rates, based on annual heat deliveries in district heating systems, have been estimated for the years 1992 - 2003 (ECOHEATCOOL d, 2006) . The high growth rates in Portugal (20%) and Netherlands (16%), are mainly due to increased industrial heat deliveries from CHP plants. Positive growth rates for non industrial district heating systems can be found in Italy (8%), Austria (6%) and Sweden (2%). The relatively low growth rate in Sweden is justified by the fact that district heating covers a high market share in this country. Germany and France have been early adopters but heat sales have not changed during the last years, although a margin for growth exists in both countries. Decreases appear in Poland (-6%) and Czech Republic (-3%), but the lost heat deliveries have been recorded mainly by industrial users.

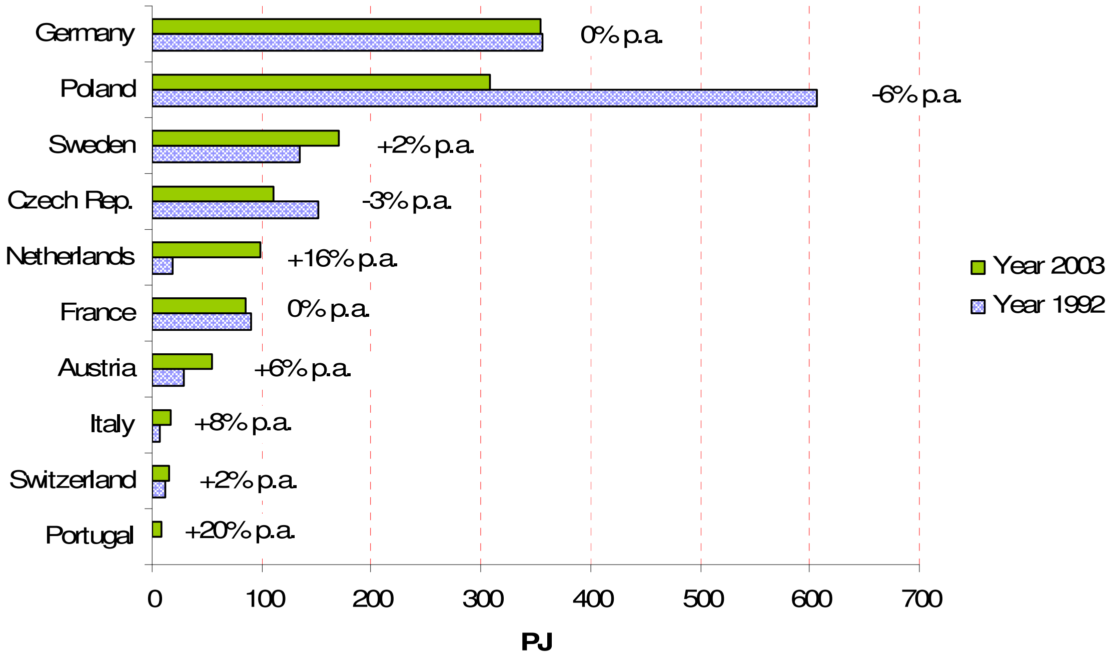

Figure 13: Heat deliveries in district heating systems in 1992 and 2003, average growth rate

Micro CHP

Micro-CHP refers to CHP in the small scale, approximately from 1 to 50 kWe. Micro-CHP is still in its early stage, with only a few products available on the market in Europe.

Recent experiences in Europe

Germany is the leading country with thousands of units installed in small commercial buildings, multi-family houses and single-family homes (Cogen Europe, 2005). The most widely adopted technology is 5 kWe gas engine (SenerTec DACHS, Ecopower). A few Stirling engines in the range of 2 - 9.5 kWe have also been commercialized. The German government has supported micro-CHP through incentives such as: a bonus price for micro-CHP electricity exported to the grid of about €0.0511 per kWh on top of the regular price; and an exemption from the mineral oil tax levied on natural gas and fuel oil used for heating purposes. Moreover, energy efficiency regulations consider micro-CHP as an energy saving instrument for newly constructed houses. Minor regulatory issues were reported due to delays in getting the permission to connect to the grid by the local utility.

In the Netherlands about one hundred 5 kWe gas engine micro-CHP units have been installed (Cogen Europe, 2004). Similarly to the German experience, the vast majority of these installations are SenerTec units 5 kWe gas engines. Regulatory aspects to be addressed in the future include: the right to interconnect micro-CHP with the distribution network, the metering requirements for micro-CHP, and a fair remunaration of the micro-CHP generated electricity that is exported to the grid. Problems are envisaged if large numbers of 1 kW units were to be installed in households.

In the United Kingdom more than 80,000 WhisperGen units are planned to be installed before 2010 (Cogen Europe b, 2005). Such units are designed for individual homes use, generate 1 kW of electricity and 8 kW of heat and are built around a Stirling engine. In addition to the WhisperGen unit, gas engines like SenerTech DACHS, EcoPower and EC Power are also sold in the UK. In 2005 the Government -in response to successful field trials- has cut the VAT from 17.5% to 5% for micro-CHP systems. The reduction in VAT is effectively a 12.5% subsidy for micro-CHP units over conventional systems.

A demonstration project in the UK by the Carbon Trust's Micro-CHP Accelerator was launched with the aim to investigate the potential benefits of Micro-CHP and understand the technical, commercial and regulatory barriers to adoption (Carbon Trust, 2007). The trial has demonstrated that the carbon and cost savings from Micro-CHP are generally better for buildings where they can operate for long and consistent heating periods. The key currently available Micro-CHP technologies are IC engines for small commercial applications and Stirling engines for domestic applications.

As for small commercial applications, the field trial has shown that Micro-CHP systems can typically provide heat outputs in the range of 50 to 500 MWh per year, depending on site requirements and system sizing, and typical carbon savings of 15% to 20% relative to a conventional heating system using modern condensing boilers -when installed as the lead boiler in appropriate environments-. The associated cost savings for such systems are expected to be in the range of £1,000 to £10,000 per year, again depending on heat demand and system sizing. Moreover, commercial Micro-CHP devices can provide significant carbon savings in applications such as residential care homes, community housing schemes and leisure centres, which have high and consistent heating or hot water demands all year round. In such scenarios, the Micro-CHP plant is typically sized so that it runs consistently throughout the year to meet the base load requirements for heat, while the electricity generated is used to meet on-site requirements for electricity.

In domestic applications the annual heat demand has been found to be a useful metric for identifying houses with a high likelihood of achieving worthwhile carbon savings. The domestic Micro-CHP systems monitored in the trial have the potential to provide typical carbon savings of 5% to 10% for older, larger houses with high and consistent heat demands. Moreover, they have been found to provide potential annual savings in the target market of around £40-£90 depending on the level of reward for exported electricity. Around half of all electricity generated by such systems in the trial has been exported to the grid, so wider adoption is likely to depend on the availability of appropriate export reward tariffs. Customer feedback suggests there are various practical and service-related issues that must be addressed before domestic Micro-CHP systems are deployed at scale.

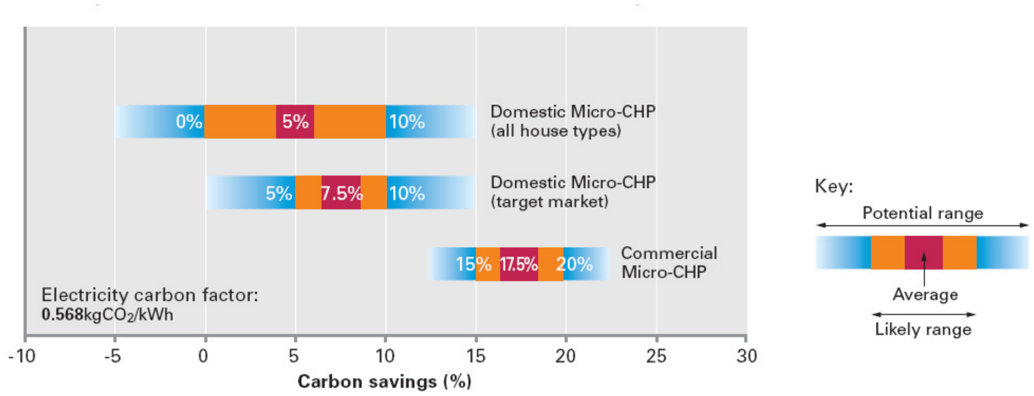

Figure 14: Range of carbon savings expected for domestic and commercial Micro-CHP (relative to a typical A-rated condensing system boiler and based on carbon emissions factor of 0.568kgCO2/kWh for displaced electricity) Source: Carbon Trust, 2007.

In light of the field trial findings, it is appropriate that Micro-CHP should be considered as an eligible technology for policy support programmes, but on the condition that support is only provided for devices installed in appropriate environments.

The majority of analysis in this report is based on using a 'marginal plant' emissions factor (rather than average grid mix) to reflect the fact that Micro-CHP systems have been shown to generate most electricity at times when the carbon intensity of the grid is expected to be higher, such as daytime/evening and winter peak demand periods.

Regarding future actions for market implementation, the study concluded that there are various actions which could accelerate the uptake of commercial Micro-CHP systems and ensure effective ongoing operation and maintenance. Extrapolation of the field trial results has shown that if manufacturers were able to improve the electrical efficiency of current domestic Micro-CHP units by just 3% (from a typical range of 6-8% to a range of 9-11%), while maintaining the same overall efficiency, this could result in a dramatic improvement in the carbon saving potential, with a near doubling of carbon savings predicted for a typical household in the target market. Domestic Micro-CHP manufacturers could also consider designing units to allow operation with higher electrical efficiency in larger and older houses. On the other hand, suppliers could potentially increase the uptake of Micro-CHP by offering customers packaged solutions of financing, installation, maintenance and electricity buy-back.

A small number of micro-CHP units with an electrical output below 50 kW are currently running in Portugal (Cogen Europe b, 2004). These include 5 kW SenerTec units running in hotels, several 15 kW Fiat Totem units running in hotels and swimming pools and some field trials of advanced micro-CHP technologies like 5 kW Vaillant fuel cells heating appliance and 30 kW Capstone microturbines. The Government supported micro-CHP through incentives on the electricity exported to the grid. The bonus price was paid on top of the base value for electricity and was differentiated according to CHP technology: 1 €c/kWh for gas engine, 1.5 €c/kWh for micro-turbines, 2.0 €c/kWh for Stirling engines and 20 €c/kWh for fuel cells.

In Czech Republic several hundreds of TEDOM Premi micro-CHP units have been installed (Cogen Europe c, 2004). TEDOM manufactures micro-CHP units in sizes from 8 kW_e (21 kW_{th}) to 45 kW_e (87 kW_{th}). The units are built around internal combustion gas engines. The Governament supported natural gas fired micro-CHP until 2005 through a guaranteed feed-in tariff of 3.8 c€/kWh for low voltage connection to the grid. After 2005, the feed-in tariff has been raised and it is currently estimated around 5 c€/kWh.

Market prospects

According to Slowe, 2008, 5 kW electrical output units are the most available commercial products and are mainly sold in Germany. The number of units sold is still low, approximately 3,000 p.a. in 2005. It is estimated that even with a steady growth by 25% p.a., the number of units sold p.a. in Europe will not exceed 5,000 - 10,000 by 2010. However, the market of 1 to 3 kWe sized products -specifically designed for single family homes- is expected to emerge in the near future, especially in the UK, Netherlands and Germany. In the small scale range, Stirling engines are expected to become the dominant technology, at least until fuel cells will find commercialization. Recently, a Dutch-German-Italian joint cooperation has been started in order to extensively test the first generation 1 kWe Stirling gas fired micro-CHP devices with over 1,000 installations to be constructed between 2008 and 2010. Gas engines are also suitable for micro-CHP, and several products in the range of 1 kWe - 50 kWe are ready for commercialization. Small-sized gas engines have been successfully tested in Japan, Germany, Czech Republic and Italy. Stationary fuel cells are mainly targeting the market of power backup systems. Only few products qualify as cogeneration unit. Among those few, real commercial products have a minimum size of 200 kW, which is too high for micro-cogeneration. Small scale prototypes of about 1 kW electrical output with heat temperatures of about 65 °C are being tested in Japanese houses. Microturbines in the range of 30 to 60 kW electric output are also a viable option for micro-CHP. They are already available on the market and have been extensively tested in the US.

Though CHP is still in an early stage, it has the potential to become the predominant technology in the field of distributed generation. The potential for micro-CHP is said to be enormous, with 5 to 12 millions of units expected to be sold by 2020 depending on political support (Micro Map, 2002). Overall, the market suffers from the lack of available products, uncertain involvement of boilers manufactures and utilities, and minor but still present regulatory barriers. The situation may turn into an exponential growth depending on how strongly boiler manufacturers engage in micro-CHP.

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Micro-CHCP systems

Micro-CHCP schemes

Although a standard micro-CHCP system does not yet exist, it is likely that a generic micro-CHCP system will be made of a cogenerator (CHP), one or more thermally driven chillers (TDCs), a heat rejection device (HR), a hot water storage (HWS) and a cold water (CWS) storage (see Figure 15). The system should be ready for integration with a conventional boiler (CB) as hot backup and a conventional chiller as cold backup (CC). Moreover, an electric switchboard (ES) will manage the electricity export to and import from the grid. The system controller will operate the TDC according to the setpoint temperature in the CWS. If present, the controller will operate the CC in sequence. Similarly, the controller will operate the CHP according to the temperature in the HWS, and the CB, if present, in sequence. The TDC should never be driven by the CB heat.

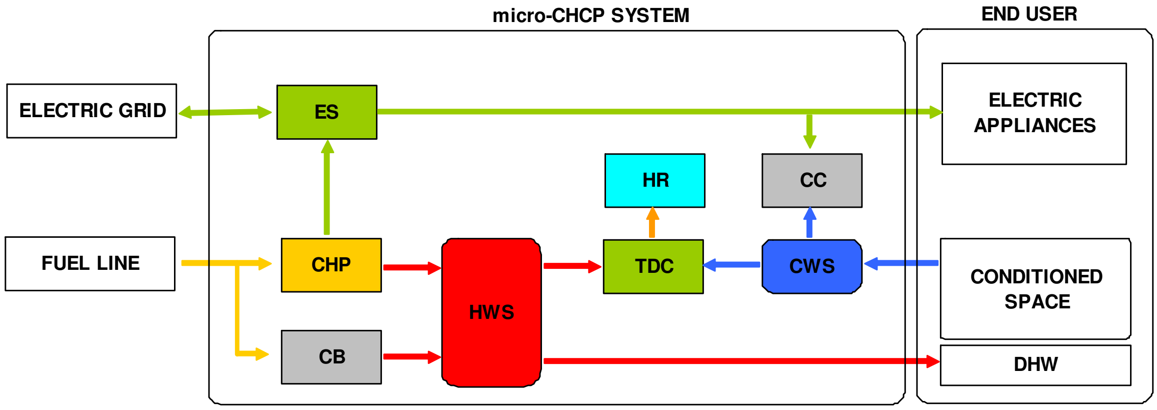

Figure 15: Scheme of a generic micro-CHCP plant

Several variants to the above mentioned CHCP plant are possible: heat autonomous, autonomous cooling, electrically autonomous, without HWS and / or CSW. Depending on the specific CHP technology, fuels commonly used can be natural gas, LPG, diesel, biogas, biodiesel or solid biomass.

The peculiar components of a CHCP system are the CHP and the TDC. In the micro-CHCP scheme, both the CHP and TDC should be small size systems: the CHP should approximately in range from 3 to 75 kW electrical output, the TDC should range from 3 to 75 kW cooling capacity. In the macro CHP and micro TDCs scheme, only the TDCs must be small scale chillers, ranging from 3 to 75 kW.

When assembling a CHCP system, two major design aspects must be taken into account: driving heat temperature and engine thermal capacity. The CHP should be able to deliver heat at the temperature required at the TDC, i.e. usually above 80°C, and the engine thermal capacity should be larger than the heat required to operate the TDC. The driving heat temperature is complicated by the fact that TDC usually works with low temperature drops between supply and return, typically 5 °C-10 °C, whilst CHP cooling circuits need in general higher temperature drops, i.e. 10-15°C.

Another concept of CHCP is based on macro combined heat and power plant(s) delivering heat to small scale TDCs installed at the users place (see **Figure 16**). District heating powered TDCs can be a sound alternative to district cooling, since they can make use of already existing infrastructures to deliver heat for cooling purposes to users without the need of a dedicated district cooling network. However, such a scheme is not yet developed, being offered only by few district heating operators in Northern European countries. It is important to mention that in large district heating networks, such as the ones operating in North

Europe, external heat deliveries are quite common, e.g., waste heat from industries, waste incinerators or other CHP plants. As a consequence, district heating powered TDCs can increase the heat demand during summer months and enhance the utilization of waste heat in large district heating networks. As previously mentioned, the driving heat temperature of the supply line and the temperature drop between supply and return line are the major technical challenges.

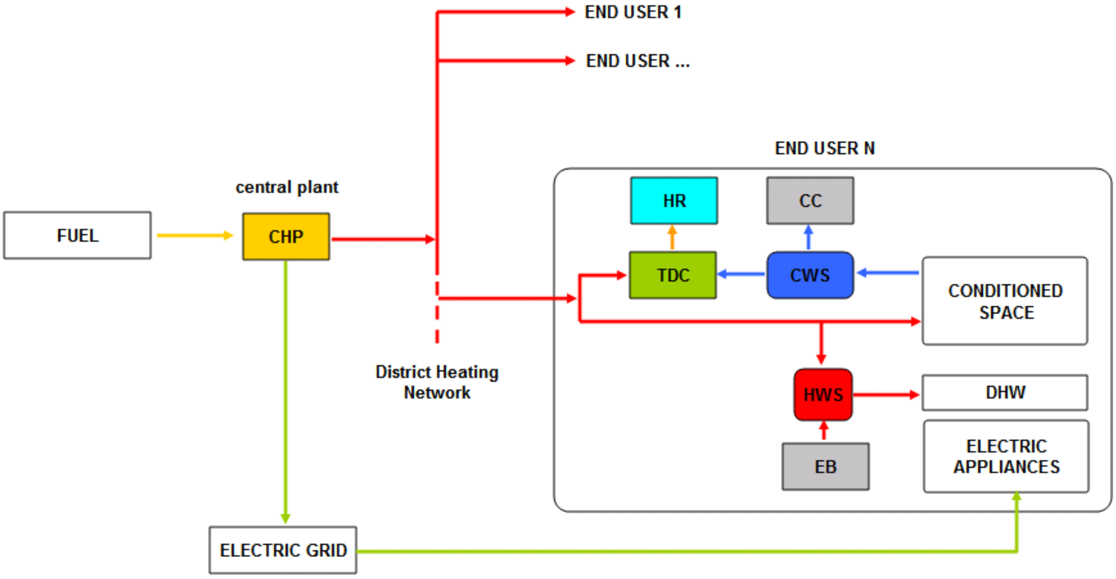

Figure 16: Scheme of a macro CHP plant with distributed TDCs

Available micro-CHCP technologies

In the afore mentioned power range of micro-CHCP, the technologies which are commercially available for CHP are:

- Reciprocating engines
- Stirling engines
- Microturbines.

As already mentioned, fuel cells in the micro-scale are not yet mature for commercialization as cogeneration unit.

The reciprocating engine is an internal combustion motor in which the fuel (e.g. gasoline, diesel, natural gas or ethanol) is compressed and combusted with the addition of external air. The hot gases created by the combustion expand to move the engine, after which the gases are expelled. Gas engine micro-CHP systems present an electrical efficiency of 20% - 30% and a total fuel efficiency of up to 90%.

The Stirling engine is an external combustion motor which makes use of an external heat source to expand inert gas inside of sealed cylinders. Such an engine is very silent but is also slow to respond to changes in the heat applied. Whilst typical electrical efficiency is only 10-18%, total fuel efficiency can be as high as 90%.

Microturbines are machines in which hot and pressurized gases (obtained from the combustion of gaseous fuel added to compressed air) are expanded through a rotating turbine, thereby acting on the motor shaft. Microtrubines show an electrical efficiency of about 30 % and a total fuel efficiency of about 80%. The smallest microturbine available on the market is a 30 kW electric output engine.

The nominal performance figures of pre-commercial and commercial CHPs below 75 kWe are shown in Table 1.

Table 1: Performance figures of micro-CHPs

Engine Type	Maximum Hot Water Temperature (°C)	LHV Fuel (kW)	HEAT (kWt)	POWER (kWe)	Electrical efficiency	Total efficiency
Reciprocating engine	96	17.4	10.0	5.0	0.29	0.86
Reciprocating engine	75	19.2	12.5	4.0	0.21	0.86
Reciprocating engine	90	21.0	12.5	5.5	0.26	0.86
Reciprocating engine	90	24.0	12.0	5.5	0.23	0.73
Reciprocating engine	90	27.0	15.0	7.5	0.28	0.83
Reciprocating engine	75	28.0	18.0	8.0	0.29	0.93
Reciprocating engine	92	53.0	32.0	17.0	0.32	0.92
Stirling engine	85	53.0	37.0	9.0	0.17	0.87
Reciprocating engine	90	63.0	30.0	15.0	0.24	0.71
Reciprocating engine	90	80.0	47.0	25.0	0.31	0.90
Reciprocating engine	90	80.2	47.0	22.0	0.27	0.86
Reciprocating engine	93	102.0	65.0	30.0	0.29	0.93
Reciprocating engine	90	103.5	55.0	34.0	0.33	0.86
Reciprocating engine	90	108.1	55.0	38.0	0.35	0.86
Reciprocating engine	90	110.0	60.0	30.0	0.27	0.82
Microturbine	95	118.0	65.0	30.0	0.25	0.81
Reciprocating engine	90	147.7	78.0	49.0	0.33	0.86
Reciprocating engine	90	148.0	79.0	50.0	0.34	0.87
Stirling engine	85	207.0	145.0	35.0	0.17	0.87
Microturbine	95	226.0	120.0	65.0	0.29	0.82
Microturbine	92	239.0	98.0	70.0	0.29	0.70
Stirling engine	85	443.0	310.0	75.0	0.17	0.87

As regards TDCs, sizes larger than 20 kW cooling power are commonly available on the market. Recent developments have covered the gap in the micro scale from 2.5 to 20 kW. At present, two main TDC technologies exist:

- absorption (water-ammonia or lithium bromide-water);
- adsorption (silica gel or zeolite).

In absorption chillers, the refrigerant medium (e.g. ammonia) is absorbed after evaporation by a working fluid (e.g. water) and the resulting solution is pumped to high pressure. Heat is applied in order to let the refrigerant evolve out of the solution in the form of pressurized vapor. Such chillers usually operate in continuous mode delivering steady cooling power to the load. The driving heat temperature is typically in the range 80 to 100 °C when wet cooling towers are employed for heat rejection.

Adsorption chillers use low pressure water as refrigerant, which is adsorbed after evaporation by the sorption medium (e.g. silica gel). The process can continue until saturation, after which the sorption medium is regenerated by applying heat. These chillers usually operate in discontinuous mode delivering intermittent cooling power to the load. The driving heat temperature is typically in the range 75 to 85 °C if wet cooling towers are employed for heat rejection.

In addition to thermally driven chillers, thermally driven air coolers deserve special mention as well. Such air coolers obtain refrigeration by dehumidification and subsequent indirect and direct evaporative cooling. Dehumidification of air is achieved through a desiccant medium (e.g. silica gel) which needs to be periodically regenerated by applying heat. The desiccant medium can be either solid or liquid. Units of approximately 5,000 m^3/h of capacity can be operated in conjunction with micro-CHPs of some tens of kW electric power. The driving heat temperature can be as low as 70 °C. Their use is limited to cases where air is the preferable cooling medium (e.g. hotels, hospitals, supermarkets).

The nominal performance figures of pre-commercial and commercial TDCs below 75 kWe are shown in Table 2 .

Table 2: Performance figures of small scale thermally driven chillers

Type	Driving Temperature (°C)	Chilled water Temperature (°C)	COP	Parasitic (including re-cooler) (kW)	Cooling capacity (kW)
Adsorption	80	10	0.40	0.45	2.5
Absorption	90	16	0.62	1.00	4.5
Absorption	96	7	0.60	0.86	6.0
Adsorption	75	15	0.50	0.56	6.0
Absorption	80	13	0.68	0.80	10.0
Absorption	75	15	0.78	0.70	10.0
Absorption	90	11	0.71	1.20	15.0
Absorption	88	7	0.70	2.30	35.0
Adsorption	75	9	0.60	3.52	52.0
Adsorption	85	9	0.60	4.66	71.0

The costs of the following items have been estimated on the basis of different sources, including literature data (Kuhn V. et al. , 2008) (Chose, 2001) (BMU, ZSW, 2006) (De Paepe M., D'Herdt P, Mertens D., 2006) (IUTA, 2002), case studies (Cogen Europe, 2005) (Cogen Europe b, 2005), manufacturer list prices (Alta, 2008) (AERMEC, 2008), formal inquiries to manufacturers and direct experience within the project:

- CHP, including control, installation, pumps and piping to the TDC and the heat storage
- TDC, including control and installation
- Cooling Towers, including control, installation, pump and connection to the TDC
- Heat and cool storages, including installation
- Auxiliary heater, including control
- Auxiliary chiller, including control and installation
- Operating and maintenance

On the basis of the different sources, the estimated cost functions have been derived (costs do not include VAT) and plotted as follows (see **Figure 17**).

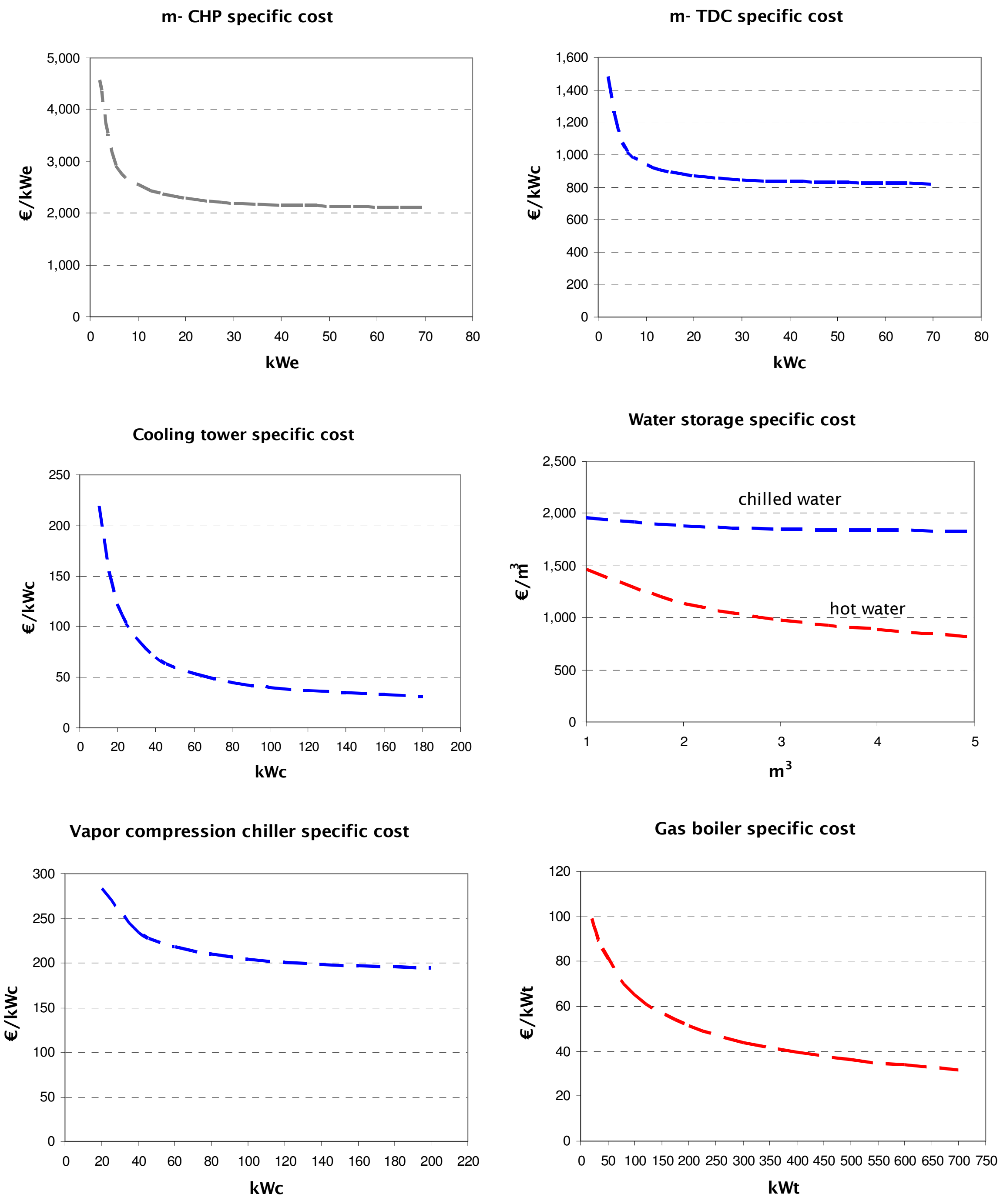

Figure 17: Cost functions for all items included in a m-CHCP system

As an example, a system suited for a 4-family house might cost as much as 30,000 € and have an annual maintenance cost of some 1,150 €. The example case includes a CHP sized 5,5 kW_e, a TDC sized 6 kW_c, a 15 kW cooling tower and all other elements, namely a chilled water storage, a hot water storage, an auxiliary chiller and an auxiliary heater.

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The economic attractiveness of micro-CHCP

The economic attractiveness of micro-CHCP has been assessed under both a financial and a socio-environmental perspective by means of two indicators: fossil fuel primary energy savings (and thus the associated saved CO_2 emissions) and financial savings.

Throughout the present study, the economic attractiveness of micro-CHCP is measured by comparing the different energy carriers utilization occuring between micro-CHCP and the separate production of heating, cooling and electricity. As it has to be clarified how the separate production is achieved, the following reference technologies have been assumed:
- conventional gas boilers (CB) for space heating and domestic hot water preparation;
- air condensed vapor compression coolers (CC) for space cooling;
- central power generation for electricity.

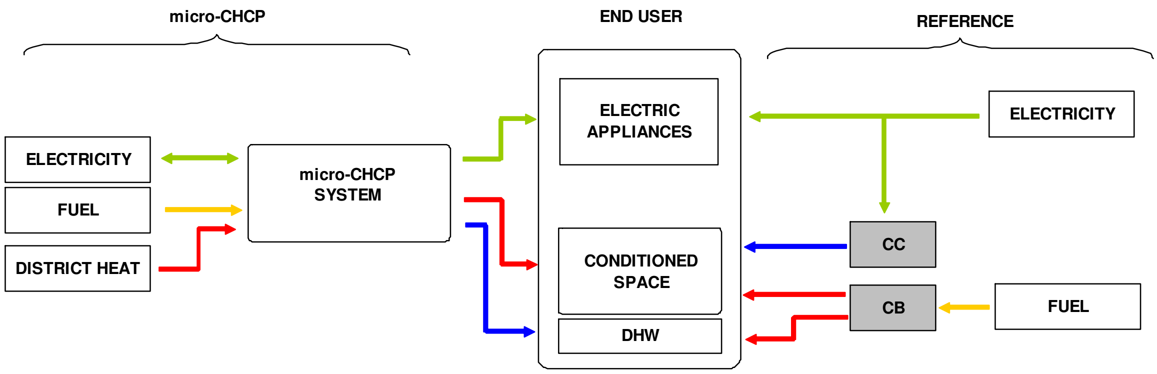


Figure 18: Different energy carriers utilization in the supplying of heating, cooling and power at the use point

Different energy carriers utilization leads to different primary energy utilization, as the primary energy content varies with the specific energy carrier.

Moreover, micro-CHCP is characterized by different operational and investement costs as compared to the reference system. Financial savings arise from this difference when the achievable yearly gross benefits are large enough to offset the differential investment and the maintenance costs, within the systems useful life. As it will be clarified, energy prices and their impact on the achievable gross savings are a key factor in assessing financial viability.

Following a top-down approach, some relevant conditions (e.g. climate, energy demand, energy prices, fuels used or incentives on distributed generation) have been surveyed in different countries and a cross-country analysis has been carried out. The objective is to assess which countries and sectors might become receptive markets for micro-CHCP in the near future. However, country average data can provide only rudimental economical figures due to a number of unknowns. To mention a few,
- climate can vary largely within a country thus affecting the real energy demand;
- to be economical, micro-CHCP should be accurately sized so that it covers only a fraction of the total load, the remaining part being covered by the auxiliaries;
- load profiles of heating (or cooling) and electricity might not be in phase, so that electricity can be generated in excess and sold to the grid;
- a disparity of treatment between electricity purchase tariff and feed-in tariff might exist, so that the electricity generated in excess would not pay off.

The overall effect of all these factors can be explored only by means of detailed computer simulations. Therefore, a custom made simulation program has been developed and some interesting cases have been fully analyzed.

Primary energy savings

In its broadest definition, primary energy is any natural energy resource before conversion into useful energy, i.e. heat or power. For example, primary energy includes natural gas, oil, coal, biomass, wind, solar and geothermal. In the field of fuel combustion, two main types of primary energy sources exist: fossil resources and renewable sources.

Fossil resources are mainly exploited for separate production of electricity, heating and cooling. The main fossil fuels and conversion technologies which find application in power generation are natural gas fired combined cycles and coal / lignite fired steam cycles. Natural gas and heating oil are commonly used for heating purposes. Cooling is conventionally obtained by electricity driven compression of refrigerant vapor.

Renewable fuels, such as solid biomass, are exploited for heating purposes in both distributed generation, like domestic size pellet burners, and central generation, like biomass furnaces feeding district heating networks. In the latter, combined generation of heat and electricity is quite common. Renewable fuels are also employed for electricity generation in medium sized power plants. The fuels can be solid (e.g. pellet, wood chips), liquid (e.g., bio-diesel) or gaseous (e.g. biogas from landfill). Co-firing of biomass is also a third possible way through which a small percentage of green fuels is mixed with fossil fuels and burned in conventional power plants.

Within this scenario, micro-CHCP can provide a more efficient way to exploit both fossil and renewable fuels, as it will be explained in the following.

In order to assess whether primary savings are achievable by a given system, the primary resource content of each energy carrier utilized by that system in the generation of heat and cool at the point of use is totalized. Savings are achieved when the system under examination totalizes less primary resource content than a proper conventional or reference system, all things being the same on the user's side. It is important to specify that electricity generated by the CHP is treated as a co-product; the associated environmental benefit is calculated through the substitution method, i.e. as primary resource consumption of the saved marginal electricity.
In other words, when electricity is generated rather than consumed at the point of use, the associated primary resource content should be subtracted from the total primary energy utilization of the system. Energy carriers are fuels but also electricity or heating (district heating) and cooling (district cooling). In order to account for the different primary energy content of energy carriers, the Primary Resource Factor (PRF) approach is used (ECOHEATCOOL c, 2006).

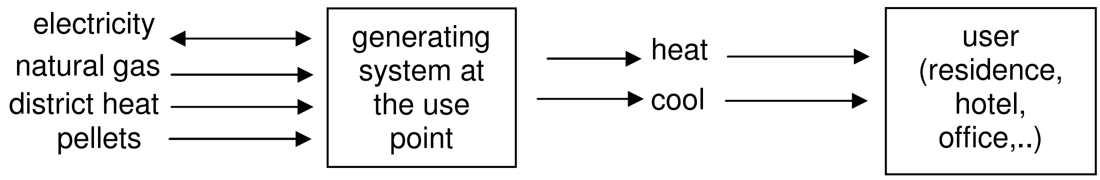


Figure 19: Energy carriers involved in the generation of heating and cooling at the use point

The primary resource factors for different energy carriers have been reported in ECOHEATCOOL c, 2006.

Table 3: Energy content (PRF) of selected fuels for end-use

Energy carrier	PRF
Natural gas	1.1
Lignite Coal	1.3

Hard Coal	1.2
Wood	0.1
Electricity	2.5

However, as it will be explained, in order to assess primary energy savings with respect to local conditions and to take into account only the electrical efficiency of fossil fuel fired thermoelectric plants, the PRF of marginal electricity has been recalculated, under simplifying assumptions, for each of the investigated countries.

Distributed micro-CHCP

Micro-CHCP systems are seen as a possible alternative to conventional boilers and vapor compression chillers in delivering useful heat and cool, respectively.

Micro-CHP can be fired by means of different fuels, such as natural gas, LPG, diesel fuel or bio-fuels. From a fuel type perspective, the Stirling engine is surely the most versatile engine. Nevertheless, micro-turbines and many internal combustion engines are suited for natural gas only.

In the following, primary energy savings are evaluated with respect to natural gas utilization. Two opposite alternatives are compared (see **Figure 20**):

1. natural gas is delivered to the user where a micro-CHCP system generates heat, cool and electricity
2. natural gas and electricity are delivered to the user where a gas boiler generates useful heat and an electricity driven cooler provides space cooling.

The primary energy consumption associated to the generation of a unit of useful heat can be calculated for both the micro-CHCP and the reference boiler by knowledge of the thermal heat efficiency of the two systems. The peculiarity of the micro-CHCP is that electricity is generated rather than consumed, and the associated primary energy content should be subtracted to the primary energy total consumption. In mathematical terms:

$$PE_{heat,mconv} = \frac{1}{\eta_{\mathrm{cb}}} PRF_{fuel} \qquad \left[\frac{kWh_{heat}}{kWh_{LHV}}\right]$$

$$PE_{heat,mCHCP} = \frac{1}{\eta_{th}} PRF_{fuel} - \left(\frac{\eta_{el}}{\eta_{th}}\right) PRF_{el} \qquad \left[\frac{kWh_{heat}}{kWh_{LHV}}\right]$$

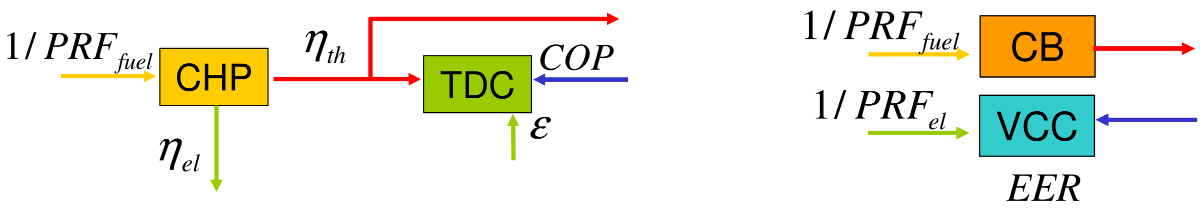
$$PES_{heat} = PE_{heat,conv} - PE_{heat,mCHCP} = \qquad \left[\frac{kWh_{heat}}{kWh_{LHV}}\right]$$

Similarly, the primary energy associated to a unit of useful cool can be calculated for the micro-CHCP and the vapor compression chiller. The micro-CHCP generates cooling in two steps: fuel is converted into heat and electricity first, then heat is converted into cool by the thermally driven chiller at the additional expense of some electricity. In contrast, vapor compression chiller converts electricity directly into useful cool. As before, electricity (either generated or consumed) is converted into primary energy. In mathematical terms:

$$PE_{cool,conv} = \frac{1}{ERR} PRF_{el} \qquad \left[\frac{kWh_{cool}}{kWh_{LHV}}\right]$$

$$PE_{cool,mCHCP} = \frac{1}{COP\,\eta_{th}} PRF_{fuel} - \left(\frac{\eta_{el}}{COP\,\eta_{th}} - \varepsilon\right) PRF_{el} \qquad \left[\frac{kWh_{cool}}{kWh_{LHV}}\right]$$

$$PES_{cool} = PE_{cool,conv} - PE_{cool,mCHCP} \quad \left[\frac{kWh_{cool}}{kWh_{LHV}}\right]$$



CB = conventional boiler
VCC = vapor compression chiller
COP = chiller thermal coefficient of performance
EER = energy efficiency ratio of the VCC
PRF_{fuel} = primary resource factor of natural gas
η_{cb} = thermal efficiency of the CB

η_{th} = thermal heat efficiency of the CHP
η_{el} = thermal electrical efficiency of the CHP
ε = parasitic consumption of the TDC
PRF_{el} = primary resource factor of electricity

Figure 20: Distributed micro-CHCP versus separate heat and cool production

Several parameters are involved and the judgment of their fair value is uncertain. However, it is found that primary energy savings are principally affected by two parameters: the electricity PRF and the thermal electrical efficiency of the micro-CHCP system. For better exemplification of the concept, primary energy savings are shown in **Figure 21** in the general case for different values of electricity PRF and micro-CHCP thermal electrical efficiency .

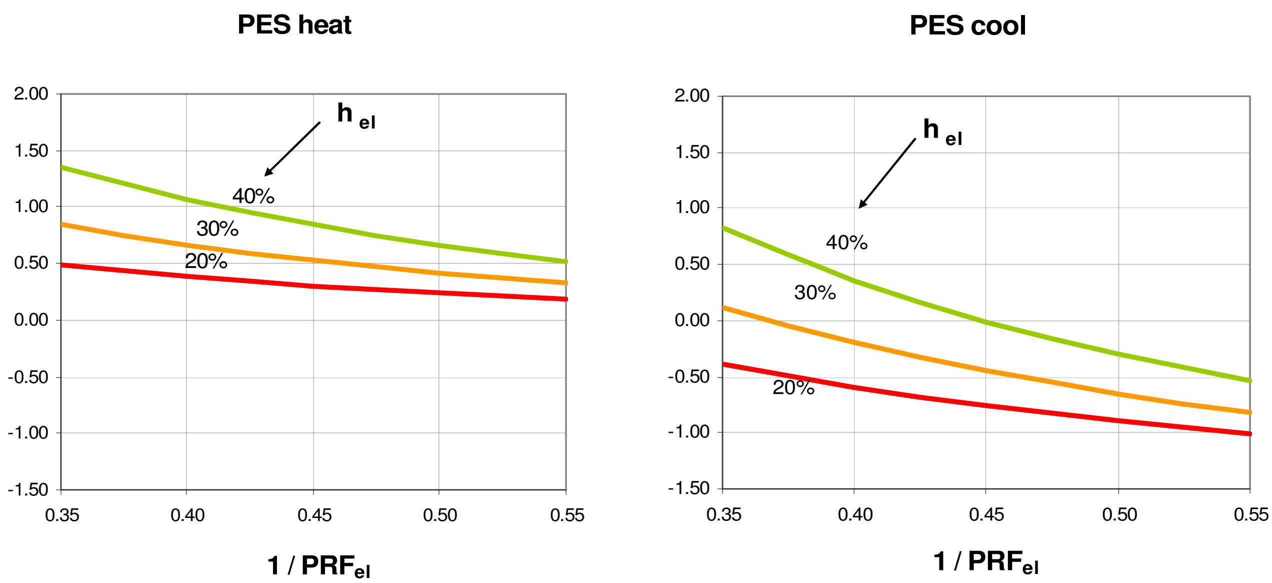


Figure 21: Natural gas fired micro-CHCP: specific fossil primary energy savings per unit of heat and cool as compared to separate heat and cool production, assuming COP=0.72, EER=4.0, $\eta_{PE,fuel}$=0.95, η_{cb}=0.9, $\eta_{th}+\eta_{el}$=0.9, ε = 0.05. Effect of varying η_{el} = 20%, 30%, 40%

At a glance, the above figures make clear that primary energy savings in cooling mode are not as easily obtained as in heating mode, and a minimum micro-CHCP electrical efficiency exists for a given electricity PRF. At the current state of technology development, this condition might not be always achieved, especially in countries where very efficient power plants are in operation. However, even in such cases, primary energy savings in heating mode can offset primary energy losses in cooling mode and, in the annual balance, total savings can be positive or near zero. In the latter case, the advantage of micro-CHCP compared to separate production could be to alleviate the need for enhancing the public grid.

District heat powered TDC

District heat powered TDCs can be a viable alternative to conventional cooling. They can also be alternative to district cooling networks when a free heat source (e.g. waste heat from industries) instead of a cool source (e.g. cold from the deep of water basins) is available. They convert free heat into cool at use point and can offer an additional chance to sell waste heat from central CHP plants, in which a fuel with a low primary resource factor (e.g., biomass, waste) is fired in order to generate electricity and heat. Depending on the primary resource content of district heating, higher primary energy savings might be achieved with respect to separate cool production from electricity.

Taking electricity driven cooling as a reference (see **Figure 22**), the achievable primary energy savings by district heating powered TDCs can be estimated as follows:

$$PE_{DH+TDC} = \frac{1}{COP} PRF_{DH} + \varepsilon\, PRF_{el} \qquad \left[\frac{kWh_{cool}}{kWh_{LHV}}\right]$$

$$PES_{DH+TDC} = PE_{cool,conv} - PE_{DH+TDC} \qquad \left[\frac{kWh_{cool}}{kWh_{LHV}}\right]$$

VCC = vapor compression chiller
COP = chiller thermal coefficient of performance
EER = energy efficiency ratio of the VCC
PRF_{DH} = primary resource factor of district heating
PRF_{el} = primary resource factor of electricity
ε = parasitic consumption of the TDC

Figure 22: District heat powered TDC versus separate cool production

In order to generate primary energy savings, the district heating PRF should be lower than a limiting value which in turn depends on the given electricity PRF. To exemplify the concept, primary energy savings are shown in **Figure 23** for different values of electricity PRF and district heating PRF.

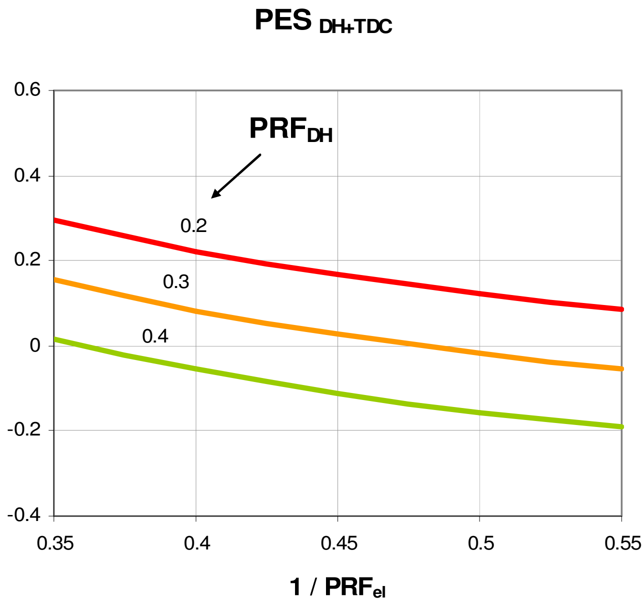


Figure 23: Effect of varying PRF_{DH} , COP=0.72, EER=4.0, ε = 0.05

Financial benefits

In the financial evaluation of innovative energy technologies, a common approach consists of estimating the differences between the new system and a proper reference system in terms of both yearly net benefits and initial costs (Garg & Kandpal, 2003). The widely used feasibility indexes (e.g. payback time, net present value, benefit to cost ratio and cost of primary energy saved) are calculated either by actualizing future benefits or annualizing initial costs, over the useful life of the system and allowing for the time value of money.

In the micro-CHCP case, incremental yearly benefits arise from both savings on electricity purchase and revenues on electricity generated in excess and fed into the public grid. As the micro-CHCP system requires more fuel input than its conventional counterpart, the benefit is diminished by the extra fuel purchase. In the usual terminology, the resulting amount is referred to as gross margin.

The yearly net benefits can be calculated from the gross margin by allowing for maintenance, discounts, taxation and incentives. The incentive types generally applicable to micro-CHCP are:

- tax breaks on natural gas fired in co-generation;
- white certificates, i.e. incentive on primary energy savings;
- green certificates, i.e. incentive on electricity generated from green fuels;
- incentives on electricity generated in co-generation.

Other financial aspects affecting the cash flow, such as interests and depreciation, are not considered for simplicity.

By no doubts, micro-CHCP would require a higher investment for the user as compared to the conventional separate production of heating and cooling. Therefore, positive net benefits are the necessary condition for micro-CHCP to be financially feasible.

Estimating net benefits is made difficult by the large number of parameters involved and by the fact that incentives are often assigned according to complex schemes. However, gross margin alone can already provide enough insight on the long term viability of micro-CHCP, as it will be discussed in the following.

Distributed micro-CHCP

The gross margin specific per unit of cooling and heating energy can be easily calculated under the simplifying assumptions:
- no difference exists between purchase price and selling price of electricity;
- no difference exists in fuel price between the CHP and the conventional boiler.

$$sgm_{cool} = -\frac{p_{fuel}}{\eta_{th} COP} + \left(\frac{\eta_{el}}{\eta_{th} COP} + \frac{1}{EER} - \varepsilon \right) p_{el} \qquad \left[\frac{€}{kWh_{cool}} \right]$$

$$sgm_{heat} = \frac{\eta_{el}}{\eta_{th}} p_{el} + \left(\frac{1}{\eta_{CB}} - \frac{1}{\eta_{th}} \right) p_{fuel} \qquad \left[\frac{€}{kWh_{heat}} \right]$$

The gross margin in cooling mode is mostly sensitive to the fuel price and the electricity price, while the gross margin in heating mode is greatly influenced by the electricity price and the conventional boiler thermal efficiency (see **Figure 24** and **Figure 25**).

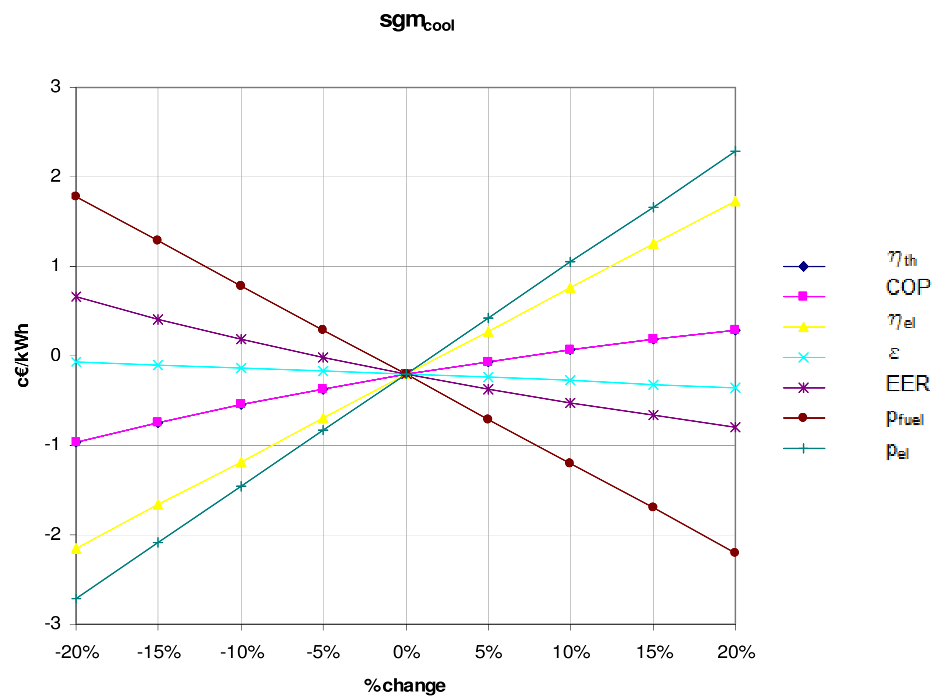


Figure 24: Specific gross margin in cooling mode, sensitivity to parameters variation

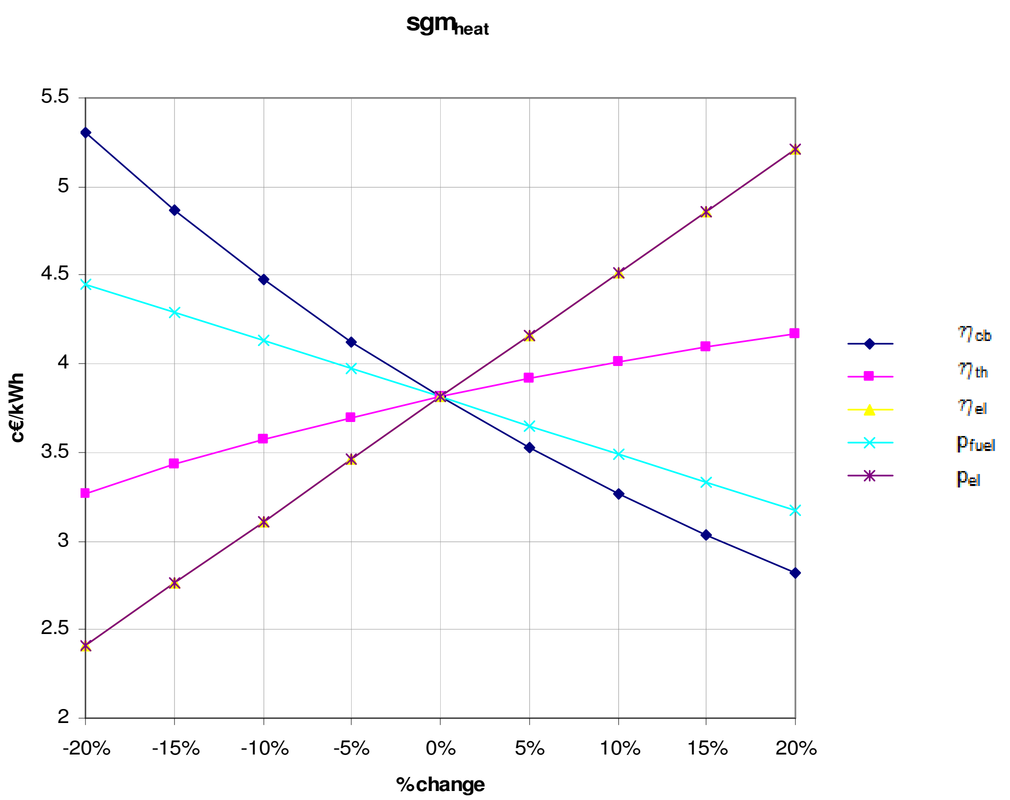


Figure 25: Specific gross margin in heating mode, sensitivity to parameters variation

Sensitivity was calculated with respect to the following mean values:

Table 4: Parameters and mean values used in sensitivity analysis

h_{cb}	0.92
h_{th}	0.60
h_{el}	0.30
COP	0.72
e	0.05
EER	4
p_{fuel}	5.5
p_{el}	14

Considering the assumed mean values for the parameters, the gross margin in the cooling mode yields negative values. Positive values can be obtained by enlarging the gap between fuel and electricity prices, as shown in **Figure 26.** On the contrary, gross margin in the heating mode is always positive in the investigated price range. It is influenced much more by electricity than by fuel prices (see **Figure 27**).

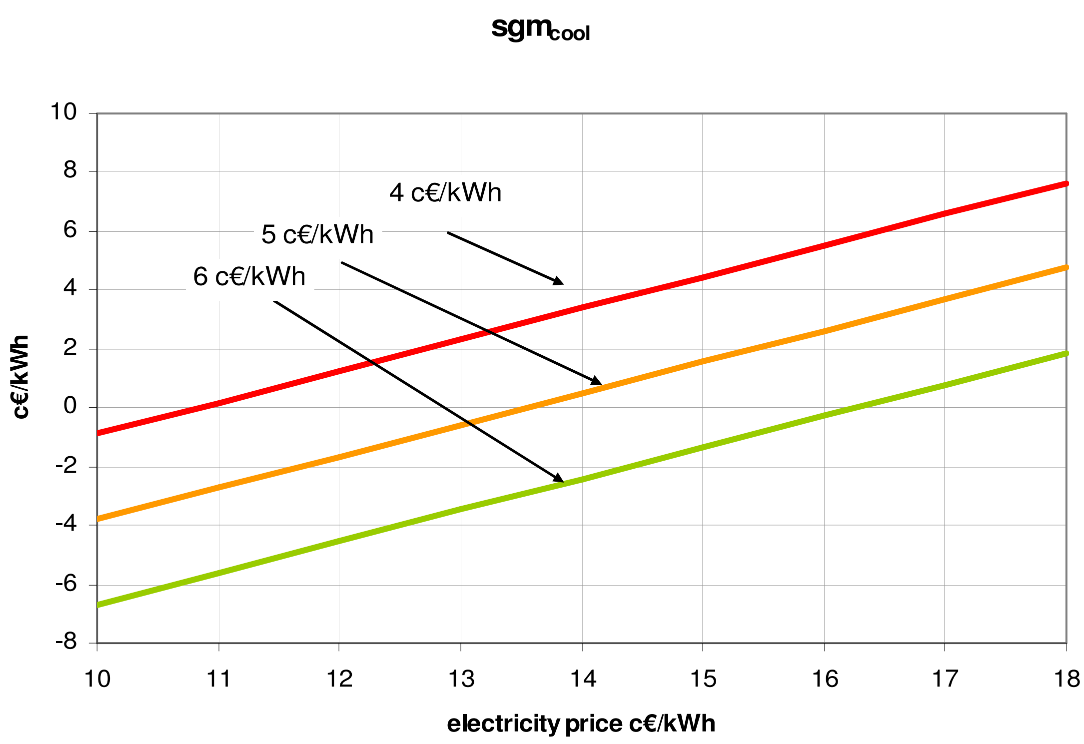


Figure 26: Specific gross margin in cooling mode, effect of varying electricity and fuel prices

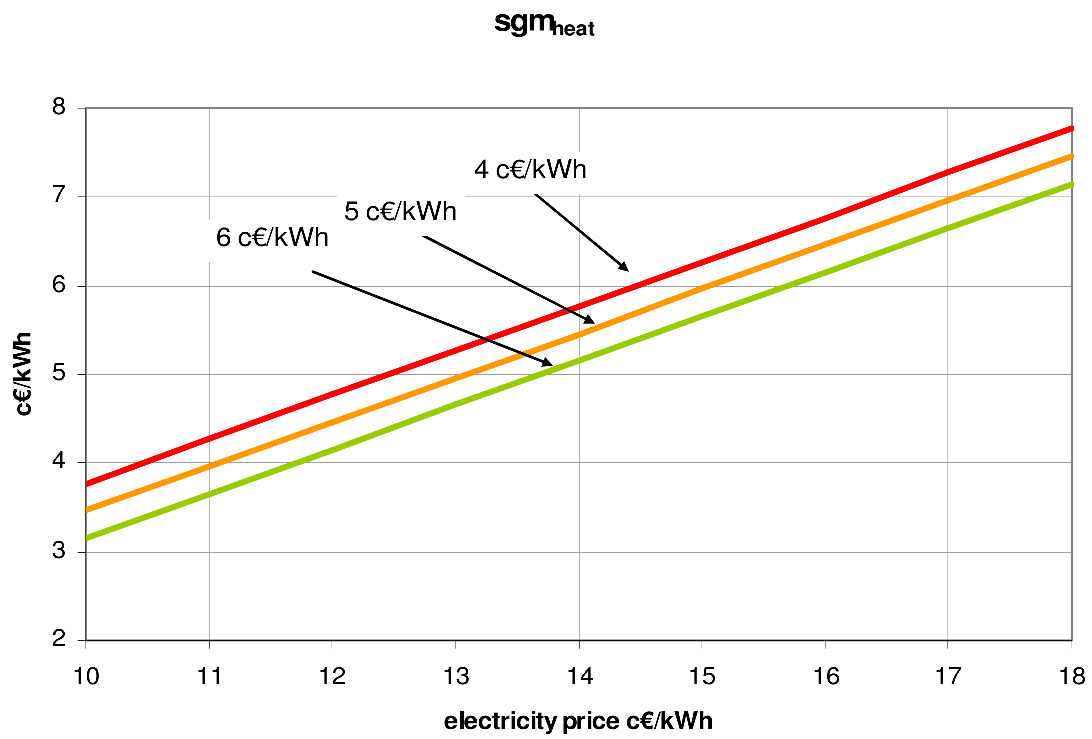


Figure 27: Specific gross margin in heating mode, effect of varying electricity and fuel prices

District heat powered TDC

The gross margin arises from savings in electricity purchase for cooling purposes, to which the cost of district heating and parasitic electricity consumed by the TDC must be subtracted:

$$sgm_{cool} = -\frac{p_{DH}}{COP} + \left(\frac{1}{EER} - \varepsilon\right) p_{el} \qquad \left[\frac{€}{kWh_{cool}}\right]$$

Due to the relatively high efficiency ratio of vapor compression chillers, the achievable savings on electricity purchase are rather modest, giving rise to a small or negative gross margin even when unrealistically large spreads between district heating price and electricity price are foreseen (see **Figure 28**).

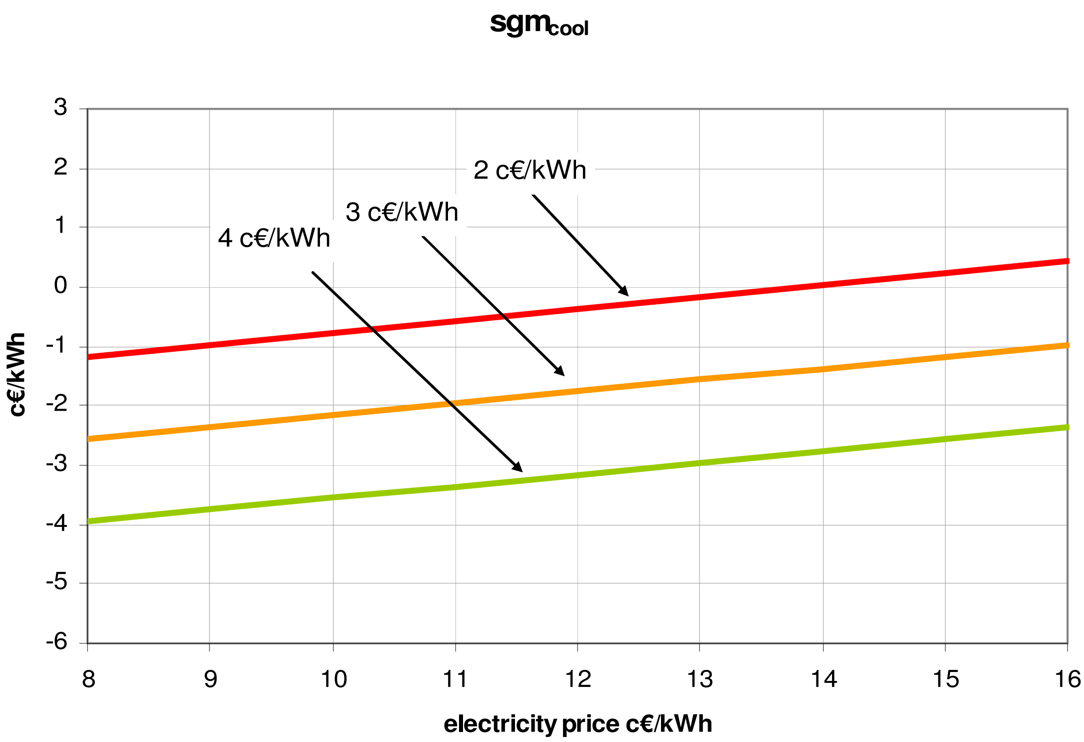


Figure 28: Specific gross margin in district heating powered TDC; effect of varying electricity price and district heating price

Cross country analysis

The viability of micro-Combined Heating Cooling and Power is assessed in terms of energy and financial saving potentials resulting from the different market conditions existing across Europe. The analysis focuses on the domestic, tourism and commercial sectors in the following countries: Austria, Czech Republic, Germany, Italy, Netherlands, Poland, Portugal, Spain, Sweden and Switzerland.

For each country, different market drivers are gathered, such as:
- Energy demand for heating and cooling;
- Energy prices;
- Primary resource factors;
- Incentives;
- Fuel availability;
- Rural and Urban development.

The key indicators in determining the economical attractiveness of micro-CHCP are the potential primary energy and the gross financial savings, estimated on the basis of country average statistics.

Two different schemes for distributed cooling from thermal energy are taken into account: Distributed combined heating and cooling and distributed cooling associated to district heating networks. Both schemes are analyzed under the assumption that natural gas and biomass are the main fuels available for micro-CHCP.

Although the analysis is carried out at a general level, the resulting picture suggests that some countries are better positioned than others and have the potential to become receptive markets in the near future, namely: Italy, Austria, Germany, Spain, Czech Republic and Poland.

Energy demand

The yearly average heating and cooling demand in the Residence and Service sectors are available in national statistics and literature (ECOHEATCOOL, 2006) (ECOHEATCOOL b, 2006). As heating and cooling depends not only on climate conditions but also on building fabric, a country average value is only a rudimental indicator of the effective energy demand in buildings. Nevertheless, it is believed that large differences in heating and cooling demand exist across Europe and that the gathered information reflects this aspect in a proper way.

The cooling to heating demand ratio is an important parameter which affects the overall energy and economical performance of micro-CHCP. Indeed, it has been shown that both primary energy savings and gross margin are more attractive during the heating operation than during the cooling operation mode of micro-CHCP. Additionally, the cooling to heating ratio may affect the number of operation hours of the system and, in turn, the payback time of the investment. The micro-CHCP is such that the chiller capacity is always lower than the hating capacity, with a limiting cooling to heating capacity ratio of about 0.7. In the case heating and cooling would be requested in different periods of the year, such as the summer and winter periods, the sizing of the CHCP would become problematic. If the application were dominated by heating, the CHP would work for a very little time during the cooling season. In the opposite condition, the CHP would result oversized during the heating season.

Country average heating and cooling energy demands in the Residential and Service sectors are shown in Figure 29 and Figure 30 respectively.

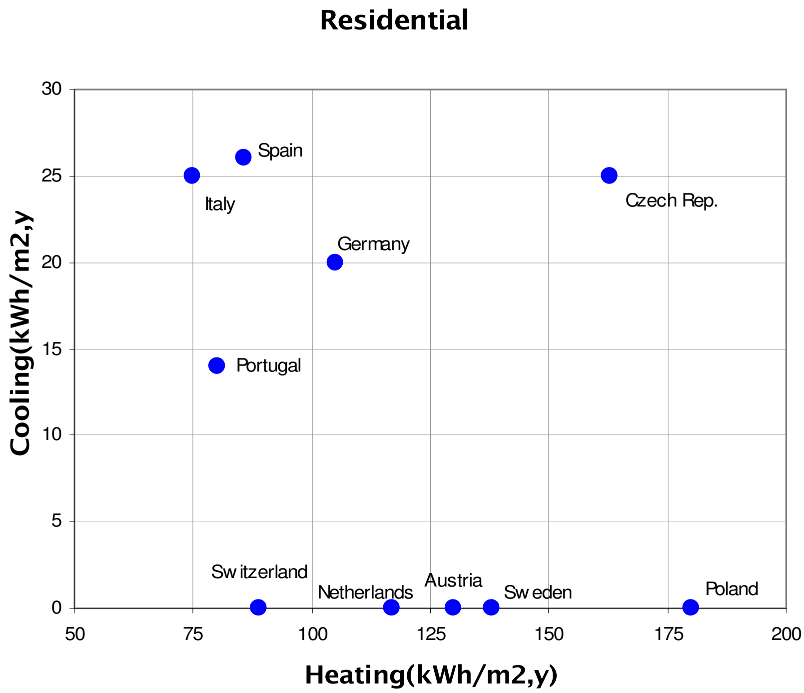


Figure 29: Yearly heating and cooling demand in the Residential sector

It can be observed that the cooling to heating ratio varies between 0 and 0.33 in the Residential sector and between 0.16 and 1.1 in the Service sector. Spain is the only country where the cooling demand exceeds the heating one in the Service sector. On the contrary, Netherlands shows the lowest cooling to heating ratio. Overall, the cooling to heating ratio seems promising in the service sector nearly everywhere in Europe. The picture is less promising in the residential sector, where the cooling demand is in general much lower than the heating demand and in many countries a zero demand was reported.

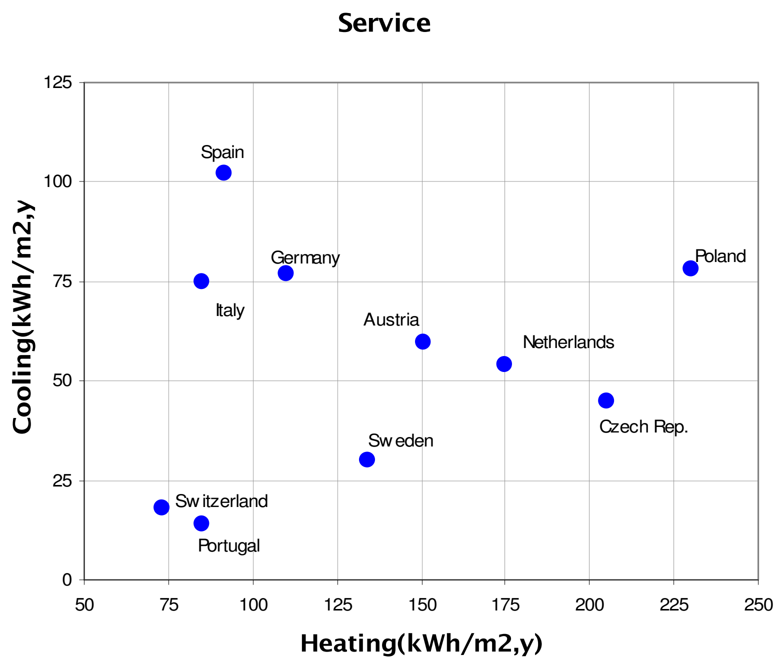


Figure 30: Yearly heating and cooling demand in the Service sector

Electricity and natural gas prices

Natural gas and electricity prices in the domestic sector vary largely across Europe, according to the available information in Eurostat, 2007 (prices are net of taxation). The price of natural gas in Sweden is nearly twice the price in Czech Republic. Same for the price of electricity, for which Italy records the highest value and Czech Republic the lowest one. In recent years, both natural gas and electricity have shown a consistent price increase all over Europe. On average in EU15, in the period 2005 - 2007, natural gas prices have increased by 15% p.a. and electricity prices have grown by 8.5 % p.a.

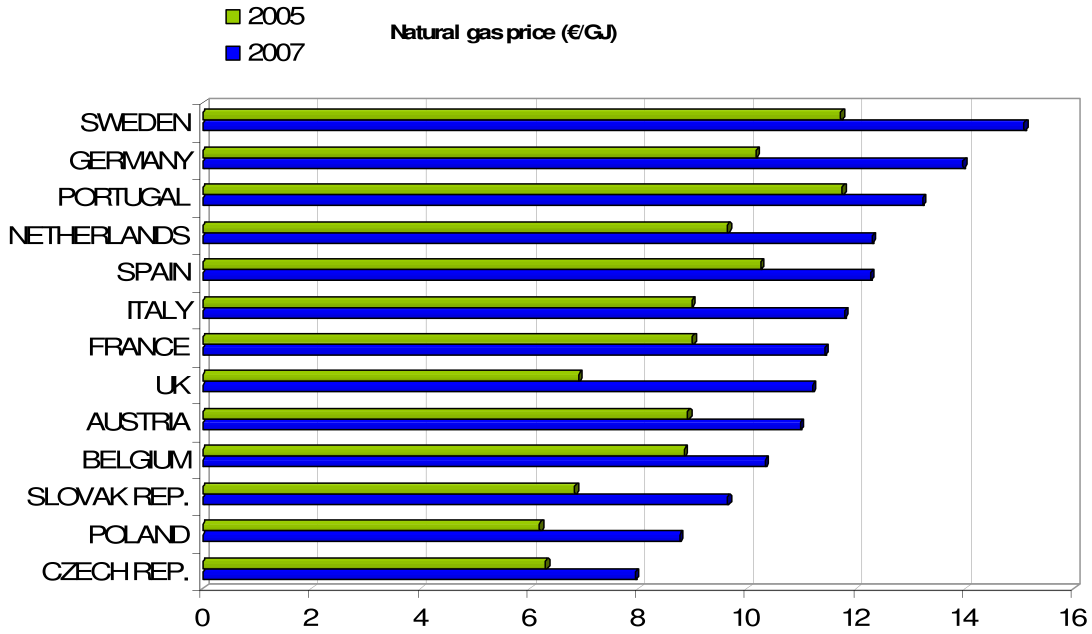


Figure 31: Natural gas prices in 2005 and 2007 [€/GJ]

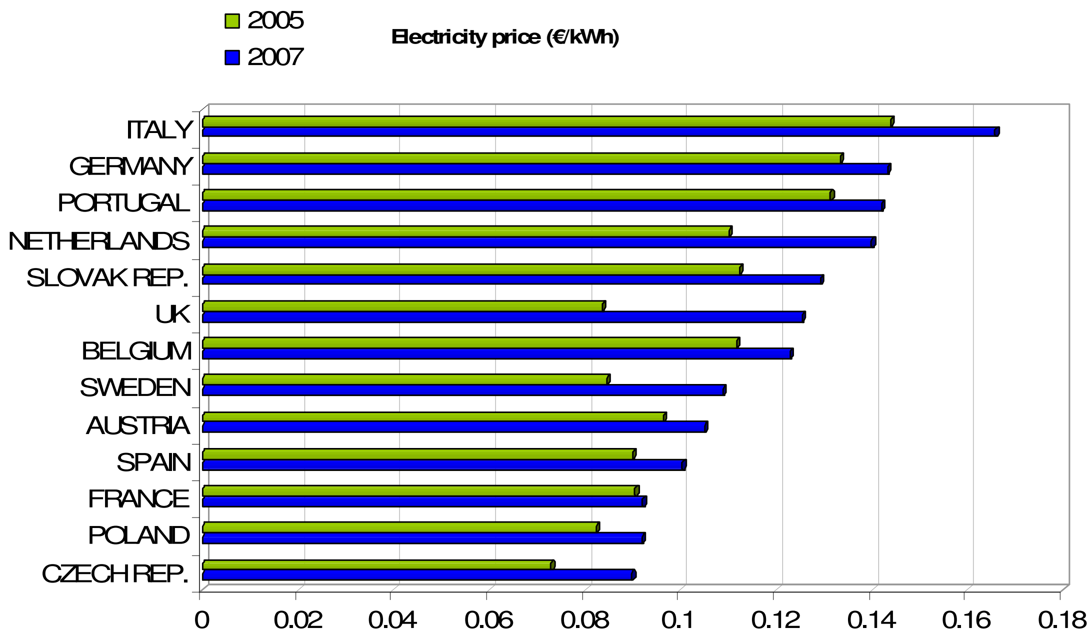


Figure 32: Electricity price in 2005 and 2007 [€/kWh]

As the financial benefits are mostly affected by the spread between gas and electricity prices, the effect of energy prices on the gross margin is investigated in the following. In order to reveal the implications of energy prices on CHCP financial viability, the gross margin concept is deepened in the following three cases:

- power generation;
- combined heating and power;
- combined cooling and power.

In power generation (PG), the gross margin per unit of generated electricity, also called "spark spread", can be calculated as the difference between the selling price of the unit of generated electricity and the cost of the fuel used to produce that unit. In mathematical terms:

$$spark\ spread = p_{el} - \frac{p_{fuel}}{\eta_{el}} \quad €/kWh$$

p_{el} = price per unit of generated electricity [€/kWh]
p_{fuel} = price per unit of fuel energy content (low heating value) [€/kWh]
h_{el} = electrical efficiency of the power plant

Spark spread should be necessarily positive in order to make power generation financially viable. This imposes that the electricity price must be higher than a minimum value:

$$p_{el} > p_{fuel} \frac{1}{\eta_{el}} \quad €/kWh_{el}$$

In combined heating and power (CHP), the condition of positive gross margin implies the price of electricity to be above a minimum value:

$$p_{el} > p_{fuel} \frac{\eta_{th}}{\eta_{el}} \left(\frac{1}{\eta_{th}} - \frac{1}{\eta_{CB}} \right)$$

In a similar way, for the combined cooling and power (CCP) case, i.e. when cooling is generated by a thermally driven chiller fed by a CHP, the minimum electricity price is:

$$p_{el} > p_{fuel} \frac{EER}{\eta_{el} EER + \eta_{th} COP}$$

The general case of combined heating, cooling and power (CHCP) would result from any combination of the CHP and the CCP case, in a proportion defined by the fraction of cooling and heating energy over the total thermal energy, as requested by the served application.

The limiting energy prices for positive gross margin conditions in PG, CHP, CCP and CHCP are represented in **Figure 33** (CHCP spanning the whole space between CHP and CCP, the represented CHCP line being valid for 50% heating and cooling energy fraction). Considering the positive gross margin conditions as a reference, the current gas and electricity prices can easily tell whether the necessary condition for CHCP financial viability is currently satisfied or not in one country. The overall picture is represented for the ten countries addressed in the present study. Most of the countries lie in between the PG and the CCP lines, indicating that the gross margin in CHCP is currently positive (data from year 2007). Italy is best positioned showing positive margin for PG only, whereas the electricity price is probably too low in France and Sweden. It can be noted that, for better evaluation, taxation should be added to energy prices, although fuel in cogeneration can be tax exempt. The fact that the positive margin condition in CHCP is satisfied at current prices values does not imply that the same will hold in the future since gas prices might increase more quickly than electricity prices.

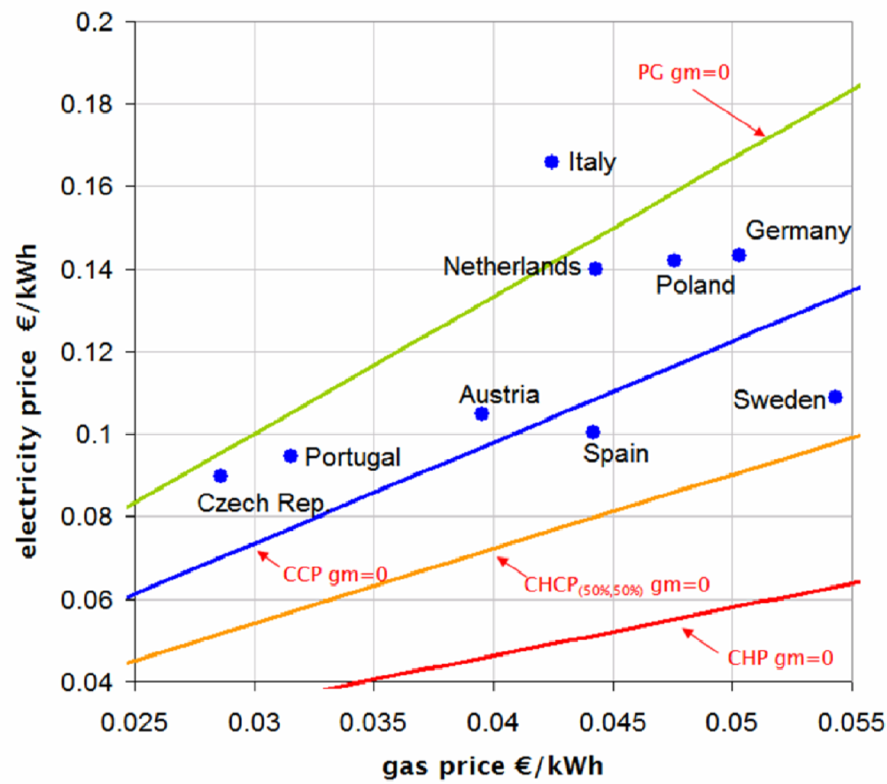


Figure 33: Gas and electricity prices for the average consumer in some EU countries (data from year 2007; prices are net of taxation; minimum electricity price for positive gross margin when EER=4, COP = 0.72 h_{el}=0.3, h_{th}=0.6 and h_{cb}=0.92)

Primary Resource factors

In the present analysis only the primary energy utilized for distribution from central plants to users is considered, excluding contributions due to other steps in the energy carrier supply chain, such as resource extraction. Consequently, only primary resource factors have been estimated on the basis of literature and statistics data.

The primary resource factor of natural gas has been assumed as of 1.1 in all countries, while the primary resource factor of electricity has been estimated for each country according to national energy balances under the following simplifying assumptions:

- national electricity imports and exports have limited relevance on the national electricity balance;
- average electrical efficiency of fossil fuel fired thermoelectric power plants (h_{te}, %) is representative of the efficiency of the marginal plant, i.e. the central power plant which is modulated with the highest priority.

The PRF of marginal electricity has been calculated as follows:

$PRF_{el} = (100+p)/h_{te}$

where p (%) represents grid losses as a percentage of national electricity consumption. Average electrical efficiency of fossil fuel electricity production was calculated in Taylor et al., 2008 according to the method presented by Graus et al., 2007 and Phylipsen et al., 1998. This method accounts for electricity output of public power plants, including both electricity only and CHP producers. Since CHP electrical efficiency is lowered by the extraction of heat, the estimate is affected by a correction factor between heat and electricity.
Results are shown in Figure 34 for different countries. The method is less significant for Switzerland and Sweden since both countries are big nuclear energy producers and only a small share of electricity is generated from fossil fuels.

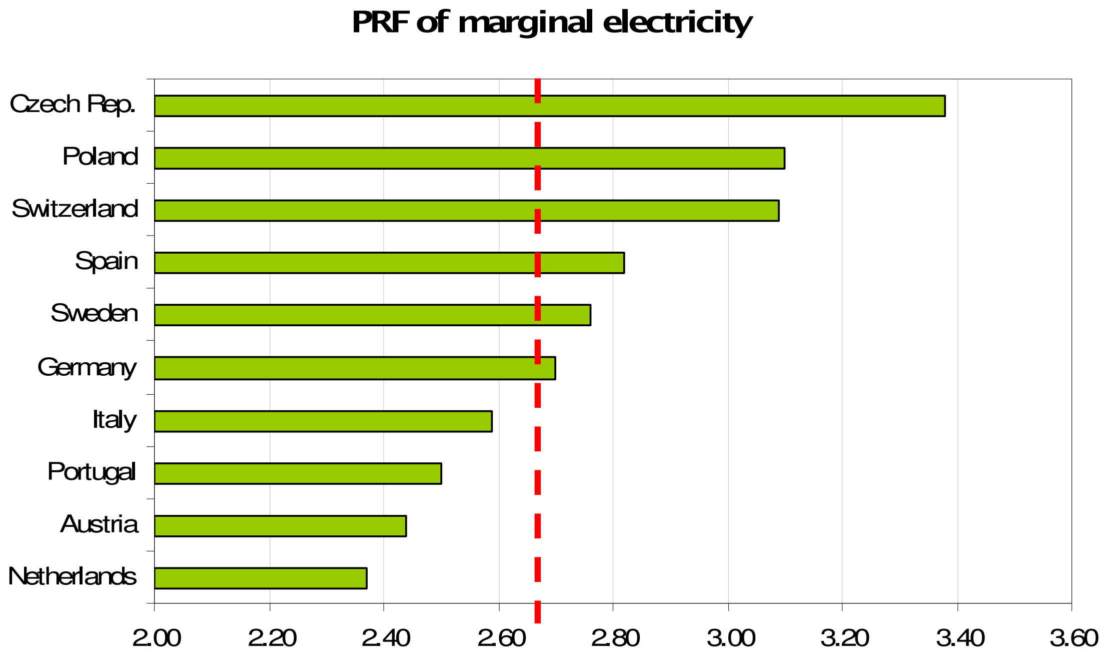


Figure 34: PRF of marginal electricity in all countries considered

Policy promoting renewable energy and energy savings

After the EU directives on the promotion of energy efficiency and renewable energy were approved, different incentive schemes have been implemented by member states in order to speed up the uptake of efficient and green energy technologies. Combined heating, cooling and power can benefit from several types of incentives, although their efficacy varies largely depending on their purpose. In general, incentives aiming at enhancing the share of green electricity (e.g. green certificates, granted feed-in tariffs) are more rewarding than incentives aiming at decreasing the energy consumption (e.g. white certificates). An overview of the incentive schemes implemented in different countries and their relevance to micro-CHCP is provided.

Table 5: Incentive schemes applicable to micro-CHCP, based on data from 2008

Country	Incentives	Remarks
Austria	• Green certificate of about 0.135 €/kWh$_e$ valid for any type of green fuel. • White certificate of about 0.010 €/kWh of saved primary energy.	• Regular feed-in tariff for electricity is about 0.036 €/kWh$_e$
Czech Republic	• Tariff on electricity generation of about 0.068 €/kWh$_e$ for biomass fuel and 0.040 €/kWh$_e$ for landfill gas.	
Germany	• Granted feed-in tariff for green electricity, about 0.195 €/kWh$_e$. Applicable to bio-fuels only. • White certificate applicable to any fuel. Average value is about 0.051 €/kWh of saved primary energy. • Tax exemption on natural gas in cogeneration; savings amount to about 0.009 €/kWh of fuel. • Extra feed-in tariff (KWK bonus) for small scale CHP (<50 kWe) and fuel	• Regular feed-in tariff for electricity is about 0.07 €/kWh$_e$

	cells, about 0.051 €/kWh$_e$. Validity of 10 years.	
Italy	• Granted feed-in tariff for green electricity, about 0.180 €/kWh$_e$. Applicable to bio-fuels only. Validity of 15 years. • White certificate on CHP and CHCP, schemes are set at regional level. Average value is too low, about 0.007 €/kWh of saved primary energy. Moreover, validity accounts only for 5 years. • Tax exemption on natural gas in cogeneration, savings per kWh of electricity generated amount to less than 0.01 €/kWh$_e$.	• No special feed-in tariff for electricity in cogeneration, average selling price for electricity is about 0.10 €/kWh$_e$
Netherlands	• Feed-in premium of 0.051 €/kWh$_e$ for green electricity • Investment subsidy of about 11% • Tax exemption on fuel used in CHP, but only for plant capacities larger than 60 kW • micro-CHP investment subsidy of 1,000 € per unit	
Poland	• Yellow certificate for small scale (<1MW) CHP plant of about 0.025 €/kWh of saved primary energy (according to the PES indicator defined by decree). • Green certificate for renewable electricity of about 0.052 €/kWh$_e$.	• Regular feed-in tariff for electricity of about 0.028 €/kWh$_e$.
Portugal	• Feed-in tariff for renewable electricity of about 0.45 €/kWh$_e$.	• Feed-in tariff for fuel other than renewable is not fixed (about 0.09 €/kWh$_e$)
Spain	• Regulated tariff for natural gas fired CHP small scale (<0.5 MW) plants, about 0.12 €/kWh$_e$, valid for 15 years, although after the first 10 years the regulated tariff will decrease. • Tax exemption on natural gas used in CHP. • Green certificate for biomass power plants.	• Regular feed-in tariff for electricity of about 0.075 €/kWh$_e$.
Sweden	• Green certificate of about 0.020 €/kWh$_e$, valid for biomass.	• White certificate under way
Switzerland	• Feed-in tariff for renewable electricity of about 0.195 €/kWh$_e$.	

Fuel and DH availability

Among the different energy carriers, natural gas, district heating, biomass and electricity constitute the major share of the total energy consumption for heating in nearly all analyzed countries, with the exception of Switzerland where heating oil is the most commonly used fuel. Netherlands, Italy, Czech Republic, Spain and Germany are big natural gas consumers, whereas Sweden and Poland are characterized by a large share of households connected to district heating networks.

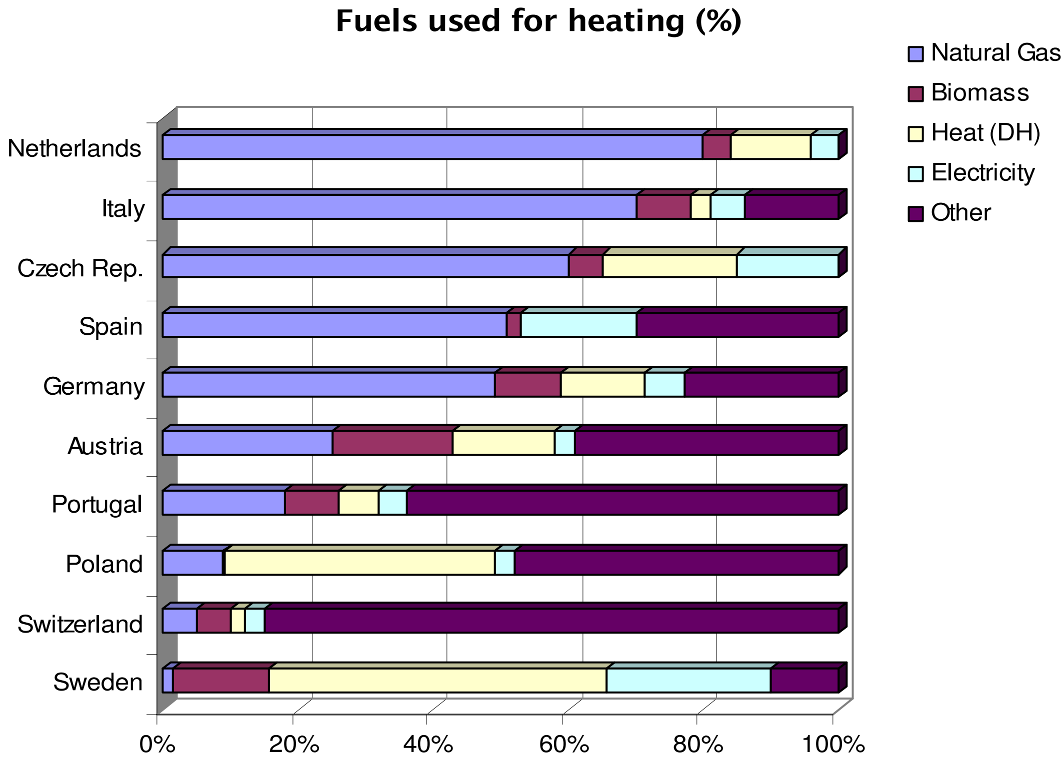


Figure 35: Share of energy carriers used for heating in the Residential sector

Rural and urban population

Most of the EU population and most of the households and services are concentrated in urban areas. The demand density for heating in urban areas is such that natural gas pipelines and district heating pipelines become economical. On the contrary, in rural areas the types of energy carriers that can be used in stand-alone heating systems, i.e. systems provided with a fuel storage, are the only viable solutions (e.g. LPG, diesel, oil or biomass). Another major difference between urban and rural areas is the concentration of pollutants in the air. Critical areas within the urban context are characterized by high population density and / or high industrial activity, two situations that can pose limitations to the diffusion of distributed generation from fuel combustion such as micro-CHP and micro-CHCP. For example, Northern Italy is a critical area for air pollution and severe restrictions apply to heating systems in terms of pollutants emission levels. The share of rural and urban population (UN, 2004) is shown in Figure 36.

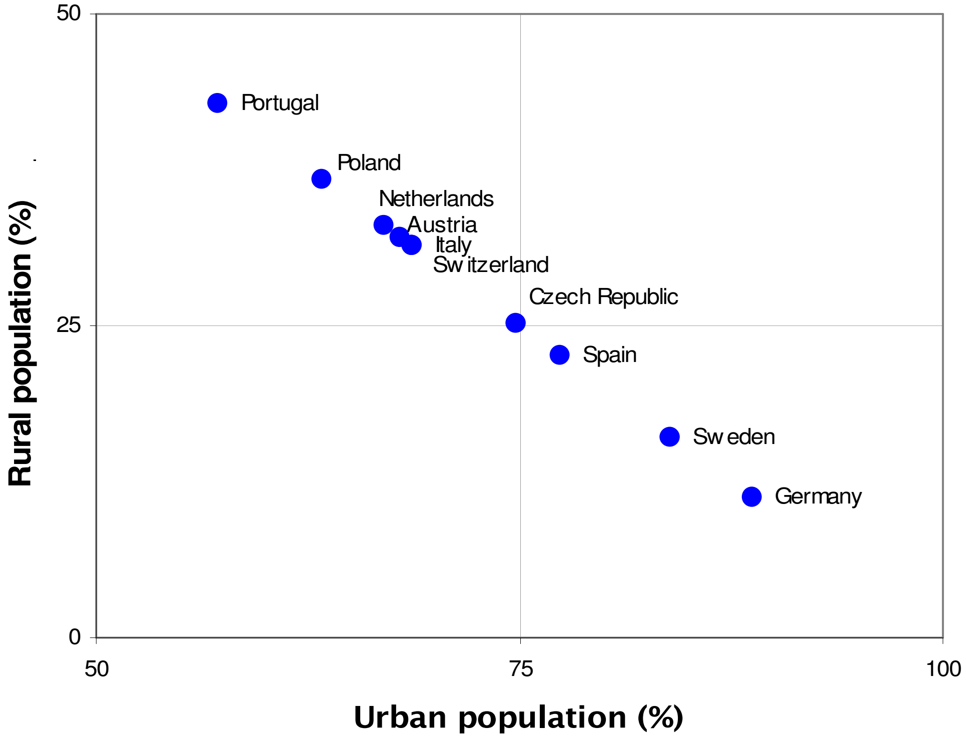


Figure 36: Share of urban and rural population (2008 estimate based on 2003 data)

Economic potential

According to the proposed methodology, primary energy savings and gross margin, specific per total heat and cold demand, have been calculated in the residential and service sector. Two different energy price sets have been used, one for the residential user, including VAT, and another for the service user, excluding VAT.

Table 6 Energy prices used for the Residential and Service sectors.

	households €/kWh		Service sector €/kWh	
Country	**Natural gas**	**Electricity**	**Natural gas**	**Electricity**
Austria	0.050	0.131	0.053	0.132
Czech Republic	0.041	0.140	0.037	0.135
Germany	0.070	0.195	0.063	0.150
Italy	0.065	0.190	0.053	0.170
Netherlands	0.060	0.155	0.053	0.144
Poland	0.046	0.122	0.039	0.105
Portugal	0.079	0.150	0.063	0.135
Spain	0.062	0.169	0.043	0.140
Sweden	0.090	0.123	0.090	0.123
Switzerland	0.064	0.133	0.051	0.109

The analysis has been carried out only for natural gas fired micro-CHCP. In the residential case, Czech Republic, Poland and Switzerland show the highest enviromental potential. The reason for that is the high heat demand and the high PRF of marginal electricity. However, the fact the cooling demand is negligible for households qualify these cases as interesting for micro-CHP only. Germany is probably a more interesting case, followed by Italy, Netherlands, Spain and Austria. Among this group, Spain characterizes for the highest cooling demand. Gross margin is definitely not best in Switzerland, Portugal and Sweden.

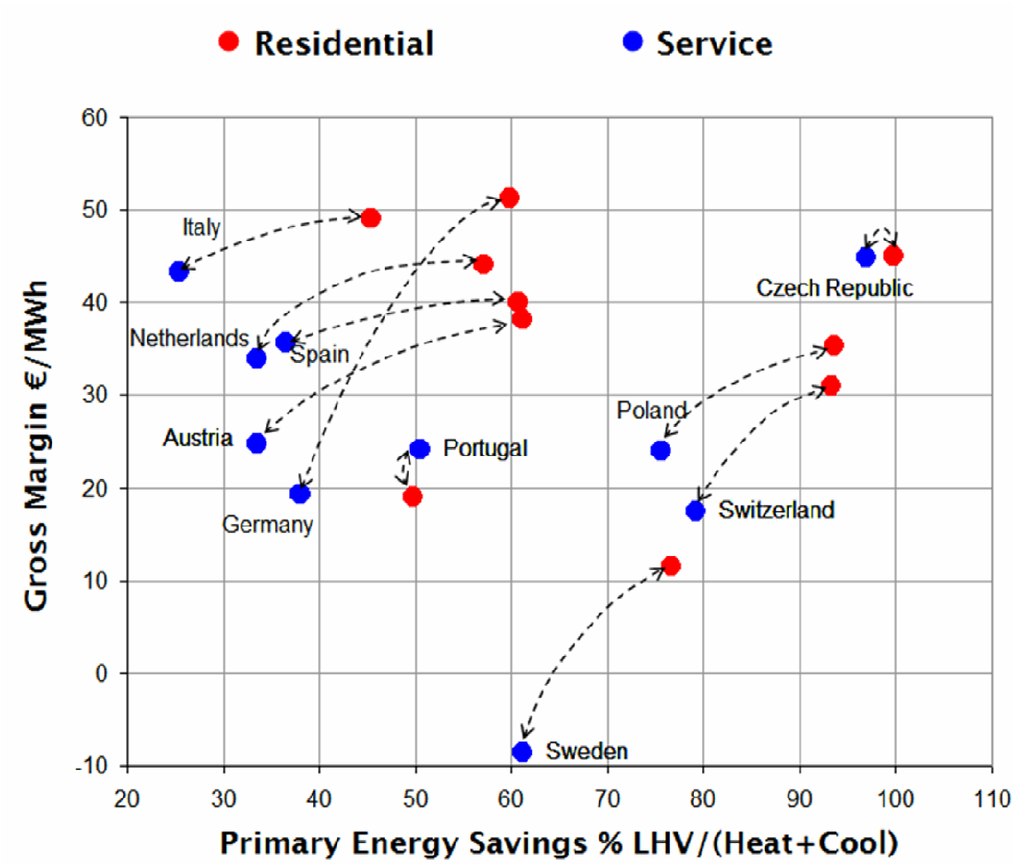


Figure 37: Natural gas fired micro-CHCP, % primary energy savings and gross margin specific per total demand of heating and cooling in the Residential and Service sector, in 2007

The picture is different for the Service sector. Czech Republic, Poland and Switzerland still show the highest enviromental potential but this time accompanied by a certain amount of cooling demand. Italy , Spain and Netherlands maintain a good financial potential, while Austria and Germany, alongh with Portugal, Poland and Switzerland, fall in the range of low gross margin. Sweden does not seem to have any finacial potential.

For what the district heat powered TDC is concerned, the gross margin analysis is not very useful as the values are not attractive. In fact, with the price of electricity driven cooling at approximately one fouth of the electricity price, the district heat utilized for driving the TDCs must be sold to such low prices (around 2-3 c€/kWh) that it is questionable if district heating network operators would find the option self-rewarding. Therefore, the analysis has focused mainly on the primary energy saving potential. The PRF for cooling has been calculated for both conventional (electricity driven) cooling and for a number of district heating networks, for which an estimate of their PRF was found in literature (ECOHEATCOOL c, 2006).

Table 7: PRF of selected district heating networks. Source: ECOHEATCOOL c, 2006.

DH network	PRF_{DH}	DH network	PRF_{DH}
Dresden	0.1	Vienna	0.36
Stockholm south	0.12	Munich	0.51
Goteborg	0.17	Stockholm central 1	0.57
Stockholm central 2	0.23	Hamburg	0.58
Brescia	0.26	Ferrara	0.58
Dinslaken	0.32		

The comparison shows that district heat powered TDCs can be an attractive solution when the primary resource content of district heat is sufficiently low, as in the case of Dresden, Brescia, Dinslaken and Vienna. The limiting PRF value for district has been calculated for the different countries and results range from about 0.40 (Netherlands, Austria) to about 0.55 (Poland, Czech Republic). Such conditions might be achieved only when the district heat PRF can benefit from the internalization of the electricity produced in central CHP plants, co-firing of green fuels and waste heat delivered by industrial activities.

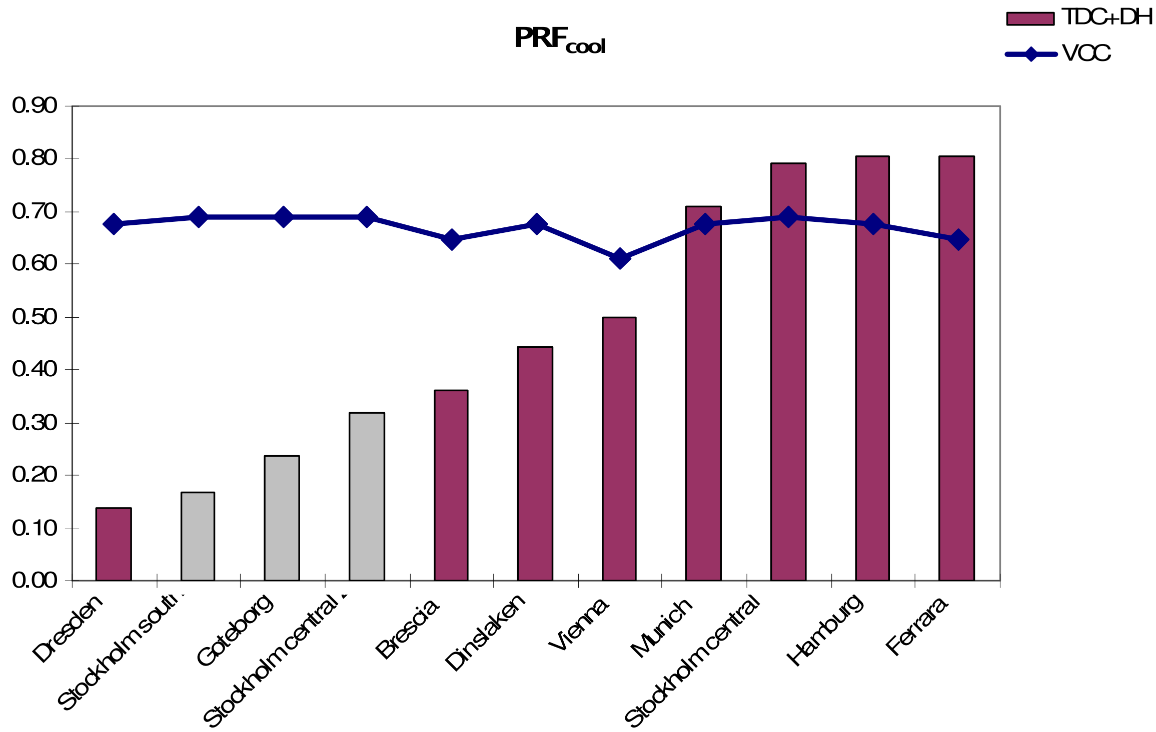


Figure 38: Primary resource factor for conventional cooling (VCC) and district heat powered TDCs (TDC+DH)

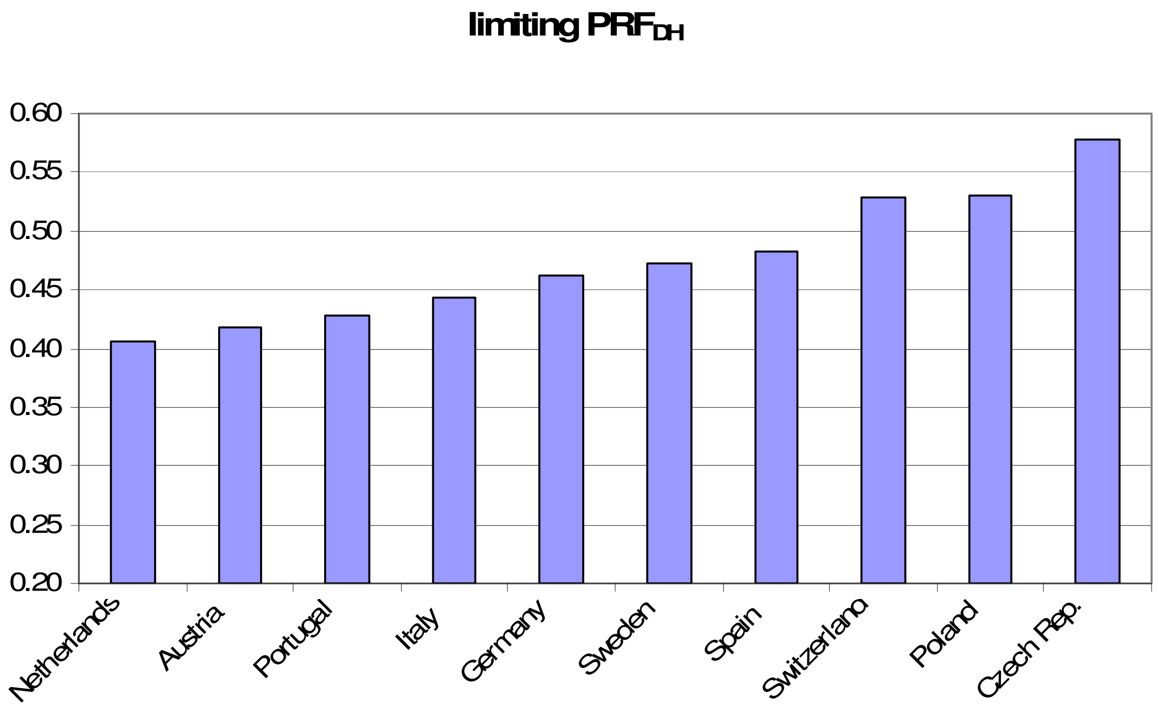


Figure 39: Limiting primary resource factor of district heat above which district heat powered TDCs can not provide primary energy savings as compared to conventional cooling

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Selected case studies

Energy and financial benefits associated to micro-CHCP need to be investigated in detail by means of simulations because of the following reasons:

- heating, cooling and power loads are time varying and must be estimated for each particular application (e.g. household, hotel, office);
- due to technical and financial reasons, the CHCP plant cannot cover the peak loads - on the contrary, a backup heater and/or chiller must be economically sized;
- the capital cost of the micro-CHCP plant includes several items, such as CHP, TDC, backup chiller and heater, heating and cooling storage and balance of the plant;
- differences in the electricity feed-in tariff and the purchase tariff imply that, for a correct evaluation of the financial benefits both electricity export and import are to be determined, and not only electricity generation;
- some incentives are assigned according to complex rules, such as white certificates;
- future energy prices are uncertain and sensitivity to energy prices is high;
- external ambient conditions have an impact on both TDC and VCC performance;
- the CHP plant is operated in discontinuous mode and start-up transients have effect on the CHP heat and power net output;
- the influence of thermal losses from the distribution pipelines and the heating and cooling storage must be considered.

In order to take all these aspects into account, a custom made simulation tool was developed (see Appendix A) and a number of case studies have been carried out. The goal was to explore in detail a few sectors (e.g. Residences, Hotels and Offices) by analyzing and grouping applications within a sector according to diverse "characterizing factors", such as climate, size and class of comfort. Uncertainty was addressed by means of scenarios analysis and sensitivity to both political support and energy prices volatility has been investigated.

The simulation tool provides the following outputs for each specific case and scenario:

- Primary Energy Savings (%)
- Net Present Value (€)
- Payback Time (years)
- Net Benefit to Investment Cost ratio

It must be clarified that primary energy savings are expressed as a percentage of the primary energy requested by the reference system for heating, cooling and power, including non-HVAC electricity.

The hotel sector in Italy

Total capacity

The tourism sector contributed to the Italian gross domestic product for about 7-8 % in the recent years (Federalberghi, 2006). Among the different receptive services (hotels, residences, camping sites, hostels and bed & breakfast), hotels alone represent about 45% of the total receptive capacity. In year 2005, the hotel sector accounted for 1,870,000 beds. The largest shares are covered by the 3 and 4 star categories: 51% and 27% respectively.

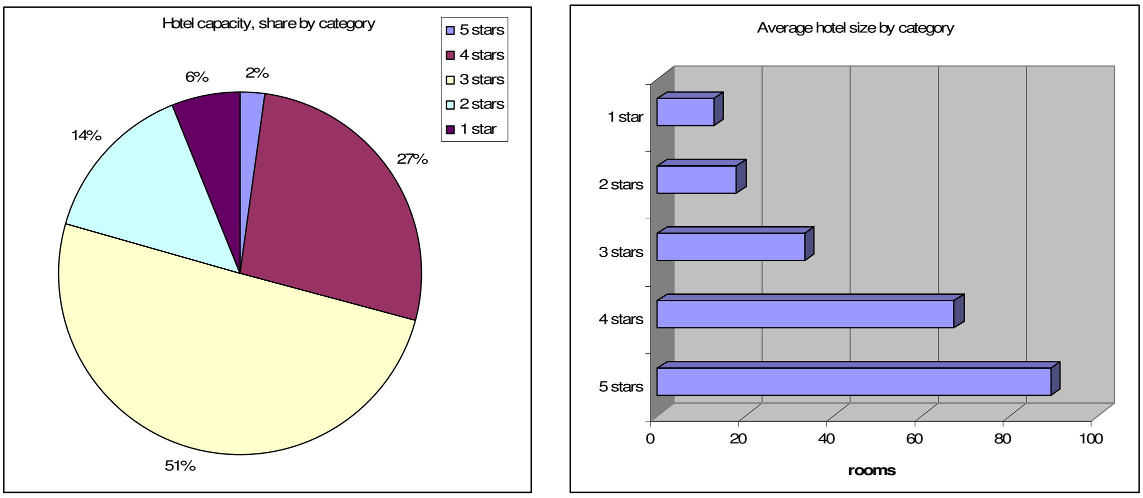


Figure 40 Hotel capacity, share by category and average hotel size by category. Source: ISTAT

The average hotel size by hotel category shows that 1 and 2 star are on average quite small, with only 10 - 15 rooms. On the opposite, 5 star are quite large, with an average size of 90 rooms. Within 4 star hotels, however, sizes are distributed over a wider range, from 15 up to 175 rooms.

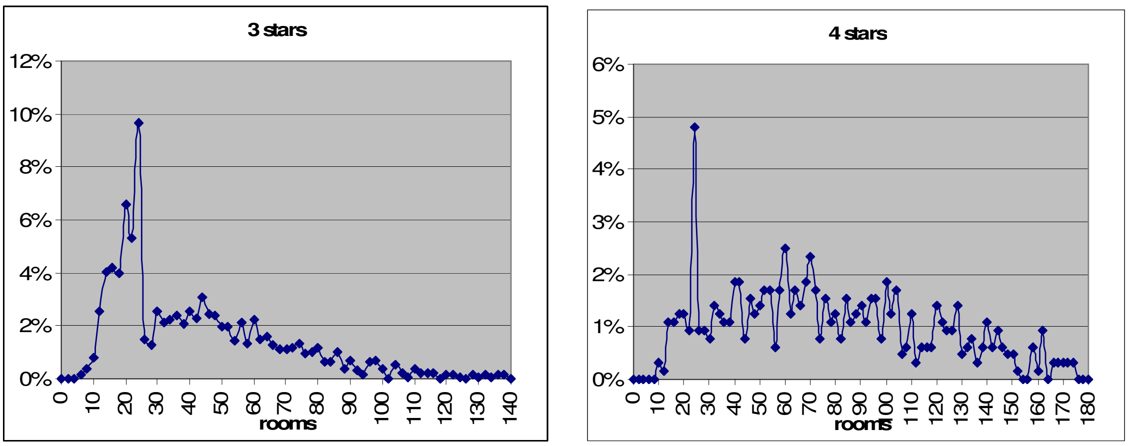


Figure 41 Distribution of 3 star and 4 star hotel by hotel size (number of rooms). Source: ISTAT

The majority of the tourism hotels are located in Emilia Romagna, Trentino and Tuscany, whereas business hotels are quite common in Lombardia and Lazio. Capacity in 3 star hotels is mostly concentrated in the North of the country, where it can achieve nearly 70% of the total hotels capacity. On the contrary, in the South 4 star hotels are as common as 3 star hotels.

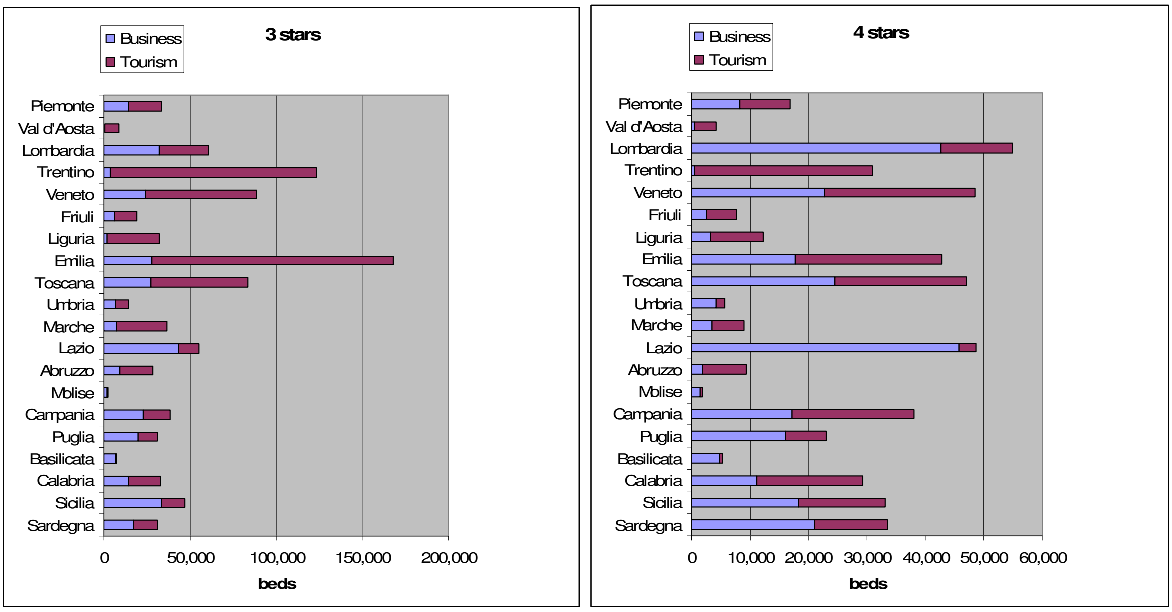


Figure 42 Hotel capacity by location type (Business, Tourism). Source: ISTAT.

Market trends

The average number of visitors every year amounts to 220 millions with an average occupancy rate of about 45%. The low occupancy rate is a consequence of the seasonality character of the hotel business in Italy, although some concerns exist on the reliability of the statistics data (De Caprariis et al., 2006). Seasonality is much stronger in Sardinia, Sicily and Emilia Romagna, where the average occupancy rate is about 10 to 20 % during the winter season and 70 to 80 % during the summer season. The occupancy profile is nearly flat in Lombardia and Lazio, where most of the all-year–round-open-hotels are located. The profile in Trentino and Valle d'Aosta shows two occupancy peaks, one in winter and another one in summer.

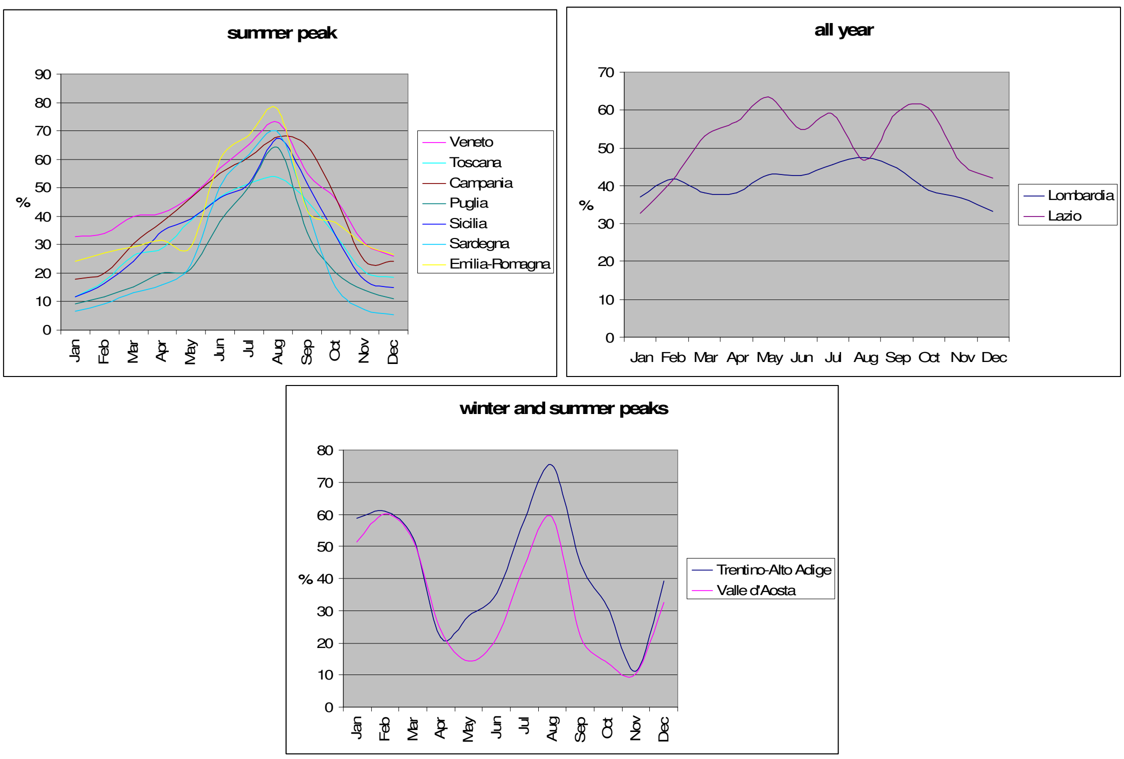


Figure 43 Monthly occupancy rate by regions. Source: ISTAT.

The variation of the receptive capacity during the last 5 years shows that 4 and 5 star hotels are growing faster than 3 star hotels, while 1 and 2 star become less and less. In particular, 3 star hotels are growing only in the North and in the Centre of the country, while 4 star capacity increases all over the country. The average growth rate of 4 and 5 star hotels was 8% p.a., corresponding to 5,000 new beds every year.

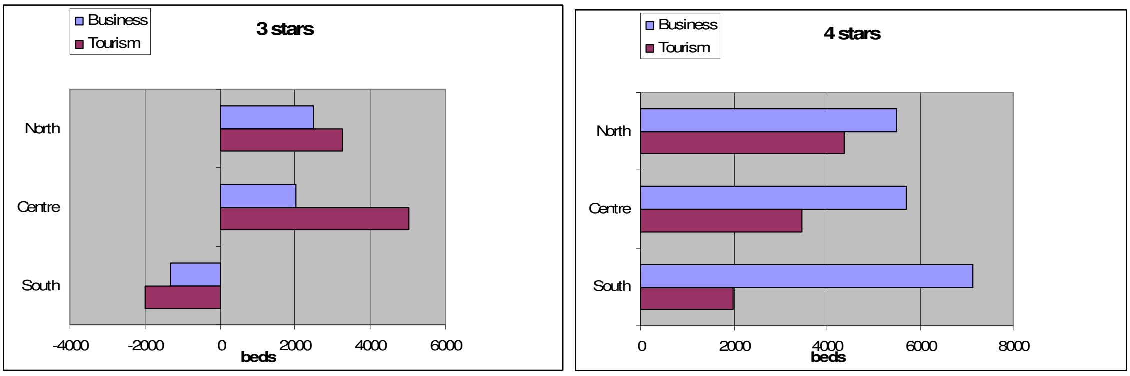


Figure 44 Variation of 3 star and 4 star capacity (number of beds) in the years 2002-2006. Source: ISTAT.

Energy needs

Highly comfortable hotels usually consist of the following zones:
- guest rooms
- reception hall
- common areas (café, bar, relax, lounge)
- conference rooms
- restaurant area
- fitness area
- swimming pool
- service area (kitchen, laundry, offices).

Some important figures about the conformation of large 4 star hotels and their energy needs are summarized hereafter. The figures have been calculated on the basis of a survey carried out in 2005 (Chose, 2001). The average size of the sample hotels was about 150 rooms. All hotels are open all year round and have conference rooms, restaurants and laundry, yet no swimming pool.

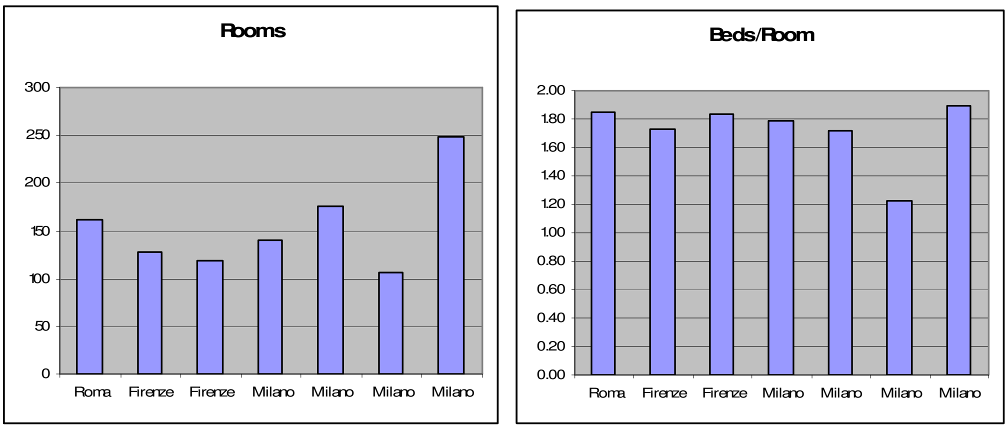


Figure 45 Composition of the surveyed hotels (Rooms, Beds/Room). Source: Chose, 2001.

The surveyed information was related to: number of beds, floor surface (guest rooms, conference room, restaurants, service area, common area and air conditioned area), fuel and electricity consumption.
The number of beds per room is quite similar within the sample: a frequent value is 1.8 beds / room. The same holds for the average room area and a value of 20 m^2 can be considered

quite common. The conference room area does not seem to be correlated to the hotel size: a specific value would range between 1 and 7 m^2/room. About the restaurant floor area, the average specific value is 3 m^2 / room. The specific service room ranges between 3 and 11 m^2/room, the specific common area ranges between 2 and 6 m^2/room and the specific air conditioned area ranges between 30 and 45 m^2/room.

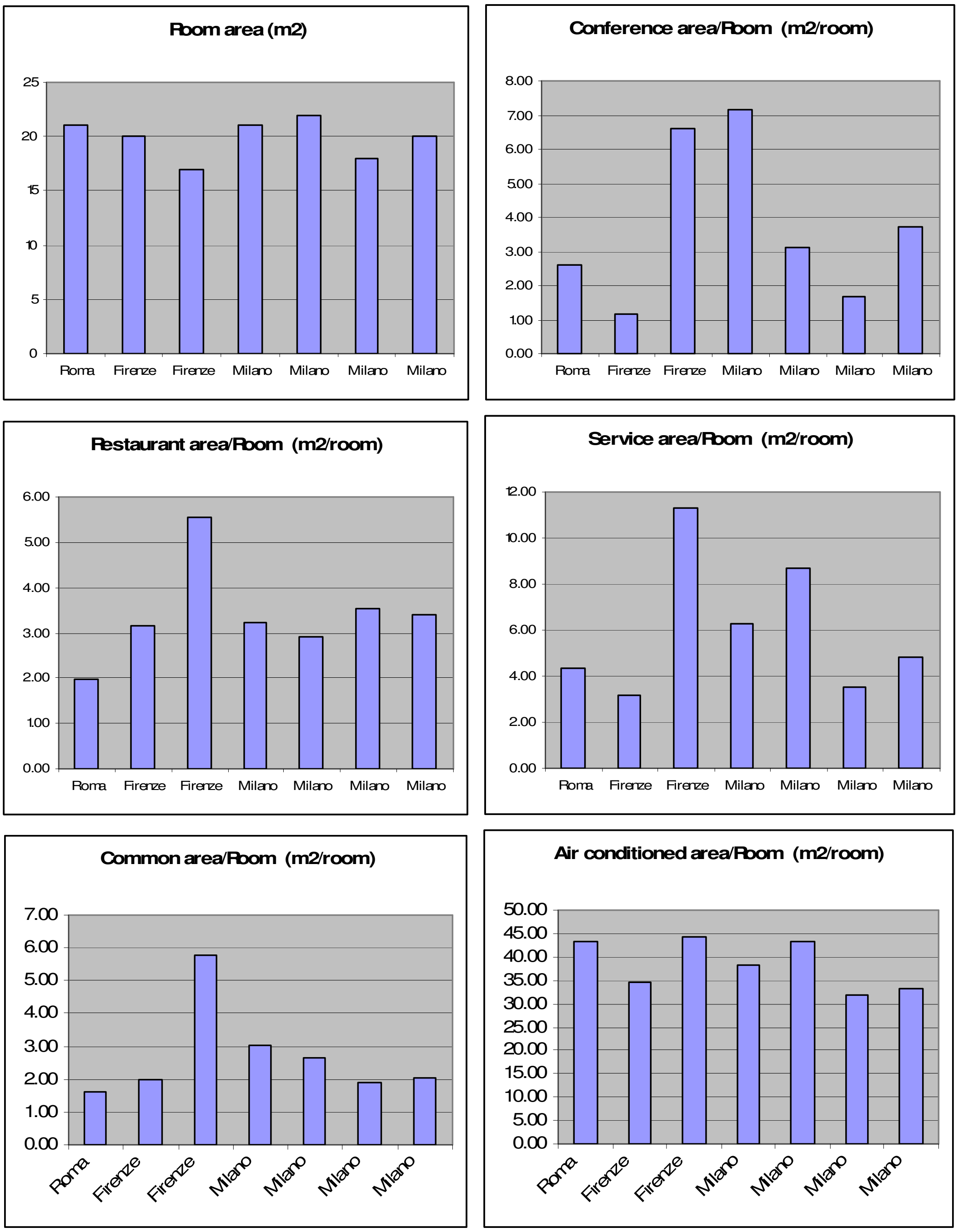


Figure 46 Specific floor area by hotel facility in the surveyed hotels. Source: Chose, 2001.

The survey also reported the allocation of the energy consumption to the different final uses and services (space heating, domestic hot water preparation, steam generation, lighting, electric appliances and refrigeration, space cooling). The specific energy demand for space heating ranges from 2.5 MWh/room in the Centre and 3.5 MWh/room in the North of the country. The specific demand for domestic hot water preparation ranges between 3.8 and 4.4 MWh/room. Electric energy consumption ranges from 5 to 11 MWh/room. Cooling energy demand ranges from 1 - 2.5 MWh/room in the North to 1 - 3.5 MWh/room in the Centre, corresponding to 30 - 60 kWh/m^2 in the North and 30 - 80 kWh/m^2 in the Centre area.

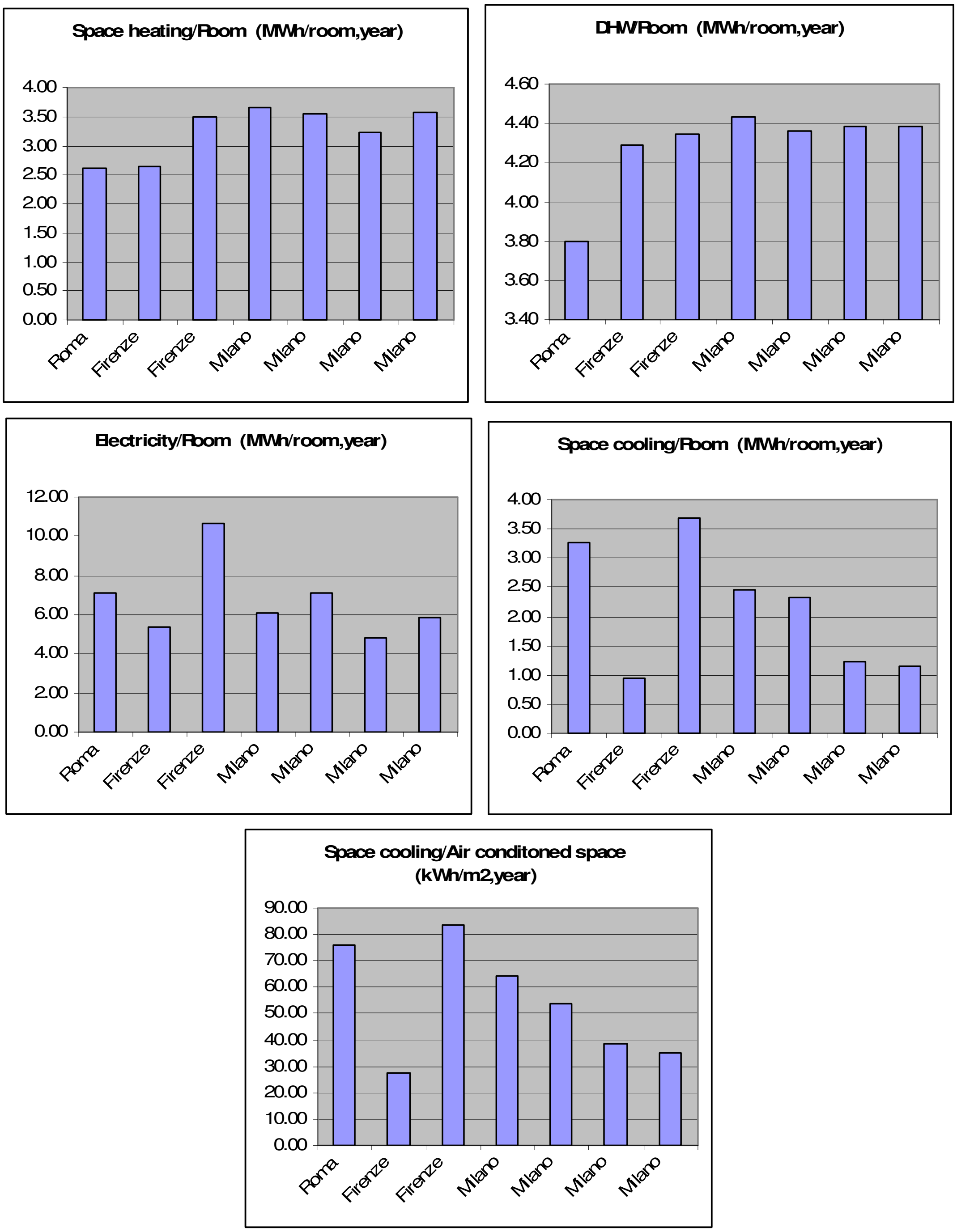


Figure 47 Energy demand specific per floor area in the surveyed hotels. Source: Chose, 2001.

A second survey (Studio Roberto Fortino e Associati, 2005) has confirmed the previously described specific figures and also revealed some new aspects that characterize the hotel industry. The survey addressed 4 and 5 star hotels with an average size of 100 rooms and 4.700 m^2 floor area. The average electricity consumption was 7.7 MWh / room. Natural gas is the heat source in 53% of the cases. Of the remaining cases, 22 % used electricity driven heat pumps. None had cogeneration systems nor were connected to any district heating network. Regarding the distribution system, all-air is the most commonly adopted solution in about 70% of the cases. Fan-coils were used in 20% of the cases, and primary air with local fan-coils was used in the remaining 10%.
Electricity and thermal energy consumption for hotels in Sicily were reported in Beccali et al., 2009. 3 star hotels presented a specific electricity consumption of 4.6 MWh/room, while the respective value in 4 and 5 star hotels was 8.6 MWh/room. As for thermal energy, values

ranging from 4.2 to 5.3 MWh/room are reported. It is believed that at least 60% of the thermal energy consumption is due to domestic hot water preparation.

Sector segmentation

On the basis of the collected information, the Italian hotels sector has been divided into segments and finally combined into clusters. This certainly introduces a certain degree of approximation; nevertheless the method allows to capture the most relevant characteristics of the whole sector. With respect to the final goal of the study, i.e. evaluating the potential benefit of micro-CHCP, the following simplification has been made.
Only 3 and 4 star hotels have been considered because: (i) they represent about 78% of the total, (ii) 1 and 2 star are probably too small for micro CHCP and (iii) 5 star tends to be too large.
For each category, two prototypical sizes have been identified according to the frequency charts. The hotels have been arbitrary grouped into segments as shown hereafter.

Table 8 Hotel segments definition, based on category and size.

Category	Size	Category - Size filter
3 star	24 rooms	3 star, less than or equal to 34 rooms
3 star	48 rooms	3 star, greater than 34 rooms
4 star	56 rooms	4 star, less than or equal to 82 rooms
4 star	112 rooms	4 star, greater than 82 rooms

Occupancy can have an influence on the yearly operation hours of the mirco-CHCP plant. Therefore, three occupancy profiles are investigated: all year, winter and summer and only summer.
Climate is also relevant because it affects the heating and cooling loads. By matching occupancy profiles with climate, five geographical segments have been defined. Each segment is characterized by its own geographical filter, as shown hereafter.

Table 9 Hotel segments definition, based on occupancy profile and climate.

Occupancy	Climate	Geographical filter
All year	Centre (Roma)	Business - Centre
All year	North - (Milano)	Business - North
Summer	North East & Centre (Ancona)	Tourism - Centre & North but the Alps
Winter and Summer	North (Bolzano)	Tourism - The Alps
Summer	South (Palermo)	Tourism & Business - South

By combining the size - category segments with the occupancy - climate segments, the whole hotels sector has been divided into twenty clusters. The number of hotels for each cluster has been estimated according to the available statistics on hotels capacity (ISTAT , 2006).

Table 10 Hotel cluster definition, based on size-category and occupancy profile-climate segments.

	3 stars - small (24 rooms)	3 stars - large (48 rooms)	4 stars - small (56 rooms)	4 stars - large (112 rooms)
Business - Centre	1292	3156	409	608
Business - North	3050	4970	1059	1033
Tourism - Centre & North but Alpes	1944	2611	930	803
Tourism - Alpes	94	677	303	192
Tourism & Business - South	1676	5990	764	1568

Having defined the character of each cluster in terms of size, category, occupancy and climate, an evaluation of micro-CHCP attractiveness for a given cluster is made possible. In

this regard, the main decision driver is the need for cooling and the presence of a central air conditioning system.
Even though a clear definition of the differences between 3 and 4 star hotels does not exist, due to the fact that hotels classification is set at a regional level, one major difference set by regional laws consists of the presence of air-conditioning in the whole building. According to regional laws (Emilia Romagna, 2007), hotels at altitudes higher than 500 meters over the sea level must provide air-conditioning to be qualified as 4 star (or up). In principle, high quality 3 star hotels might be equipped with central air conditioning systems and not be qualified as 4 star hotels due to a lack of some other services. Indeed, a survey on the web (Traveleurope) has revealed that this situation is quite frequent. Therefore, it can be concluded that micro-CHCP can certainly find application in 4 star hotels and most likely in 3 star hotels, if not located on the mountains. A graphical representation of the proposed clusters is shown hereafter, where numbers represent the equivalent number of prototypical hotels in each group.

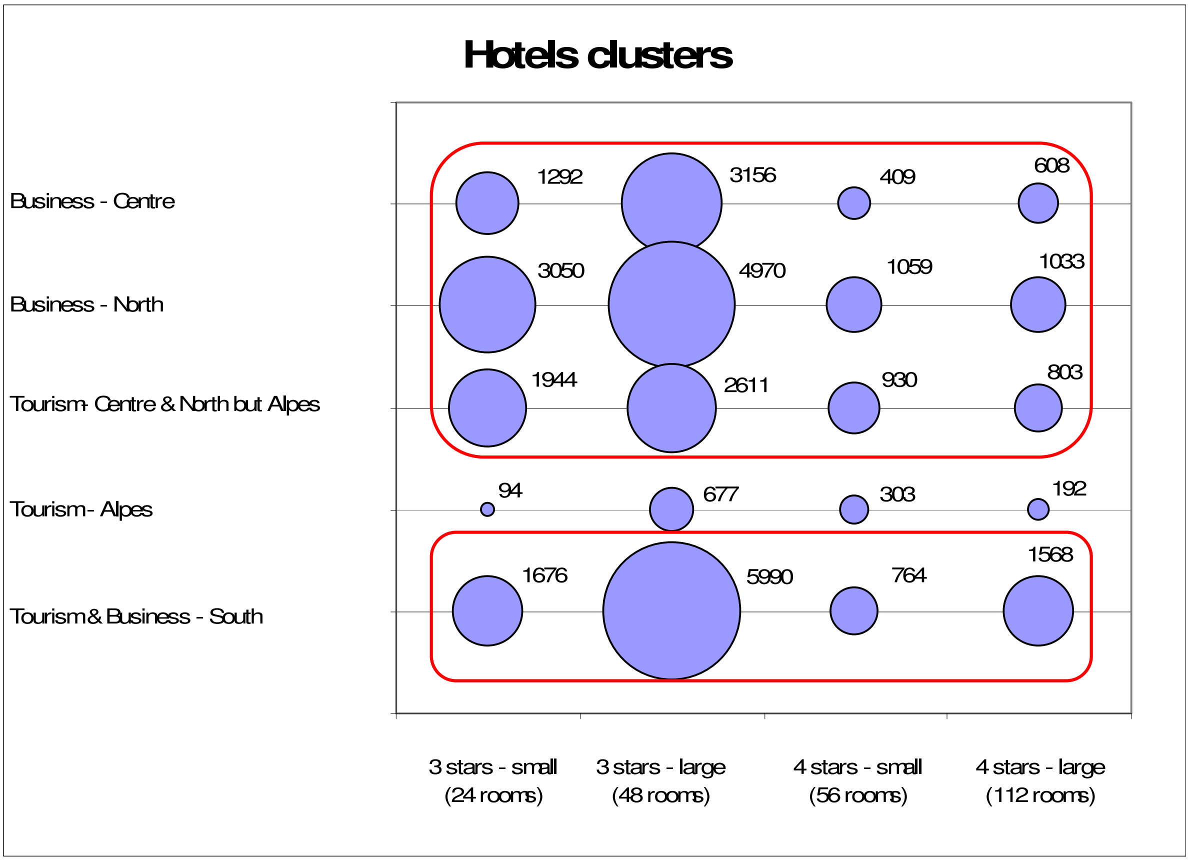


Figure 48 Composition of hotel clusters in terms of number of prototypical hotels in each cluster.

Load profiling

For each of the clusters of interest, the hourly load profiles of heating, cooling and electricity have been generated by using TRNSYS building simulation tool. Heating included both space heating and domestic hot water preparation. The four prototypical buildings have been defined according to the requested number of rooms and the specific figures from the hotels conformation previously described. The kitchen area has been separated from the rest of the service area because in this zone ventilation is high and comfort is seldom provided. The remaining part of the service area has been included into the common area, for simplicity. Finally, it is assumed that 3 star hotels do not have conference rooms and the restaurant is open for breakfast only. All buildings are supposed to be 4 storey. Restaurant, kitchen, reception, lounge area and conference room are all located at the ground floor. Guest rooms are located at the first, second and third floor. The floor areas in each zone of the four prototypical hotels are shown hereafter.

Table 11 Floor area in each facility of the four prototypical hotels.

	Floor area (m^2)					
Hotel type	Rooms	Common	Restaurant	Kitchen	Conference	Total
3 stars 24 rooms	421	195	70	24	N/A	710
3 stars 48 rooms	842	390	140	48	N/A	1420
4 stars 56 rooms	1125	550	160	70	112	2017
4 stars 112 rooms	2250	1100	320	140	224	4034

For the sake of simplicity, load profiles are assumed to vary in direct proportionality with floor area, although this is not exactly true. In this way, the simulation work has been reduced from 4 cases two 2 main cases: the "3 star 48 rooms" hotel and the "4 star 112 rooms" hotel. Space heating and cooling loads have been calculated assuming the following set-point for temperature and humidity: 22°C, 50% R.H. in winter and 25°C, 50% R.H. in summer in all zones except for the kitchen.
The hotel building standards have been chosen according to the most common standards of buildings erected during the last 25 years in Italy (CTI, 2003). The envelope averaged U-value is 1.35 W/m^2K and windows are equipped with double glazing (U=2.83 W/m^2K and τ = 0.693).
Internal gains and domestic hot water consumption are assumed to vary with occupation. Peak values are shown hereafter for the two main hotel types, along with examples of the resulting hourly profiling in a typical winter and summer day for the case of 4 star 112 rooms hotel of the Business - Centre segment.

Table 12 Internal gains considered in the load simulations.

Area	3 stars 48 rooms	4 stars 112 rooms
Maximum number of People (person)		
Rooms	90	190
Common	50	130
Restaurant	50	130
Kitchen	6	12
Conference	0	130
Electric peak load (W/m2)		
Rooms	16	19
Common	19	19
Restaurant	13	19
Kitchen	400	550
Conference		19
Ventilation (1/h)		
Rooms	1	1
Common	1	1
Restaurant	4	4
Kitchen	15	15
Conference		2
Recuperator efficiency (%)		
Rooms	0	0
Common	55	55
Restaurant	55	55
Kitchen	0	0
Conference		55
Hot water consumption (l/h)		
Rooms	8640	20160
Common	55	55
Restaurant	55	55
Kitchen	0	0
Conference		55

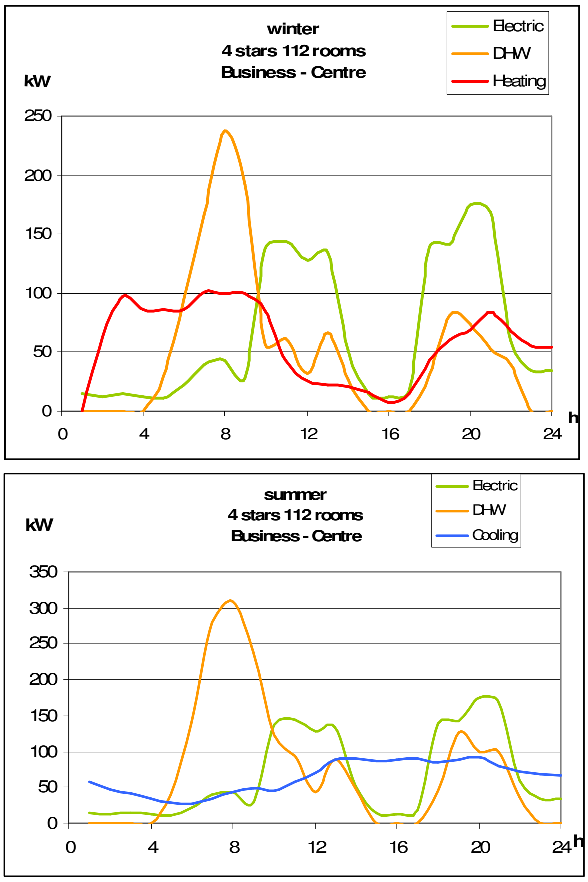
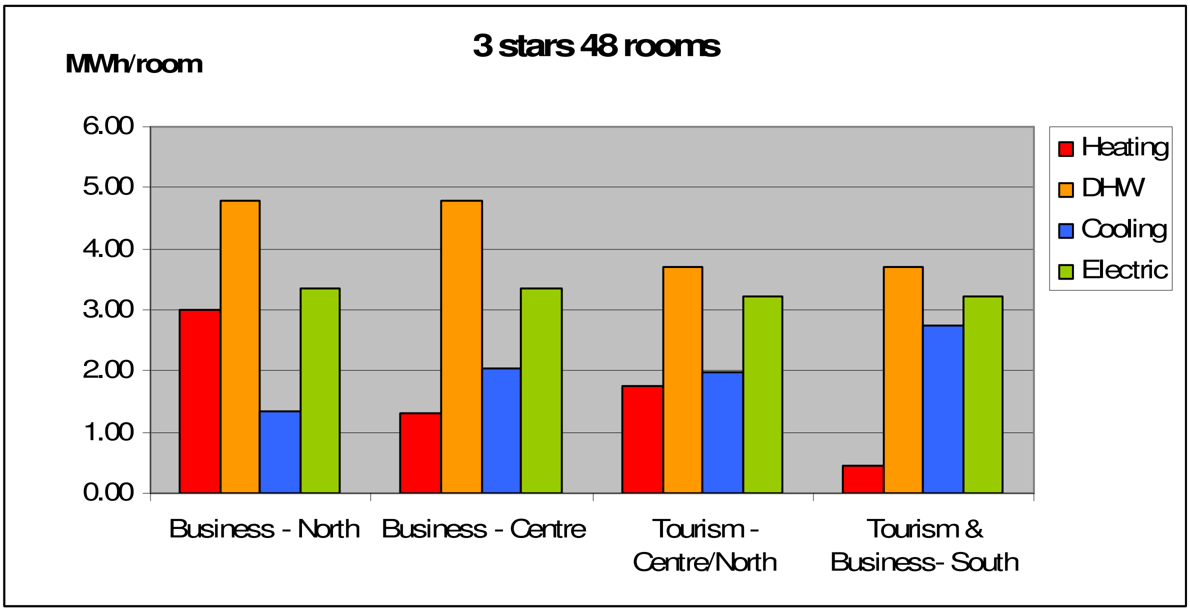


Figure 49 Load profiles in a typical winter day and summer day.

The simulated annual load for heating, domestic hot water, cooling and electricity is shown hereafter. Values are in good agreement with typical hotels energy needs.



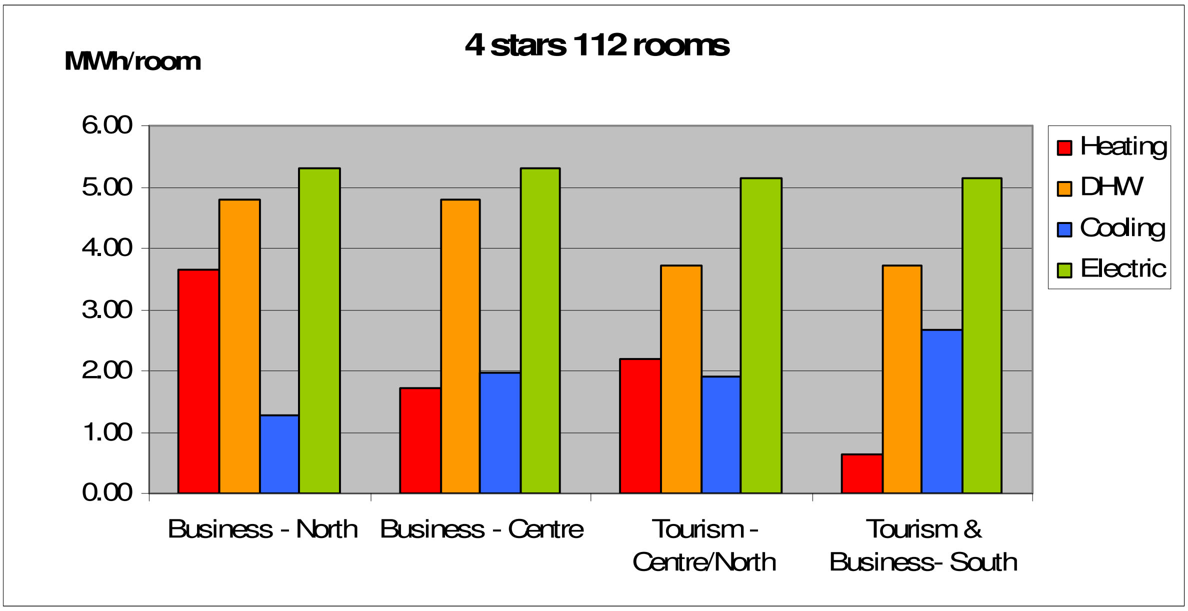


Figure 50 Yearly energy demand, specific per hotel room and for each hotel cluster.

Estimated total energy needs

By means of the proposed segmentation, an estimate of the whole sector energy needs can be given. Moreover, by combining the primary energy conversion factor with the energy needs, a rough estimate of the total primary energy needs and its distribution among clusters can be provided too. In this regard, the following primary energy conversion factors are assumed for the three types of energy needs:

heating:	1.18
cooling:	0.68
electricity:	2.56

The resulting total primary energy consumption for each cluster is shown hereafter.

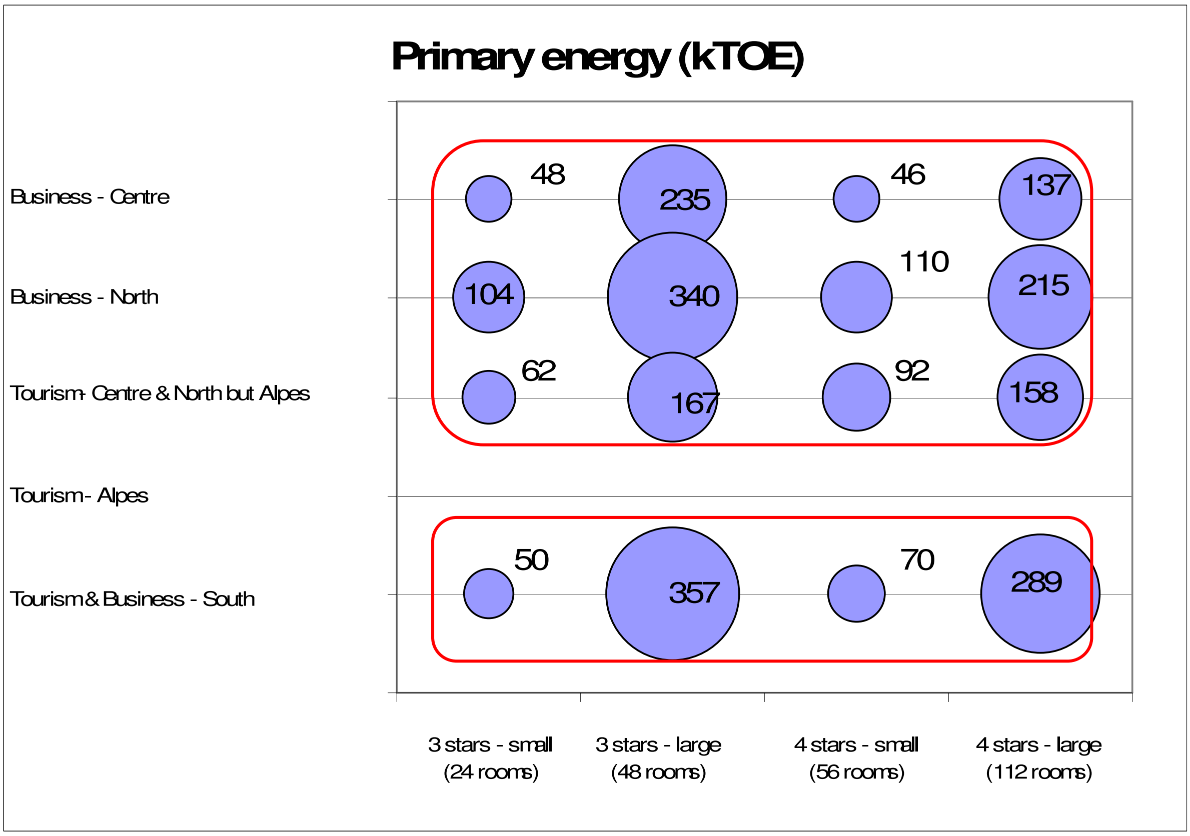


Figure 51 Primary energy demand estimated in each cluster (ktoe).

Energy prices and incentives

Electricity and natural gas are the main energy sources in Italian hotels, followed by liquid fuels like diesel and LPG. The main features in determining the energy price for hotels are destination of use (non-domestic) and consumption class. On the basis of the specific per room annual consumption data, annual consumption of natural gas and electricity can be estimated for the 4 types of hotels considered so far.

Table 13 Estimated annual consumption of natural gas and electricity for each category-size segment.

Hotel type		Specific per room annual consumption		Total per hotel annual consumption	
Category	Rooms	Natural gas [MWh/year]	Electricity [MWh/year]	Natural gas [Sm^3/year]	Electricity [kWh/year]
3 star	24	6	5	14,500	120,000
3 star	48	6	5	29,000	240,000
4 star	56	9	7	50,000	390,000
4 star	112	9	7	100,000	780,000

From the data above it can be concluded that hotels are non-domestic users with annual consumption of natural gas less than 200,000 Sm^3 and electricity annual consumption less than 2,000,000 kWh.

Electricity

The total electricity price is mainly given by the sum of the energy price and the taxes. Besides VAT, the two main taxes which apply to non-domestic user with monthly consumption less than 200,000 kWh are the consumption tax (central) and the additional distribution tax (local). In the liberalized market, the cost of energy depends on the utility, although differences among large players are nearly negligible. Taxes are fixed at a central and a local level: the consumption tax amounts to 0.31 c€/kWh and the additional distribution tax may vary between 0.93 and 1.14 c€/kWh, depending on the province. Consumption taxes are due by the energy producer based on the consumed energy, so they are due even if produced and consumed in the same site. Distribution taxes apply only when electricity is purchased from the grid. The average total electricity price excluding VAT has been calculated (Confartigianato, 2007) (Gestore mercato elettrico) and reported steady growth during the last years:

Table 14 Electricity price before VAT in 2005, 2006 and 2007 for the average hotel.

Electricity price	Year		
c€/kWh	2005	2006	2007
Total price before VAT	11.24	13.96	15.93

VAT on electricity is set to 20% for all users but the domestic ones, to which a reduced VAT of 10% is applied.

Natural gas

The total gas price consists of the energy price, the consumption tax and the additional distribution tax, which is set at a regional level. Tax rates are differentiated by destination of use and geographical location. Moreover, tax breaks and exemptions are allowed for specific uses in the industrial and commercial sector, among which hotels and restaurants. On average, the consumption tax amounts to 17 c€/Sm^3 and the regional distribution tax to 1.3 c€/Sm^3, but thanks to tax breaks, the total taxes for hotels amount to less than 1.3 c€/Sm^3. The energy price varies depending on the utility and the type of contract. Average values have been estimated for both the regulated and the free market (AEEG b, 2007), showing differences of about 8%. For non-domestic users in the consumption class 5,000 - 200,000 Sm^3, the following values, in c€/Sm^3, have been reported:

Table 15 Natural gas price before VAT in 2005, 2006 and 2007 for the average hotel.

Gas price in c€/Sm^3	Year		
Contract type	2005	2006	2007
Regulated market	32.12	38.21	36.16
Free market	29.76	35.78	37.10

VAT on natural gas is set to 20% for all users but the domestic ones, to which a reduced VAT of 10% is applied. Moreover, most industries benefit from the reduced VAT of 10% (e.g. manufacturing industries or electricity producers).

CHP regulation and promotion

Since the recommendations and directives of the European Union are being followed, the situation is changing rapidly. The liberalization and privatization of both the electricity and natural gas sectors is taking place, and, during the last few years, the Italian energy sector has paid increasing attention to the issue of distributed generation and cogeneration in small-scale power plants. However, current incentives cannot be considered so effective in promoting small scale cogeneration, as it will be explained in the following.
Among the different energy sources, particular importance is assumed by **natural gas** based cogeneration applications, which have market potential in the short to medium term and might usefully exploit the availability of the Italian fuel distribution network. The Italian natural gas market is well established as the third largest in Europe, after Germany and the UK, with over 75 billion m^3 of natural gas distributed annually through a 30,000 km network. This gas comes mostly from imported sources (about 80%), with a smaller fraction (20%) coming from domestic production. In recent years the market has become increasingly liberalized and open in accordance to EU directives. Within the framework of energy market liberalization, potential CO_2 emission savings with respect to the Kyoto protocol and electricity grid

saturation have pushed Italian regulators to undertake measures for promoting distributed cogeneration. Presently, interest is focused on new proposals for small-scale power plants, ranging from 1 to 1,000 kW and addressing the civil sector (residences, hotels, office buildings, shopping malls and hospitals).
This initiative aims to overcome some of the barriers still present in this field (bureaucracy, authorization and fiscal costs, and grid connection issues), which is generally designed to deal with centralized generation and unidirectional distribution of energy to the final users. The process is ruled by the Italian Authority for Electric Energy and Natural Gas (AEEG) by means of several directives. Regarding cogeneration, Directive 42/02 (AEEG, February 2002) introduced a definition of cogeneration that opens up the way to small scale cogeneration installations.
The directive qualifies 'cogeneration' as the combined production of electricity and heat with an index of energy saving above 10%. The index of energy saving (IRE, in Italian) compares the primary energy consumption of the cogeneration plant with the consumption which would result from a conventional separate generation of electricity and heat, and it is defined as:

$$IRE = 1 - \frac{E_{fuel}}{\frac{E_{el}}{\eta_{el,ref} \times p_{gr}} + \frac{Q_{th}}{\eta_{th,ref}}}$$

where E_{fuel} is the fuel consumption of the cogeneration plant, E_{el} the electricity generated, Q_{th} the heat generated and $\eta_{el,ref}$, $\eta_{th,ref}$ the two reference efficiencies for electricity and heat generation, defined separately. The factor p_{gr} accounts for grid losses, depending on the voltage level of the grid which the cogeneration plant is connected to. It should be noted that in CHCP, a more sophisticated formula applies, since cooling energy should be compared to the reference cooling generation, i.e. a vapor compression chiller. The IRE equation is defined as:

$$IRE = 1 - \frac{E_{fuel}}{\frac{E_{el}}{\eta_{el,ref} \times p_{gr}} + \frac{Q_{th}}{\eta_{th,ref}} + \frac{Q_c}{\varepsilon_{ch,ref} \times \eta_{el,ref} \times p_{gr}}}$$

where Q_c is the cooling energy generated and $\varepsilon_{ch,ref}$ is the reference chiller EER.
The reference values for electrical efficiency are shown in Table 16 and are a function of both fuel and size of the plant. Larger plants compete with high efficiency power stations while small plants are in advantage compared to much less efficient electric competitors.

Table 16 Reference values for electrical efficiency used to calculate the energy saving index in the AEEG Directive on cogeneration. (*) including biomass.

Electrical efficiency for IRE calculation				
Nominal power, MW	**Natural gas, liquid gas**	**Oil, naphta, diesel fuel**	**Solid fossil fuels**	**Solid refuse fuels (organic and inorganic*)**
<1 MWe	0.38	0.35	0.33	0.23
> 1 ÷ 10 MWe	0.40	0.36	0.34	0.25
> 10 ÷ 25 MWe	0.43	0.38	0.36	0.27
> 25 ÷ 50 MWe	0.46	0.39	0.37	0.27
> 50 – 100 MWe	0.49	0.39	0.37	0.27
> 100 ÷ 200 MWe	0.51	0.39	0.37	0.27
> 200 – 300 MWe	0.53	0.39	0.37	0.27
> 300 – 500 MWe	0.55	0.41	0.39	0.27
> 500 MWe	0.55	0.43	0.41	0.27

Reference thermal efficiency is set to 0.8 for civil cogeneration and 0.9 for other cases. The reference chiller EER is set to 3.0.
For plants qualified as "cogenerators" (i.e., that respect the limit set for IRE) and fed by natural gas, the fuel is exempt from consumption and distribution taxes in the quantity of 0.25 $Nm^3/\ kWh_{el}$. Table 17 reports tax values for natural gas, according to the various sectors.

Table 17 Tax values for natural gas in Italy.

Sector	Consumption (Sm^3/year)	Geographic area	€/Sm^3
Industry	< 1,200,000 >= 1,200,000		0.012498 0.007499
Domestic heating	< 250	NORTH	0.0788526
		SOUTH	0.0386516
	>= 250	NORTH	0.1733074
		SOUTH	0.1242182
Hotels, restaurants, sport facilities, district heating			0.0124983
Commercial and public buildings		NORTH	0.1733074
		SOUTH	0.1242182
Hospitals		NORTH	0.1733074
		SOUTH	0.1242182

Within 2010, all EU countries have to traduce into national laws the EU directive 2004/8CE on the promotion of cogeneration. The aim of the EU directive is to promote high efficiency cogeneration, especially micro (<50 kW) and small scale one (<1 MW), establishing that the authorization procedure for such plants should be greatly simplified, particularly for micro cogeneration that should be compared to a boiler equipment having the same nominal thermal input.
The index to evaluate energy savings of cogeneration plants (PES, Primery Energy Saving) is very similar to the one established by Italian legislation (IRE), and is defined as:

$$PES = 1 - \frac{E_{fuel}}{\dfrac{E_{el}}{\eta_{el,ref} \times p_{gr}} + \dfrac{Q_{th}}{\eta_{th,ref}}}$$

with the only difference that the reference values for electrical efficiency are independent by fuel type or plant size. The limit for the definition of high efficiency cogeneration plant is 10% for plants above 1 MW_{el} and 0% for smaller plants. The standard reference values for the PES calculation are: $\eta_{el,ref}$ = 52.5 % and $\eta_{th,ref}$ = 90 %. Minor corrections to reference electrical efficiency are introduced for each country, due to different yearly average temperatures. For Italy the reference value becomes 52.3 %.
Regarding tariffs and economic incentives, every country can adopt its own rules. Italy formally adopted the EU directive in its legislation (law 8-2-2007, n. 20), but some more decrees are still necessary to effectively apply the regulation. One important incentive established by the Italian law (8-2-2007, n. 20), once fully implemented by operational decrees, is going to allow full reverse metering (RMF=1 or "scambio sul posto") for high efficiency cogeneration systems up to 200 kWe; the same privilege is given to renewable power plants. Currently, this incentive is not in operation yet.

Another kind of incentive relevant to cogeneration plants is the energy efficiency certificate or 'white certificate' (in Italian, TEE). Only qualified energy companies (ESCOs) can qualify for the management of energy saving initiatives. The qualification procedure was opened at the beginning of November 2004, and by February 2005 the number of qualified ESCOs reached 162. Qualified companies can sell white certificates in a quantity proportional to the amount of the primary energy saved, receiving a rebate which has been fixed for 2005 and 2006 at 100 €/toe, whereas in 2007, subject to market free exchange, it fluctuated around 70 €/toe. A peculiarity of white certificates is that the energy savings are transformed into efficiency certificates of two main types, referred to as type 1 (electricity) or type 2 (natural gas) savings. At present, the economic remuneration for both certificates is the same. Moreover, white certificates are earned for a total duration of 5 years. With respect to CHCP, white certificates are earned on the basis of IRE and the useful electricity, heating and cooling production defined as:

$$PES_{TypeI}[toe] = \frac{IRE[\%]}{100} \times \left(\frac{Q_c[MWh]}{3.0 \times \eta_{el,ref}} + \frac{E_{el,grid}}{\eta_{el,BAT}} + \frac{E_{el} - E_{el,grid}}{\eta_{el,ref}} \right) \times 0.086[toe/MWh]$$

$$PES_{TypeII}[toe] = \frac{IRE[\%]}{100} \times \frac{Q_{th}[MWh]}{\eta_{th,ref}} \times 0.086[toe/MWh]$$

where $E_{el,grid}$ is the share of the generated electricity fed into the grid, the reference efficiency $\eta_{th,ref}$ for heat generation is set to 0.8, $\eta_{el,ref}$ is set to 0.201 and $\eta_{el,BAT}$ is set to 0.148. On average, this kind of incentive can be considered too low to significantly sustain the economics of a small-scale cogeneration plant, yielding a final incentive below 0.5 c€/kWh$_{el}$, as shown in the following example.

Table 18 Example of white certificate amount in 2007 for a CHCP plant.

CHCP plant		
Fuel in CHCP	100	MWh,pe
CHP electrical efficiency	30	%
CHP thermal efficiency	60	%
TDC C.O.P.	0.6	
Electricity generated to User	30	MWh,e
Heat recovered	60	MWh,th
Heat recovered to TDC	40	MWh,th
Heat recoverd to User	20	MWh,th
Cool generated to User	24	MWh,c
Reference system		
Primary energy for heating generation	25	MWh,pe
Primary energy for cooling generation	20	MWh,pe
Primary energy for electricity generation	75	MWh,pe
Primary energy savings		
IRE	0.17	
Type I (at 70 €/toe)	1.36	toe
Type II (at 70 €/toe)	0.36	toe
White certificate amount	103.2	€
Specific white certificate amount per kWe	0.34	c€/kWhe

Tariff and incentives scenario for micro-CHCP

In this paragraph tariffs and economic incentives regarding cogeneration in Italy are examined, both in the current legislation and in future scenarios. Three scenarios are investigated defined as: business as usual, strong political support and moderate political support.

Business as usual

Considering the concepts and rules examined in the previous paragraph, the existing incentives to cogeneration in Italy can be summarized as follows:

- priority for electricity sale to the grid, right after renewable power plants

- tax breaks of the fuel up to 0.25 Nm^3/kWh_{el}
- white certificates: 70 €/toe.

For cogenerator sizes below 10 MVA, the price of electricity sold to the grid is established by the AEEG directive N°34/05. The resulting electricity prices, calculated both for day-time of working days and night time and week-ends, are reported in Table 19.

Table 19 Prices of electricity sold to the grid during 2007 (c€/kWh, AEEG 34/05).

Period	HT/MT	LT
Day-time of working days	12.26	13.57
Night-time and week-end days	6.92	7.65

Prices are also different according to the tension level of the grid the plant is connected to. HT means high tension (130, 220, 380 kV), MT stands for medium tension (15, 20 kV) and LT means low tension (380 V).

Regarding electricity purchased from the grid, average values of the Italian market are summarized in Table 20.

Table 20 Average price before VAT of electricity purchased from the grid during 2007 (c€/kWh).

	HT MT	LT non-domestic	LT domestic
Day-time of working days	14	16	18
Night-time and week-end days	8	10	18

Natural gas costs are summarized in Table 21.

Table 21 Price before VAT of natural gas during 2007 (c€/kWh, ref. LHV).

	Industry Hotels Restaurants	Public buildings Hospitals Commercial	Domestic
Natural gas average price (c€/kWh, LHV)	3.8	4.7	5.4

Strong political support

In addition to the incentives already established by present legislation, the "strong political support scenario" considers the following ones:

- white certificates: 100 €/toe
- full reverse metering (RMF=1 or "scambio sul posto") for high efficiency cogeneration systems up to 200 kWe
- partial rebate of 19% of investment costs with a maximum of 30,000 €.
- increase of natural gas prices net of taxation at a yearly rate of 5%
- increase of electricity prices net of taxation according to the following equation:

$$\text{Electricity price} = 2.135 \times \text{Natural Gas price} + 0.075 \qquad [€/kWh]$$

Moderate political support

In a climate of moderate political support, a more likely scenario can be considered as a sort of average between the two above depicted scenarios. In addition to the incentives described in the business as usual scenario, the moderate political support considers the following ones:

- white certificates: 85 €/toe
- reverse metering (RMF) equal to 0.8 for high efficiency cogeneration system up to 200 kWe

- Increase of natural gas prices net of taxation at an yearly rate of 5%
- Increase of electricity prices net of taxation according to the following equation:

$$\text{Electricity price} = 2.135 \times \text{Natural Gas price} + 0.075 \qquad [€/kWh]$$

Economic attractiveness

The PolySMART Energy and Financial Assessment Tool has been used to calculate the energy and financial performance of micro-CHCP in the Italian hotels sector. The best achievable primary energy savings vary between 10 and 35% of the total consumption. Savings are higher for small hotels as a consequence of two facts, namely: 1) the larger the share of energy demand covered in CHCP mode, the higher the primary energy savings, and 2) the maximum power of micro-CHCP is limited to about 50 kWe, 100 kWt and 50 kWc, which does not allow for covering the total energy demand of large hotels characterized by heating and cooling peak loads above 100 kW.

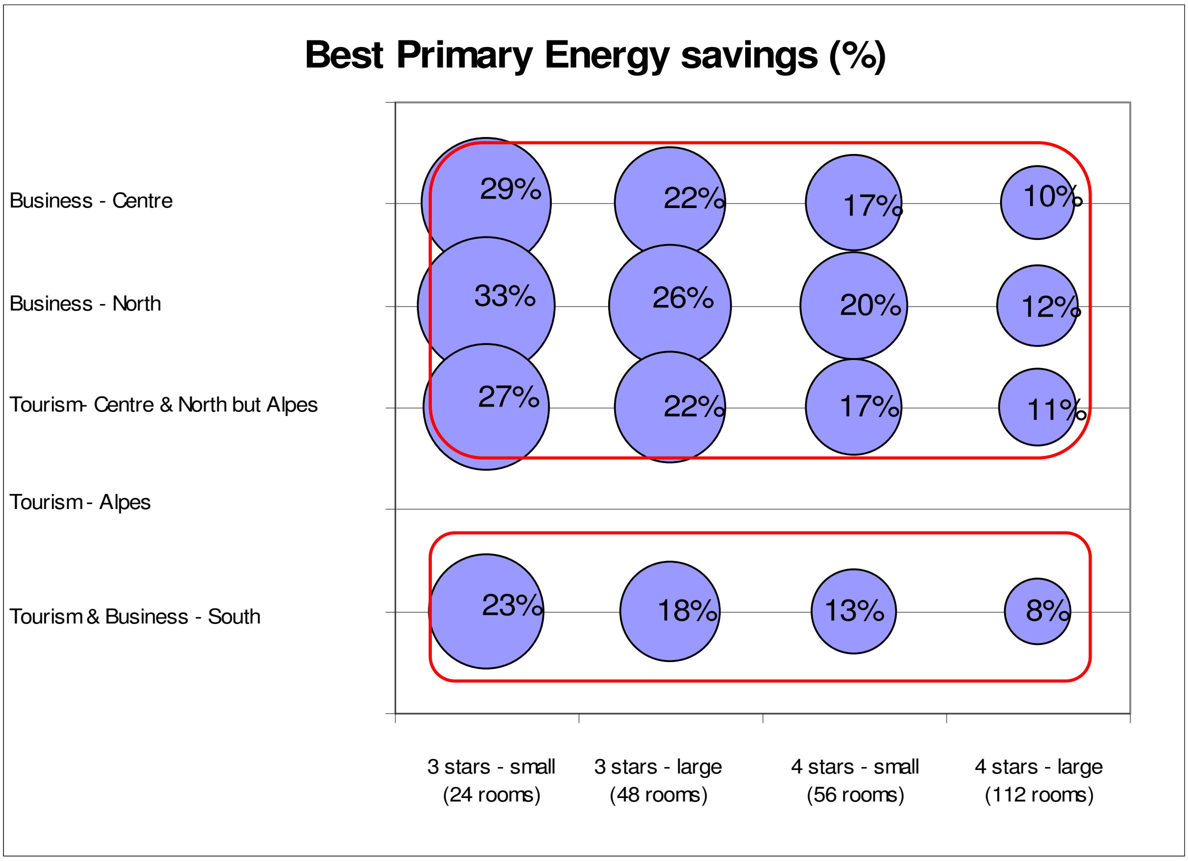


Figure 52 Best achievable primary energy savings (% over estimated primary energy demand) in each cluster.

Within the same hotel category, savings are higher in business hotels located in the North and the Centre of the country.

On the contrary, the profitability index "net benefit to cost ratio" is higher in large hotels than in small hotels. The explanation for this behaviour is manyfold:

- larger hotels need larger CHCP plants, which are characterized by slightly higher electrical efficiency of the CHP;
- larger hotels have larger loads, which imply a longer operation time of the micro-CHCP plant and thus a shorter payback time;
- the share of electricity exported to the grid over the total electricity generated decreases with increasing hotel and load sizes, thus affecting the margin as feed-in tariff is generally lower than purchase price.
- larger loads imply larger auxiliary boilers and chillers, so that the differential investment tends to be of little importance as compared to the investment in the reference conventional plant.

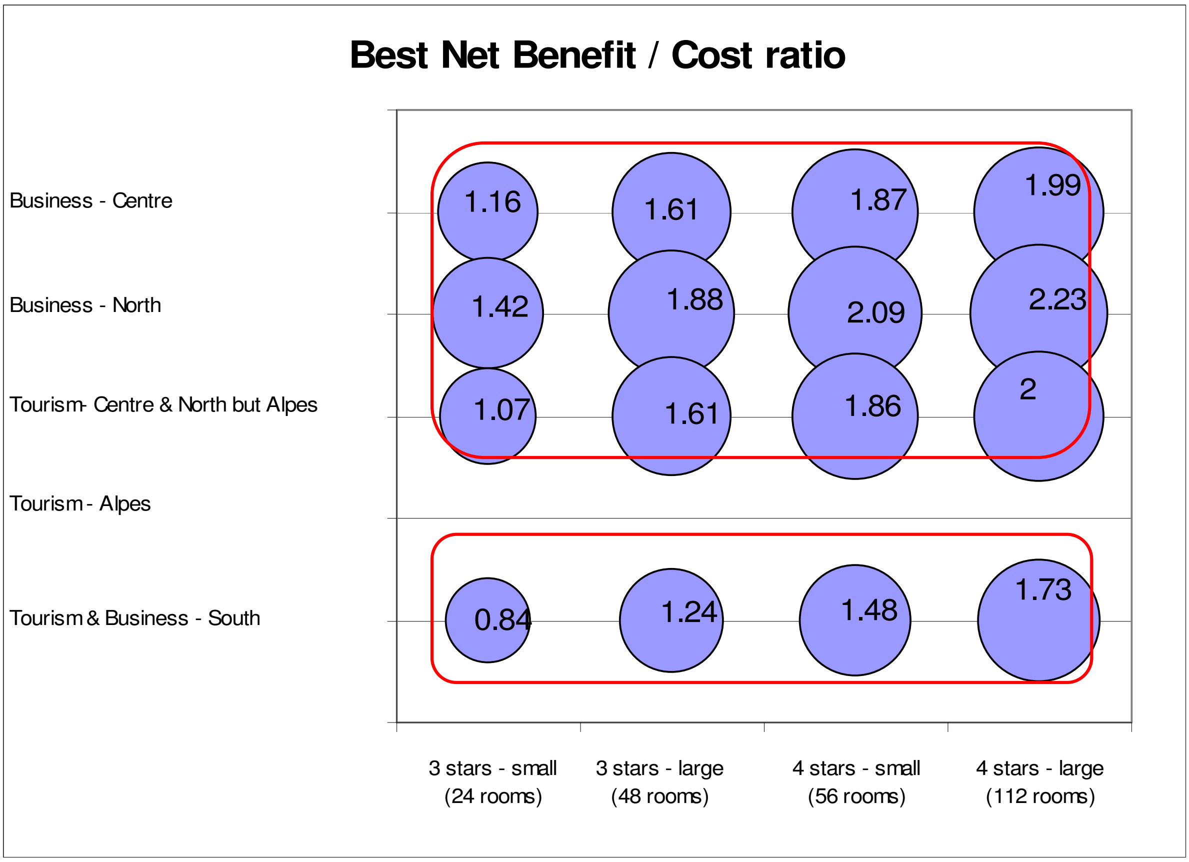


Figure 53 Best achievable Net Benefit / Cost ratio in each cluster. Net Benefit / Cost higher than 1 indicates that the investment is profitable.

Similarly to what has been discussed regarding primary energy, also the net benefit to cost ratio shows better results for business hotels in the North and the Centre than Tourism hotels in the Centre and the South. The explanation is found in the specific gross margin, which is higher for heating than for cooling.

As primary energy savings are calculated in each cluster, for the system that promises higher profitability, the resulting values are considerably lower than the maximum achievable primary energy savings. On average, the reduction is of 50%. In order to be profitable, the CHCP plant must cover only a fraction of the total heating and cooling energy demand, as the initial costs are lower and the yearly operation hours are larger.

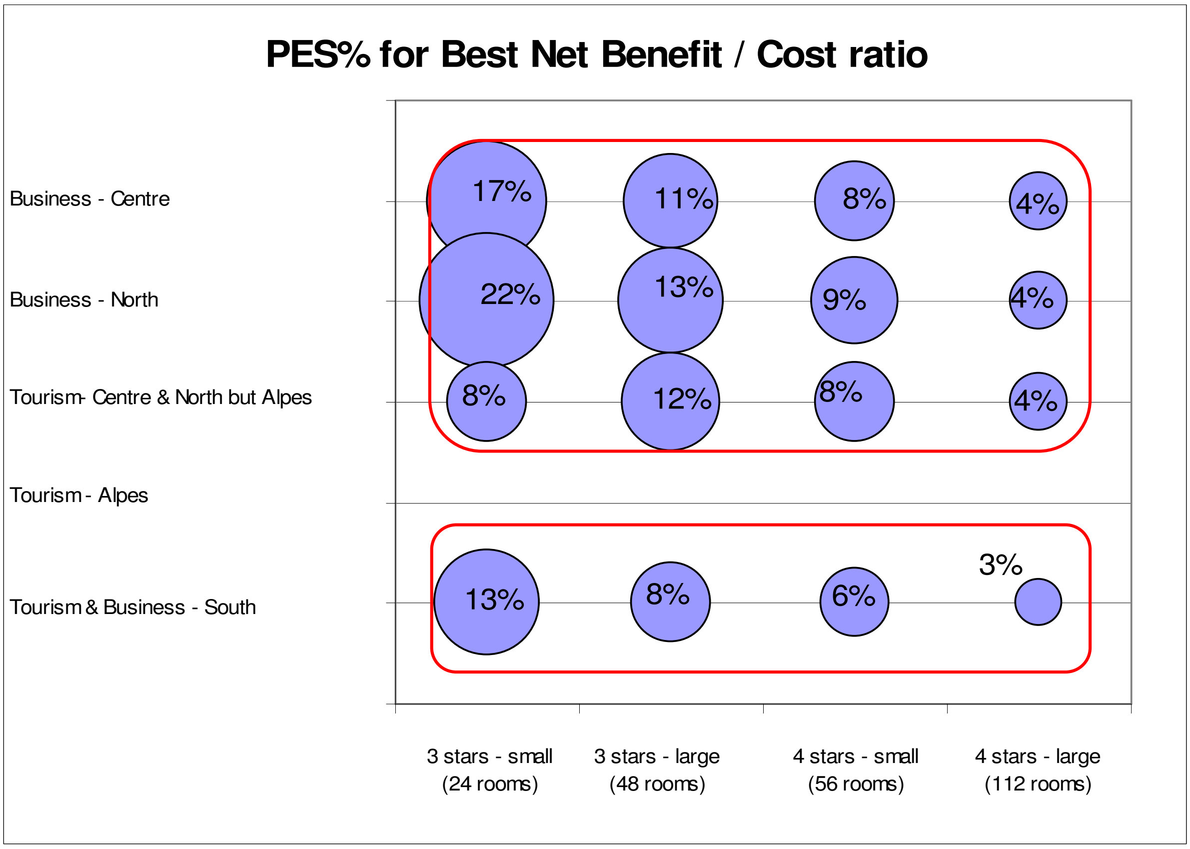


Figure 54 Primary energy savings achievable in relation to the most profitable investment (i.e. showing the highest Net /Benefit to Cost ratio).

Overall, the calculated financial indicators show that the investment tends to be more attractive in the following conditions:

- in the Business hotel rather than the Tourism hotel
- in the North - Centre rather than the Centre - South
- in 4 star large hotels rather than 3 star small hotels

Moreover, the payback time becomes very attractive only in the framework of the strong support scenario, i.e. when a capital subsidy is provided. The investment is reasonably attractive in the moderate support and business as usual scenarios as well, but only in the most profitable applications, i.e. in 4 star Business hotels located in the North - Centre.

Table 22 Payback time (5% discount rate) in each cluster for the considered scenarios.

	Payback time		
Cluster	**Business as usual**	**Moderate support**	**Strong support**
3 star 24 rooms BC	>15	12.3	6.2
3 star 24 rooms BN	11.7	9.5	5
3 star 24 rooms TC	>15	13.7	6.6
3 star 24 rooms TS	>15	>15	8.4
3 star 48 rooms BC	9.1	8	4.4
3 star 48 rooms BN	7.7	6.7	3.8
3 star 48 rooms TC	9.3	8.1	4.3
3 star 48 rooms TS	12.5	11.1	5.7
4 star 56 rooms BC	7.4	6.8	3.9
4 star 56 rooms BN	6.6	6	3.5
4 star 56 rooms TC	7.6	6.8	3.9
4 star 56 rooms TS	9.7	8.9	5

4 star 112 rooms BC	6.7	6.2	3.4
4 star 112 rooms BN	6.2	5.5	3.2
4 star 112 rooms TC	6.7	6.2	3.2
4 star 112 rooms TS	7.8	7.3	3.8

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The residential sector in Spain

Total scope

By the end of year 2000, there were near 1,900 millions of m^2 built in Spain for residential uses (INE, 2001). Percentage distribution of this area by construction date is shown in Figure 55.

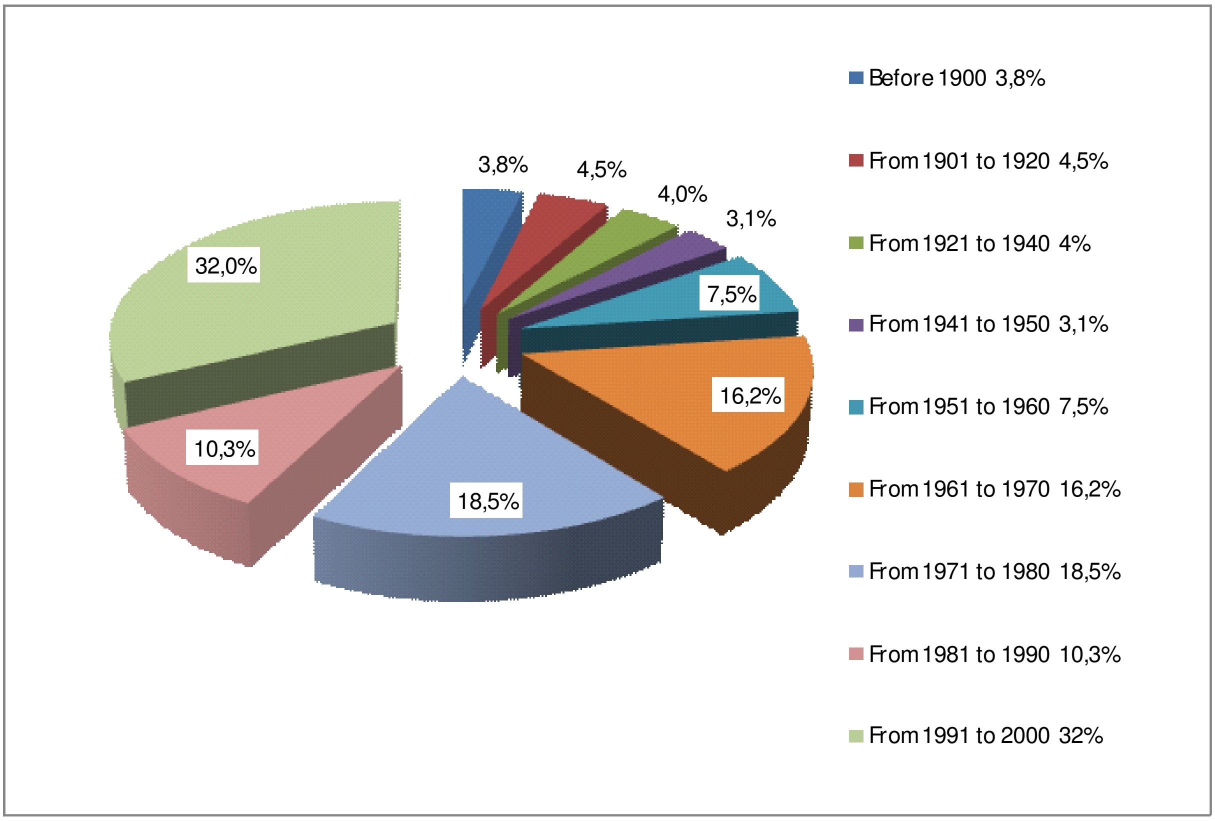


Figure 55 Distribution of built residential area by construction date. Source: INE, 2001.

Data concerning the number of existing buildings, number of dwellings per building, mean area and volume of the dwellings and mean number of occupants are shown in Table 23.

Table 23 Number of buildings and dwellings. Source: INE, 2001.

NATIONAL (2001)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	6885843	6907503	102,14	285,98	705505254	1975414710	1,91
2	623788	1255563	95,82	268,29	120303789	336850609	1,92
3	174345	528443	90,61	253,72	47884024	134075267	1,75
4	121046	489474	86,31	241,67	42246302	118289647	1,76
5-9	356282	2479460	82,21	230,18	203828051	570718541	1,96
10-19	302102	4034063	82,54	231,13	332991289	932375608	2,07
20-39	129658	3378252	81,06	226,98	273856347	766797771	2,09
40 or more	30811	1873796	82,33	230,52	154264686	431941120	1,69
TOTAL	8623875	20946554	89,39	250,28	1872325998	5242512796	1,95

According to the Spanish Building Technical Code, climatic regions are defined with a letter A to E defining winter severity (being A the mildest and E the coldest zones in winter) and a number 1 to 4 defining summer severity (being 1 the coolest and 4 the hottest zones in summer).

Heating demands: A: (almost) null B: low C:medium D:high E: very high

Cooling demands: 1: (almost) null 2: low 3:medium 4:high

There are no A1 or A2, B1 or B2 zones in Spain; these would be zones with both null or low heating and null or low cooling demands. Also, there are no E2, E3 or E4 zones. These would be zones with both medium-high cooling demands and very high heating demands. Finally, there are no D4 zones. These would be zones with both high cooling and high heating demands. Distributions of building type (nº of dwellings per building) for each Spanish "summer climatic region" are given in Table 24 . It is interesting to remark that there are considerably more buildings built in regions 3 and 4 (high summer severity) than in 1 and 2 regions. Especially, the summer regions 3 are clearly the one that contains more dwellings.

Table 24 Distribution of buildings by type and climatic regions. Source: INE, 2001.

SPANISH DWELLING/BUILDING DISTRIBUTION IN DIFFERENT CLIMATIC REGIONS

		Building model	Dwelling/building	Buildings
REGION 1	C1, D1, E1			
		Single Family House	1	1228620
		Double Family House	2	99779
		Small Multi-Family House	3 a 4	58707
		Medium Multi-Family House	5 a 9	75317
		Large Multi-Family House	10 a 19	66226
REGION 2	C2, D2			
		Single Family House	1	1205538
		Double Family House	2	103218
		Small Multi-Family House	3 a 4	60589
		Medium Multi-Family House	5 a 9	74463
		Large Multi-Family House	10 a 19	62263
REGION 3	A3, B3, C3, D3			
		Single Family House	1	2745948
		Double Family House	2	281861
		Small Multi-Family House	3 a 4	124989
		Medium Multi-Family House	5 a 9	148926
		Large Multi-Family House	10 a 19	132687
REGION 4	A4, B4, C4			
		Single Family House	1	1705737
		Double Family House	2	138930
		Small Multi-Family House	3 a 4	51106
		Medium Multi-Family House	5 a 9	57576
		Large Multi-Family House	10 a 19	40926

Market trends

More updated data about building sector show that the residential stock amounted to 23,9 million dwellings in year 2006. This means that almost 3 million new dwellings were built in the lapse 2001-2005 (an increase of 14% of the residential building stock in 5 years).
The Figure 56 below shows the change of the market evolution since 1991 to 2006 (Ministerio de Economia b, 2003). However, it must be pointed out that at the end of 2007 the building market started to decline and at this moment the residential construction activity is almost stopped. What will be the trend in the next years? Having in mind that the number of occupants per dwelling is already relatively low, it seems reasonable to consider that the new building construction activity will stay very low for as long as the crisis stay with us and then will probably grow to the first 1990's levels or less. On the other hand, the refurbishment market is expected to grow as soon as the crisis recedes.

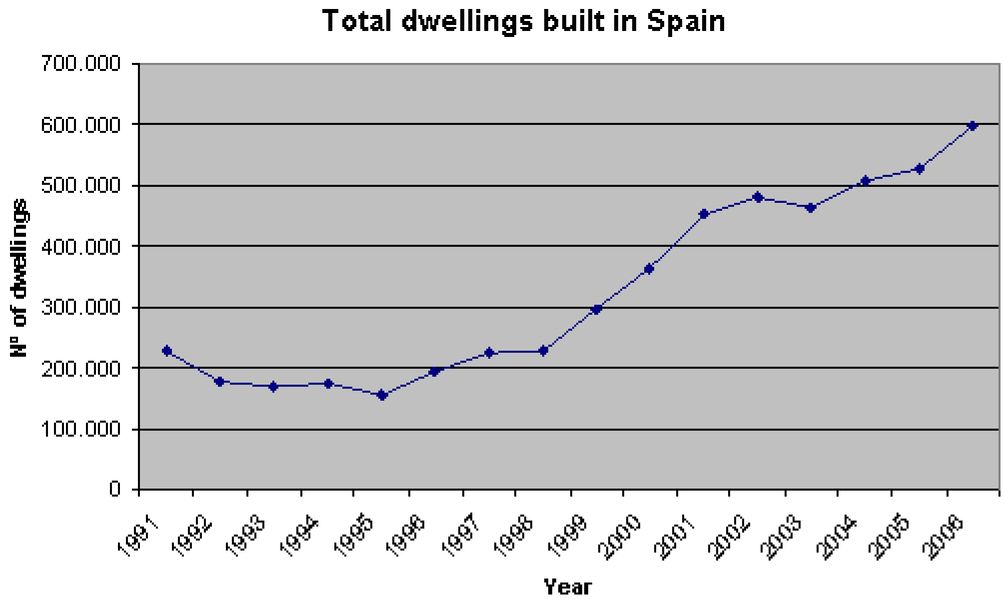


Figure 56 Residential market evolution between 1991 and 2006 in Spain.

In 2006, about 16.4 million were main (permanent) dwellings, and 7,5 million were summer residences (used for summer and holidays). From the 16.4 million dwellings, in 2006, 87% were resident-owned and 13% were rented ones. Summer residences are very abundant in zones 3 and 4, especially in the Mediterranean coast, where a lot of them have been built in the last years. These houses typically lack a proper heating system; when heat is necessary, they use electric radiators. An increasing solution is, though, electric air conditioning with reverse cycle (heat pump), which is especially well suited to the mild winter climates.
Air conditioning is a relatively new product in the residential sector so its market penetration has been continuously growing in the last few years. Thus, in 2001 year 550,000 units were sold in this sector.

Energy demand

The energy consumption in the building sector (residential and services), including heating, cooling, DHW and lighting was 18,123 ktep in 2005, representing about 17% of the Spanish total energy consumption (106,940 ktep). The residential sector energy consumption was of 10,793 ktep, representing 10% of the Spanish total energy consumption.
Energy consumption in residential building depends mainly on the surface of the home and the number of occupants. Of course, also of the energy habits and the comfort levels of the users: heating and DHW energy bills for different families in the same multifamily building are usually very different when they are individually heat-metered. The average energy consumption values calculated by IDAE are the ones shown in Table 25:

Table 25 Energy Consumption average value in Residential Sector.

	Average value
Multi Family House	43 kWh/m^2
Detached House / Single Family House	107 kWh/m^2

At first sight, these consumptions may seem low and it could be concluded that Spanish homes are energy-efficient. As it has been said above, achieved comfort levels (and hence energy use) are typically very uneven between homes. For example, a significant number of homes in Spain don’t have a heating system. The distribution of this energy between different uses in the home is given in the table below.

Table 26 Energy uses distribution in Spanish Residential Sector. Source: IDAE.

USE (%)	Multi Family House	Single Family House	Consumption indicators
D.H.W.	29%	25%	500 kWh /person
Cooking	15%	0%	200 to 250 kWh/year*person
Lighting	13%	6%	8-9 kWh/year m^2
Air-conditioning	5%	0%	-
Heating	26%	45%	-
Computers	1%	0%	-
Appliances	5%	0%	8-9 kWh/year m^2
Others	6%	24%	-
Total	*100%*	*100%*	

Although air conditioning demand shows a low energy consumption in residential buildings, it is increasing at a high rate in the last years in zones 2, 3 and 4 and it is problematic due to its incidence in the electricity demand peaks (possibility of causing black-outs in certain geographical zones). Of the global energy sources utilized in the residential building, 25% is represented by electricity and 75% by fuels. The high use of fuels in residential sector is due to the use of fuels in heating and DHW, and also for cooking. Gas is somewhat more common than electricity as a source for space heating, having a share of almost 40 %. The use of gas heating is increasing in new buildings. Individual heating systems are dominant, although centralized systems are also used. District heating is very rare (see Table 27).

Table 27 Central heating incidence & heat source in Spanish climatic regions. Source: INE.

SPAIN. CENTRAL HEATING INCIDENCE %

		single F.H.	double F.H	small F.H	medium F.H	large F.H
zona 1	C1, D1, E1	4,1%	8,4%	19,7%	15,7%	29,2%
zona 2	C2, D2	7,0%	10,3%	15,7%	14,5%	23,7%
zona 3	A3, B3, C3, D3	5,1%	8,4%	23,1%	16,3%	23,6%
zona 4	A4, B4, C4	5,8%	8,0%	18,7%	10,5%	16,0%

Spanish Climatological Region: FUEL SHARES

		Gas and liquid fuels	solid fuel	electricity	district heating	total
zona 1	C1, D1, E1	76,2%	12,2%	11,6%	0,0%	100,0%
zona 2	C2, D2	84,9%	4,3%	10,8%	0,0%	100,0%
zona 3	A3, B3, C3, D3	58,5%	5,8%	35,7%	0,0%	100,0%
zona 4	A4, B4, C4	35,2%	3,6%	61,2%	0,0%	100,0%

Regarding the energy efficiency characteristics of the Spanish residential building stock, the following can be said:

- Thermal insulation in buildings became mandatory in Spain in 1979 and was put in practice in 1980, so it can be seen that about 1094 million m^2 were built before the mandatory use of thermal insulation and before the double pane windows became common place. Part of this built area has afterwards been equipped with thermal insulation, better windows, etc., but there are currently no statistic data available regarding the extent of this refurbishment.
- Mandated minimum insulation levels have been updated in 2006 but, quite surprisingly, the new mandated insulation levels are broadly similar to the old ones. To give an idea of the insulation standards, in a climatic zone having 2000 heating degree-days base 18 °C (Madrid is in such a zone, winter region D), the maximum allowed thermal transmittances are the following ones:

opaque part of vertical exterior walls: 0,66 W/m^2ºC

windows in vertical walls oriented to South+-67º(if they amount to 20 to 30% of total wall surface): 3,50 W/m^{2}ºC
windows oriented to North+-45º(same condition): 2,50 W/m^{2}ºC
windows with other orientations(same condition): 2,90 W/m^{2}ºC
ceilings: 0,38 W/m^{2}ºC

- Efficiency of heating and DHW equipment is undergoing a slow improvement in the last years, but is still clearly behind European averages. To give an idea, in 2008 424,000 non-condensing and 36,000 condensing boilers were sold in Spain, while in Europe the non-condensing boilers sold were near 2,000.000 and the condensing ones, 3,000.000.

Natural ventilation has been traditionally used in Spanish homes, helped by the use in kitchens and bathrooms of vertical shunts that run into the roof. Ventilation rate was high until the 70's because windows and “blind boxes” were generally loose. From then on, ventilation rates began to decrease due to the use of increasingly tighter windows (although there are no “official measurements” of them). Since 2006, the use of mechanical ventilation is mandatory to ensure a ventilation rate which depends on dwelling area and nº of rooms and is usually around 0,8 renovation per hour. Ventilation heat recovery is still unusual.

The average energy demand profile in the Spanish buildings has been broken down by the four main regions. Specific building loads have been analysed in those climates and low, medium and high energy requirements are given for each of them:

Table 28 Load files of buildings in different climatic regions in Spain.

		Madrid			Barcelona			Sevilla			Bilbao		
		LER	MER	HER	LER	MER	HER	LER	MER	HER	LER	MER	HER
Space Heating	[kWh/m2a]	59,89	92,09	161,00	40,36	62,06	108,50	25,95	39,90	69,75	57,57	88,52	154,75
Cooling	[kWh/m2a]	14,60	22,45	39,25	11,25	17,30	30,25	31,06	47,76	83,50	0,00	0,00	0,00
Domestic Hot Water per	[kWh/m2a]	16,46	25,31	44,25	16,18	24,88	43,50	15,53	23,88	41,75	16,55	25,45	44,50
Domestic Hot Water per Household	[kWh/a]	1636,22	2515,91	4398,45	1608,49	2473,27	4323,90	1543,78	2373,77	4149,95	1645,47	2530,13	4423,30
Household Electricity	[kWh/m2a]	33,29	51,19	89,50	34,22	52,62	92,00	34,22	52,62	92,00	36,55	56,20	98,25
Household Electricity per Household	[kWh/a]	3309,42	5088,68	8896,30	3401,87	5230,83	9144,80	3401,87	5230,83	9144,80	3632,97	5586,18	9766,05

Sector segmentation

Regarding the sector segmentation by building type (nº of dwellings in the buildings), detailed data (year 2001, source: INE) for each Spanish climatic region are given in the tables below.

Table 29 Distribution of buildings by type and climatic zones in Spain.

:LIMATIC REGION: A3 (Cádiz, Málaga, Melilla, Las Palmas de Gran Canaria and Santa Cruz de Tenereife)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	693439	696205	95,76	0,00	66666309	0	2,27
2	83647	168300	90,43	0,00	15218888	0	2,17
3	22870	69211	86,00	0,00	5951918	0	1,97
4	14313	57833	81,81	0,00	4731325	0	1,84
5-9	35973	244814	77,96	0,00	19085099	0	1,94
10-19	22063	298351	80,43	0,00	23997582	0	2,00
20-39	10219	269914	82,15	0,00	22172111	0	1,93
40 or more	4123	287955	80,52	0,00	23185291	0	1,31
TOTAL	886647	2092583	87,07	0,00	182193911	0	1,99

CLIMATIC REGION: A4 (Almería)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	141626	142850	98,08	0,00	14010867	0	2,12
2	8563	17226	92,33	0,00	1590546	0	1,87
3	1954	5931	89,81	0,00	532650	0	1,81
4	1458	5888	87,76	0,00	516751	0	1,81
5-9	3823	25937	84,39	0,00	2188892	0	1,97
10-19	2701	36234	85,48	0,00	3097299	0	1,91
20-39	863	22536	86,86	0,00	1957507	0	1,75
40 or more	255	15037	84,53	0,00	1271062	0	1,36
TOTAL	161243	271639	93,06	0,00	25278007	0	1,98

CLIMATIC REGION: B3 (Castellón, Ceuta, Murcia, Palma de Mallorca, Tarragona and Valencia)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	1009354	1012050	105,76	0,00	107032709	0	1,75
2	108062	217398	100,95	0,00	21946289	0	1,83
3	31273	94624	97,49	0,00	9225084	0	1,65
4	18933	76508	94,15	0,00	7202906	0	1,64
5-9	53555	372654	89,94	0,00	33515404	0	1,82
10-19	45943	606395	91,75	0,00	55639052	0	1,94
20-39	16948	439140	89,81	0,00	39440948	0	1,83
40 or more	4272	278398	88,80	0,00	24720822	0	1,10
TOTAL	1288340	3097167	96,47	0,00	298782398	0	1,75

CLIMATIC REGION: B4 (Alicante, Córdoba, Huelva and Sevilla)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	849554	852387	100,07	0,00	85297704	0	2,01
2	78215	157330	97,29	0,00	15306202	0	1,95
3	18039	54713	94,36	0,00	5162655	0	1,73
4	13014	52714	88,79	0,00	4680586	0	1,76
5-9	38627	268606	82,99	0,00	22292948	0	2,04
10-19	30024	402277	82,65	0,00	33250009	0	2,11
20-39	10916	287907	84,18	0,00	24237272	0	1,92
40 or more	3338	228295	85,34	0,00	19482412	0	1,11
TOTAL	1041727	2304229	91,13	0,00	209981929	0	1,91

CLIMATIC REGION:C1 (Bilbao, La Coruña, San Sebastián, Oviedo, Pontevedra ande Santander)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	655395	657637	98,47	0,00	64757810	0	2,37
2	59404	119864	91,02	0,00	10910225	0	2,01
3	21841	66116	86,71	0,00	5733081	0	1,73
4	16254	65707	83,64	0,00	5495784	0	1,77
5-9	51374	358912	80,28	0,00	28814835	0	2,00
10-19	47887	619501	80,98	0,00	50169533	0	2,13
20-39	17903	456351	79,66	0,00	36353020	0	2,17
40 or more	2844	154809	79,50	0,00	12307628	0	2,14
TOTAL	872902	2498897	85,73	0,00	214240345	0	2,16

CLIMATIC REGION: C2 (Barcelona, Girona and Ourense)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	656548	658674	105,38	0,00	69408811	0	1,97
2	72557	146217	93,29	0,00	13639990	0	2,01
3	26766	81181	87,19	0,00	7077953	0	1,83
4	20256	81866	84,93	0,00	6953223	0	1,79
5-9	56240	390132	80,64	0,00	31461958	0	1,92
10-19	48735	654007	78,73	0,00	51491882	0	2,01
20-39	23630	617937	75,76	0,00	46816811	0	2,09
40 or more	4386	250690	75,81	0,00	19005277	0	1,85
TOTAL	909118	2880704	84,90	0,00	244574737	0	1,98

CLIMATIC REGION: C3 (Granada)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	205135	206467	101,26	0,00	20907324	0	2,02
2	16927	34093	97,85	0,00	3336150	0	1,90
3	3598	10964	94,85	0,00	1039890	0	1,73
4	2003	8178	91,26	0,00	746355	0	1,65
5-9	5303	36501	87,18	0,00	3182239	0	1,71
10-19	3713	50911	90,00	0,00	4581918	0	1,82
20-39	2107	55843	91,40	0,00	5103940	0	1,78
40 or more	667	39312	91,14	0,00	3582972	0	1,35
TOTAL	239453	442269	96,45	0,00	42658732	0	1,86

CLIMATIC REGION: C4 (Badajoz, Cáceres, Jaén and Toledo)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	714557	715965	98,74	0,00	70697612	0	1,80
2	52152	104780	96,84	0,00	10146875	0	1,92
3	10226	30921	95,47	0,00	2952071	0	1,79
4	6415	25863	90,69	0,00	2345549	0	1,89
5-9	15126	102271	87,35	0,00	8933236	0	2,08
10-19	8201	108854	87,76	0,00	9552684	0	2,19
20-39	2578	65799	88,17	0,00	5801608	0	2,23
40 or more	422	21971	90,62	0,00	1991044	0	2,24
TOTAL	809677	1176424	95,34	0,00	112156996	0	1,91

CLIMATIC REGION: D1 (Lugo, Palencia, Pamplona and Vitoria)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	237962	238748	107,89	0,00	25757986	0	2,02
2	18758	37762	98,93	0,00	3735753	0	1,79
3	5929	17943	93,55	0,00	1678527	0	1,79
4	4848	19509	88,57	0,00	1727969	0	1,75
5-9	11879	82598	84,62	0,00	6989188	0	1,97
10-19	10377	137790	84,61	0,00	11658707	0	2,14
20-39	3945	101714	84,02	0,00	8546045	0	2,23
40 or more	595	31941	88,56	0,00	2828639	0	2,41
TOTAL	294293	668005	93,69	0,00	62586258	0	2,05

CLIMATIC REGION: D2 (Cuenca, Huesca, Logroño, Salamanca, Segovia, Teruel and Valladolid)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	548990	549897	99,78	0,00	54870756	0	1,48
2	30661	61683	96,56	0,00	5956341	0	1,68
3	7725	23526	91,21	0,00	2145783	0	1,50
4	5842	23713	85,56	0,00	2028913	0	1,63
5-9	18223	127614	82,21	0,00	10491496	0	1,86
10-19	13528	181477	84,33	0,00	15303603	0	2,02
20-39	5467	141324	83,65	0,00	11821782	0	2,06
40 or more	1142	60396	83,60	0,00	5048897	0	1,99
TOTAL	631578	1169630	91,15	0,00	106609025	0	1,72

CLIMATIC REGION: D3 (Albacete, Ciudad Real, Guadalajara, Lleida, Madrid, Zaragoza)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	838020	840546	111,50	0,00	93721059	0	1,80
2	73225	147441	99,47	0,00	14666077	0	1,83
3	18478	56218	88,56	0,00	4978772	0	1,80
4	13521	54800	81,85	0,00	4485537	0	1,89
5-9	54095	386689	78,65	0,00	30413339	0	2,10
10-19	60968	833015	79,17	0,00	65950274	0	2,22
20-39	32209	846159	78,56	0,00	66470802	0	2,30
40 or more	8356	483126	82,58	0,00	39897152	0	2,22
TOTAL	1098872	3647994	86,32	0,00	314896300	0	2,10

CLIMATIC REGION: E1 (Ávila, Burgos, León and Soria)							
Nº of dwellings/ Buldings	**Nº of buildings**	**Nº of dwellings**	**Medium m2 per dwellings**	**Medium m3 per dwellings**	**Total m2**	**Total m3**	**Medium Nº of occupants**
1	335263	336077	99,78	0,00	33533109	0	1,31
2	21617	43469	92,54	0,00	4022621	0	1,43
3	5646	17095	88,59	0,00	1514483	0	1,43
4	4189	16895	83,91	0,00	1417654	0	1,55
5-9	12064	82732	82,55	0,00	6829397	0	1,71
10-19	7962	105251	86,26	0,00	9079434	0	1,89
20-39	2873	73628	85,95	0,00	6328656	0	2,06
40 or more	411	21866	87,02	0,00	1902800	0	2,06
TOTAL	390025	697013	91,80	0,00	63988489	0	1,57

The distribution of buildings regarding their number of floors is shown in Figure 57. Thus, 4-5 floors building typology is the most representative one of residential sector. There is also an important amount of buildings with 1 and 2 floors that in total sum up to 33.1 %.

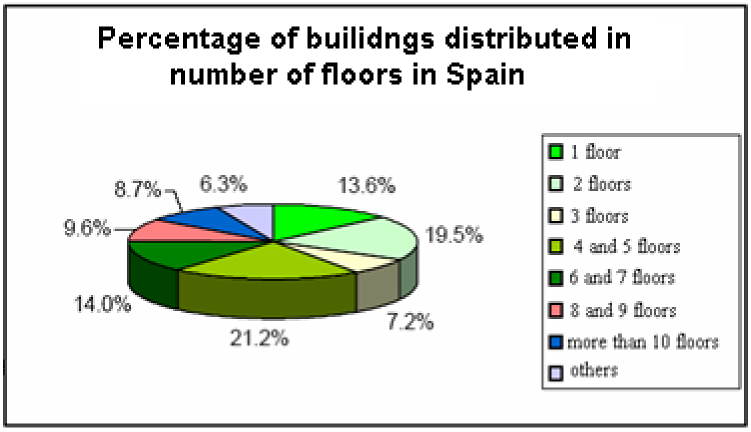


Figure 57 Percentage of buildings distributed in number of floors in Spain.

The tables below show the distribution of individual versus centralized heating systems, for homes using different sources of energy: gas, electricity, oil, coal, wood and others. Also, the incidence of air conditioning systems is provided in the table corresponding to electricity.

Table 30 Distribution of buildings by typology, incidence of centralized heating systems and source of heating energy in Spain.

SPANISH RESIDENTIAL SECTOR							
	Size	Fuel	Nº of applications (dwellings)	Incidence of central heating (%)	Incidence of individual heating (%)	Incidence of cooling (%)	Incidence of district heating
NATIONAL	1	GAS	435443	5,33	94,67	0	0
	2		92497	6,98	93,02	0	0
	3		51874	6,38	93,62	0	0
	4		62872	6,95	93,05	0	0
	5-9		483652	7,78	92,22	0	0
	10-19		1027507	11,30	88,7	0	0
	20-39		903723	16,43	83,57	0	0
	40 or more		387884	24,99	75,01	0	0
	TOTAL		*3445452*	*12,67*	*87,33*	*0*	*0*

Climatic Region	Size	Fuel	Nº of applications (dwellings)	Incidence of central heating (%)	Incidence of individual heating (%)	Incidence of cooling (%)	Incidence of district heating
NATIONAL	1	ELECTRICITY	256598	4,57	95,43	7,50	0
	2		59425	4,26	95,74	8,96	0
	3		29457	3,49	96,51	8,54	0
	4		31720	3,20	96,80	9,10	0
	5-9		183732	3,13	96,87	11,11	0
	10-19		286172	3,84	96,16	13,02	0
	20-39		206057	5,02	94,98	13,59	0
	40 or more		82329	7,93	92,07	11,79	0
	TOTAL		*1135490*	*4,40*	*95,60*	*10,51*	*0*

Climatic Region	Size	Fuel	Nº of applications (dwellings)	Incidence of central heating (%)	Incidence of individual heating (%)	Incidence of cooling (%)	Incidence of district heating
NATIONAL	1	LIQUID FUELS FROM OIL	831052	5,22	94,78	0	0
	2		145816	11,98	88,02	0	0
	3		42566	19,05	80,95	0	0
	4		32127	23,06	76,94	0	0
	5-9		130233	47,84	52,16	0	0
	10-19		244626	78,82	21,18	0	0
	20-39		283997	91,94	8,06	0	0
	40 or more		170930	95,68	4,32	0	0
	TOTAL		*1881347*	*40,19*	*59,81*	*0*	*0*

Climatic Region	Size	Fuel	Nº of applications (dwellings)	Incidence of central heating (%)	Incidence of individual heating (%)	Incidence of cooling (%)	Incidence of district heating
NATIONAL	1	WOOD	72950	4,88	95,12	0	0
	2		10597	8,75	91,25	0	0
	3		2582	9,18	90,82	0	0
	4		1760	8,30	91,70	0	0
	5-9		5195	9,37	90,63	0	0
	10-19		6147	26,96	73,04	0	0
	20-39		3972	40,33	59,67	0	0
	40 or more		1507	38,75	61,25	0	0
	TOTAL		*104710*	*8,79*	*91,21*	*0*	*0*

Climatic Region	Size	Fuel	Nº of applications (dwellings)	Incidence of central heating (%)	Incidence of individual heating (%)	Incidence of cooling (%)	Incidence of district heating
NATIONAL	1	COAL OR DERIVATIVES	88800	5,52	94,48	0	0
	2		14888	8,18	91,82	0	0
	3		4817	8,28	91,72	0	0
	4		4270	9,39	90,61	0	0
	5-9		19195	20,22	79,78	0	0
	10-19		34455	64,03	35,97	0	0
	20-39		35966	85,92	14,08	0	0
	40 or more		14943	90,39	9,61	0	0
	TOTAL		*217334*	*35,55*	*64,45*	*0*	*0*

Climatic Region	Size	Fuel	Nº of applications (dwellings)	Incidence of central heating (%)	Incidence of individual heating (%)	Incidence of cooling (%)	Incidence of district heating
NATIONAL	1	OTHER	6324	8,71	91,29	0	0
	2		1351	17,32	82,68	0	0
	3		452	21,02	78,98	0	0
	4		461	21,48	78,52	0	0
	5-9		2135	34,66	65,34	0	0
	10-19		4192	54,34	45,66	0	0
	20-39		4613	69,00	31,00	0	0
	40 or more		2913	78,41	21,59	0	0
	TOTAL		*22441*	*42,17*	*57,83*	*0*	*0*

Selection of relevant clusters
In order to decide the simulations to be done with TRNSYS, and after considering the data presented above, it was decided to combine climate and building type in clusters as follows:

Regarding the climatic zone, we have chosen to simulate buildings in 4 cities that represent the 4 different "summer zones" in Spain (1 to 4):

- Barcelona (zone C2, which counts 6,484,410 inhabitants)
- Madrid (zone D3, which counts 8,811,456 inhabitants)
- Vitoria (zone D1, which counts 1,458,975 inhabitants)
- Seville (zone B4, which counts 5,073,676 inhabitants)

These 4 zones sum up to 21,828,517 inhabitants, being the Spanish total population 46,008,985 inhabitants (all data taken from 2009 census).
We have avoided choosing A cities because they have almost no need of heating. We have avoided choosing E zone because it is very loosely populated.

Regarding the size/typology of the houses, we have chosen to simulate:
One 10-homes multifamily building and
One single-family building (equipped with 3 different levels of insulation).
These buildings are defined in the next chapter.

Load profile

Single Family houses

Heating and cooling demands of three single family houses have been simulated with TRNSYS. In fact, it is the same building with three different levels of insulation ("high efficiency", "low efficiency" and "very low efficiency").

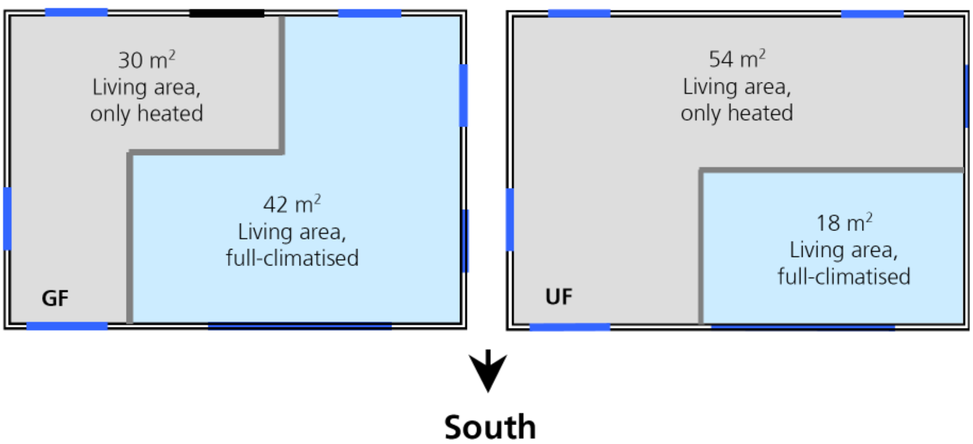


Figure 58 Single-family house. Plan of the ground floor (GF) and the upper floor (UF) with both heated and full-air-conditioned rooms. Not true-to-scale.

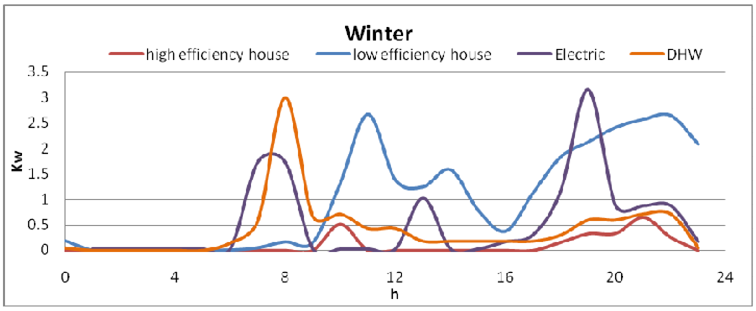
The building is a two-storey residence house without basement, oriented along an east-west major axis. The area of each floor is 72 m² (total living area 144 m²). Window area is 22% of vertical walls total area. The area on each floor of the building was partitioned into two types of spaces. On the ground floor there are a full-air-conditioned room of 42 m² and a 30 m² zone which is only heated. On the upper floor there is a full-air-conditioned room of 18 m² and another one, of 54 m², which is only heated. Figure 58 shows both floor plans. The internal gains peak values amount to 21,5 kWh/day. It should be said that this value is quite high for Spanish standards, but it was retained in order to facilitate comparisons. This house was equipped with three different energy envelopes: "low efficiency" "high efficiency" and "very low efficiency". U-values of envelope components and transmissivity of windows are given in the table below for the three considered efficiency levels.

	External wall U-value W/m^{2}K	Ceiling U-value W/m^{2}K	Window U-value W/m^{2}K	Window τ
Low efficiency	0.452	0,307	1.4	0.426
High efficiency	0.189	0,127	0.4	0.268
Very low efficiency	0,608	0,307	2,46	0,627

The following set-point temperature values are assumed to calculate heating and cooling loads:

- Heating period: 21 °C from 9 to 23h; at night, setback of 17 °C.
- Cooling period: 25 °C from 8 to 23h; at night, step-up of 28 °C.

The resulting hourly profiling in a typical winter and summer day for two cases is shown below:



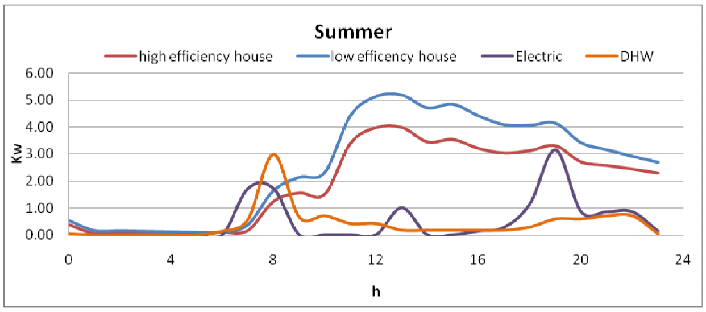


Figure 59 Loads of single-family houses in a typical winter and summer day in Madrid.

Multifamily residential building

The defined building is a ten-storey residence house, oriented along an east-west major axis. The area of each floor contains 4 dwellings and 255 m². Thus, the whole area amounts 2550 m². Anyway the living area is 63 m^2 for each of the 40 dwelling of the building. The net floor area on each dwelling was partitioned into two types of spaces: a full-air conditioned one having a floor of 45 m² and an only-heated one of 18 m². The temperature set-points for full air-conditioning rooms were defined taking into account the room to be conditioned and the hour of the day. Thus:

- Heating period: 20 °C from 8 h to 22 h in all air-conditioned rooms.
- Cooling period:
  - 22ºC from 18 to 22 h in the bedrooms.
  - 30ºC from 0 to 18 h and from 22 to 24 h in the bedrooms.
  - 25ºC from 10 to 23 h in the dining room.
  - 28ºC from 0 to 10 h and from 23 to 24 h in the dining room.

There is approximately a 30% of window surrounding area. The envelope averaged U-value and windows U-value and ζ are given in the table below.

	External wall U-value W/m^{2}K	Ceiling U-value W/m^{2}K	Window U-value W/m^{2}K	Window τ
Multifamily house	0.666	0.45	2.89	0.746

These levels of thermal insulation can be considered representative of Spanish real buildings of the last years. The internal gains amount to 7 kWh/day for every home.
The resulting hourly loads in typical winter and summer days are shown below (15th January and 15th of July):

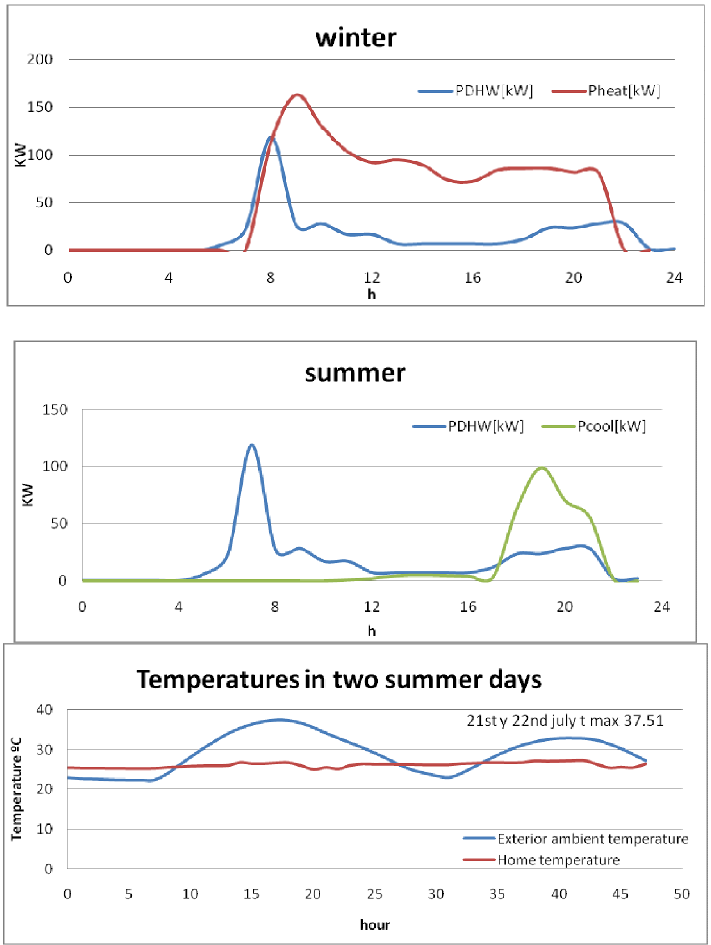


Figure 60 Loads of multi-family house in a typical winter and summer day in Madrid. Home average temperature in two summer days.

Energy prices and incentives

Incentives consist in the possibility of choosing different tariffs, usually differentiated by connected power and day/night use discrimination (electricity) or annual consumption (natural gas). Considering prices for electricity and natural gas, the “average final prices” for “average consumers” of natural gas and electricity have been evaluated. Hence, price of NG is about 0.062 €/ kWh for residential houses, 0.037 for offices and 0.048 €/ kWh for hotels.

And electricity price for residential houses, without day/night discrimination is 0.169 €/kWh (a contracted power of 3,3 kW is supposed).

Table 31 Average final prices for average consumers.

	Year 2007	
Sector/ Values	**Electricity €/kWh**	**Natural Gas €/kWh**
Residential house	0.169	0.062
Offices	0.141	0.037
Hotels	0.138	0.048

CHP regulation and promotion

Spanish RD 616/2007 law promotes high efficiency combined heat and power systems. The objective of Spanish “Plan de Acción 2008-2012” is to achieve 8.400 MWe of CHP installed power by 2012. The following incentives exist for CHP owners:

- Tax exemption: exemption from distribution and consumption taxes on natural gas
- Green certificates: biomass: RD 661/2007 tariff is valid for the first 15 years and corrections apply in the next years.
- Efficient Complement: Efficiency-Complement=1,1*(1/REEmin - 1/REEi)*Cmp, see annex I RD661/2007 (supposed REEi about 75%)
- Reactive Energy complement (Art 29 RD 661/2007, a percentage of 7,8441 c€/kWh revised annually)

The Royal Decree RD 661/2007 (issued in BOE of May 25th 2007) regulates the electricity production activity in “special régime”. Each installation owner (<50 MWe) can choose from two payment ways: regulated tariff or “free market price” plus bonus. The values calculated by decree are not fixed, but they are updated every three or twelve months period following the evolution of the RPI (Retail Prices Index). Final average fuel and electricity prices and incentives for the average residential users have been calculated and are shown hereafter.

Table 32 Average fuel and electricity prices and incentives for the residential user.

Fuel / Electricity	**price c€/kWh**
Electricity import	15.40
Electricity export	15.40
Natural gas	6.28
Electricity generation	2-46
Primary Energy savings	1.80

Tariff and incentives scenario for micro-CHCP

At this moment, apart from the incentives for CHP shown in the chapter “CHP regulation and promotion”, there are no more special tariffs or incentives for micro-CHCP. Several Spanish Residential scenarios have been defined considering fuel prices evolution separately from electricity prices evolution. Thus, it is possible to study the sensitivity of the Market Analysis results to prices with both equal and different escalation rates.
The electricity prices evolution is defined with Optimistic, Average and Pessimistic scenarios, while the fuel prices evolution is defined with A, B and C cases.

- Optimistic: 8% of annual electricity price increase
- Average: 5% of annual electricity price increase
- Pessimistic: 2% of annual electricity price increase

- Case A: 8% of annual fuel price increase
- Case B: 5% of annual fuel price increase
- Case C: 2% of annual fuel price increase

Combining A, B and C cases with optimistic, average and pessimistic scenario provided a total number of 9 different cases.

Table 33 Energy prices evolution possibilities in study.

	ENERGY PRICES EVOLUTION SCENARIOS								
	Optimistic			Average			Pessimistic		
	Case A	Case B	Case C	Case A	Case B	Case C	Case A	Case B	Case C
Elect. Import	8%	8%	8%	5%	5%	5%	2%	2%	2%
Fuel Import	8%	5%	2%	8%	5%	2%	8%	5%	2%

Moreover, the optimistic scenario yields a subsidy of 20% (up to 200.000€), the average scenario subsidy is of 10% (up to 200.000 €) and there are no subsidies for the pessimistic scenario. Other input data values are equal for all cases, i.e. the following values are assumed: Fees equal 0, useful life is 15 years, discount rates are about 5% and VAT 16%.

Economic attractiveness

Polysmart "Energy and Financial Assessment" Tool (see Appendix) has been used to calculate energy and financial performance of micro-CHCP in the Spanish residential sector. One single-family house (equipped with 2 high insulation levels) and one multifamily house have been simulated in four cities: Vitoria, Barcelona, Madrid and Seville. Also, a parametric study varying heating and cooling loads has been performed for the single-family house equipped with an insulation level typical of the Spanish new houses. In the table below, some of the data input to the Tool are given.

Climate	City	Building	Area m^2	Number of buildings	Incidence of Central heating %
D1	Vitoria	Single Family House	144	237962	2.7
		Multi Family House	2522	4540	34.2
C2	Barcelona	Single Family House	144	656548	4.7
		Multi Family House	2522	28016	8.9
D3	Madrid	Single Family House	144	838020	3.5
		Multi Family House	2522	40565	24.9
B4	Seville	Single Family House	144	849554	7.3
		Multi Family House	2522	14254	9.1

Simulation results on single-family houses

Results show that the heating demand of High and Low Efficiency single family houses is 100% covered and cooling demand is 90 to 100% covered. However, PES values are always negative for both houses in the four cities: between -15 % and -21 % for the high efficiency single house and between -3 % and -18 % for the low efficiency single house. In order to study sensibility to different future evolutions of fuel and electricity prices, 3 cases have been defined in each scenario, corresponding to annual fuel price increases of 8%, 5% and 2%. The heating and cooling demands corresponding to this example are given in Table 34. It can be seen that heating loads are very low, which is mainly due to the high insulation and high internal gains of the houses.

Table 34 Heating and cooling demand of Low and High Efficiency SFH, Madrid

	HEATING kWh	COOLING kWh
Low efficiency	1,904	6,892
High efficiency	323	6,172

However, the levels of insulation of both “High efficiency” and “Low efficiency” houses are not representative of Spanish standards.
On the other hand, the “Very-low-efficiency” SFH, which is more representative of Spanish standards, obtains positive PES results of 9% in Madrid for the three scenarios. Nevertheless, the payback is always more than 15 years for all the studied cases.

Very low efficiency single family house Madrid D3			HEATING kWh	COOLING kWh
	Max PES %	PB (y)		
OPTIMISTIC	9	>15	6,831	6,786
AVERAGE				
PESSIMISTIC				

As a general conclusion, a very good insulated and small single family house, with a low heating and cooling demand, is not the best choice to implement a micro-CHCP system. Anyway, micro-CHCP can have sense in bad insulated single family houses, although economic subsidy should be granted in order to make the investment self-rewarding.

Simulation results on multi-family houses

Results obtained from the simulation of the multifamily building in the four cities, are summarized in Table 35. The respective annual loads are:

- Barcelona: 67,463 kWh heating and 67,587 kWh cooling
- Madrid : 124,055 kWh heating and 60,689 kWh cooling
- Sevilla : 41,661 kWh heating and 100,548 kWh cooling
- Vitoria 147,712 kWh heating and 25,281 kWh cooling

Some conclusions can be drawn from the results presented in Table 35:

- PES are positive for the 4 cities. Maximum PES value in Vitoria is 28%, 24% in Madrid, 18% in Barcelona and 13% in Seville. The location with higher heating requirements and lower cooling requirements, Vitoria, has the best PES values; while the one with lower heating demand and higher cooling demand has the worst PES values. This is the same trend observed for single-family houses.
- As was expected, case C (lower fuel and higher electricity price increases), shows better NPV, B/C and PB results than case B and this than case A.
- In the pessimistic scenario, no case nor city show a positive NPV.
- In the average scenario and only for Case C, Vitoria and Madrid show a positive NPV, with payback times of 13 and 13,4 years respectively.
- In the optimistic scenario, Vitoria, Madrid, Barcelona and Sevilla show positive NPV and paybacks between 7,2 and 14,9 years in all cases, except for Seville case A than is more than 15 years .

Table 35 Multi family house results in Vitoria, Barcelona, Madrid and Seville.

Multifamily house Madrid Case A				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	24	1,59	22262	10,7
AVERAGE		0,37	-21184	>15
PESSIMISTIC		-0,2	-41029	>15

Multifamily house Madrid Case B				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	24	2,82	61126	8,5
AVERAGE		0,82	-9124	>15
PESSIMISTIC		0,16	-30917	>15

Multifamily house Madrid Case C				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	24	3,97	96235	7,2
AVERAGE		1,16	8191	13,4
PESSIMISTIC		0,43	-23172	>15

Multifamily house Vitoria Case A				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	28	1,74	27082	10,1
AVERAGE		0,53	-17523	>15
PESSIMISTIC		-0,04	-37049	>15

Multifamily house Vitoria Case B				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	28	2,45	60807	8,4
AVERAGE		0,91	-4564	>15
PESSIMISTIC		0,27	-28015	>15

Multifamily house Vitoria Case C				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	28	3,26	92310	7,5
AVERAGE		1,2	10323	13
PESSIMISTIC		0,5	-21096	>15

Multifamily house Barcelona Case A				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	18	1,01	555	14,9
AVERAGE		0,05	-24810	>15
PESSIMISTIC		-0,41	-43635	>15

Multifamily house Barcelona Case B				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	18	1,97	22634	10,8
AVERAGE		0,48	-14638	>15
PESSIMISTIC		-0,05	-33463	>15

Multifamily house Barcelona Case C				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	18	2,98	40974	8.8
AVERAGE		0,82	-6050	>15
PESSIMISTIC		0,22	-25672	>15

Multifamily house Sevilla Case A				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	13	0,75	-4583	>15
AVERAGE		-0,18	-27243	>15
PESSIMISTIC		-0,53	-46651	>15

Multifamily house Sevilla Case B				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	13	2,02	14681	11,4
AVERAGE		0,3	-16597	>15
PESSIMISTIC		-0,2	-36005	>15

Multifamily house Sevilla Case C				
	Max PES %	B/C net	NPV (€)	PB (y)
OPTIMISTIC	13	3.4	37549	8,8
AVERAGE		0,67	-8443	>15
PESSIMISTIC		0,09	-27852	>15

The main conclusion to be drawn from simulation results of multi-family houses in Spain is that micro-CHCP systems give positive PES in every location, but economic profitability is strongly dependent on scenario, case and the micro-CHCP system used, and profitability is achieved in relatively few cases.

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Eficiencia Energética y Cogeneración en 2007

The office sector in Germany

Quantifying of the potential market sectors

There is little data available covering the quantity and quality of German office buildings. Statistics about commercial activities mirror the structure of business branches, not the types of buildings used. Relevant data is provided by real estate companies, which at least cover parts of the office market. We extrapolated the total amount of office floor area in Germany from publications of Deutsche Bank Research, 2007. Here, statistical data for the largest 51 of German cities, grouped in three size categories, is provided.

Table 36 Office stock, statistical data for the largest 51 of German cities grouped by size.

Category	Primary	Secondary	Tertiary
range of number of inhabitants	> 575,000	250-575,000	150-250,000
Number of cities	7	20	24
total number of inhabitants 2006	9,266,631	7,819,570	4,726,761
mean number of inhabitants 2006	1,323,804	390,979	196,948
cumulated number of inhabitants	9,266,631	17,086,201	21,812,962
office floor area in million m² 2006			
mean value	11.9	2.5	1.1
Max	18.2	4	1.9
Min	7	0.7	0.4
office floor area in m²/1000 inhabitants	**9,154**	**6,404**	**5,578**

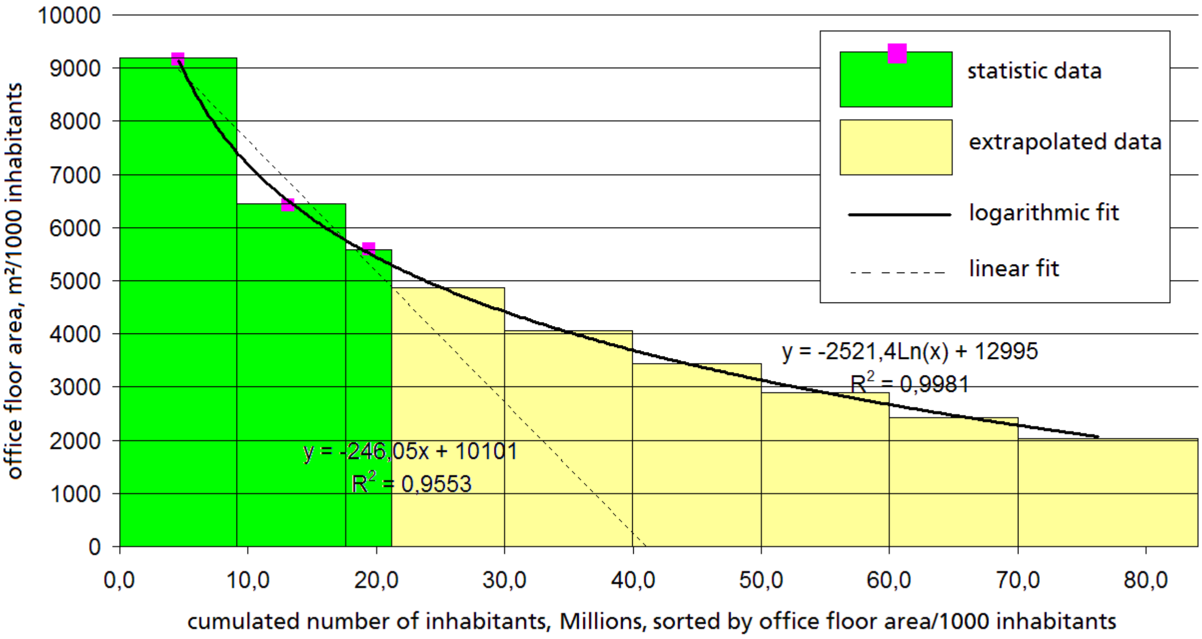

Figure 61 Office stock, statistical data for the largest 51 of German cities, grouped in three size categories, and logarithmic and linear extrapolation for total German population.

To get a total number of the office floor area in Germany, a mathematical function is generated, describing the office density (office floor area in m²/1000 inhabitants) in dependence of the percentile of the number of inhabitants. Assuming a linear equation, extrapolating the larger cities' data leads to an integral of 100 Millions m² of office floor area. However, the linear least square fit indicates, that half of the Germans would live in cities without any offices. This surely is not realistic. A better fit to the given statistical data can be achieved using a logarithmic equation. The integration delivers a number of 360 Millions m² of office floor area. The logarithmic least square fit gives an office density for the last percentile of 2 m² of office floor area per inhabitant. This seams a reasonable number. Another statistical source is OSCAR, 2007.

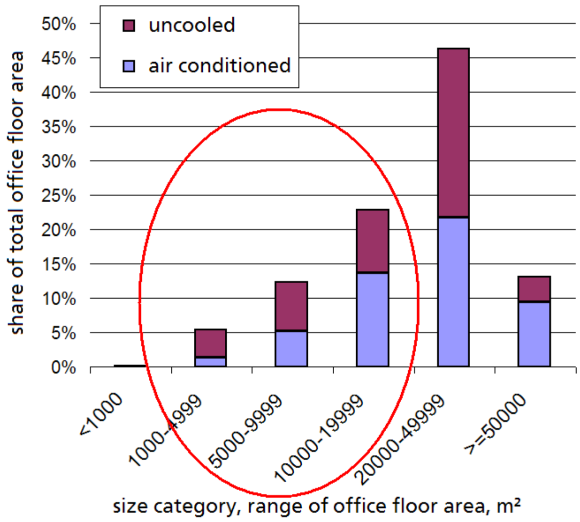

Figure 62 Share of office floor area, size categories. Source: OSCAR, 2007.

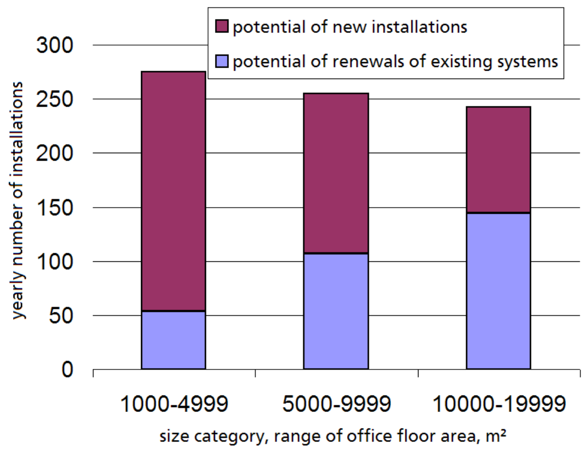

Figure 63 Number of yearly installations (new and renewals) of heating and cooling devices. Assumption: 5% of the stock each. Source: OSCAR, 2007.

To identify the size of the buildings, where the CHCP systems of the regarded power range are applicable, we carry out a preliminary simulation loop. After carrying out yearly simulations, we analysed the results of the market analysis tool in terms of the shares of the heating and cooling supply by the CHCP: the results are shown in Figure 64. Each dot represents one CHCP system. Using the building description and the operation schemes previously described we see, that depending of the building size, the differently sized CHCP-systems (performing CHP thermal powers from 10 to 300 kW) cover differing ranges of supply share.

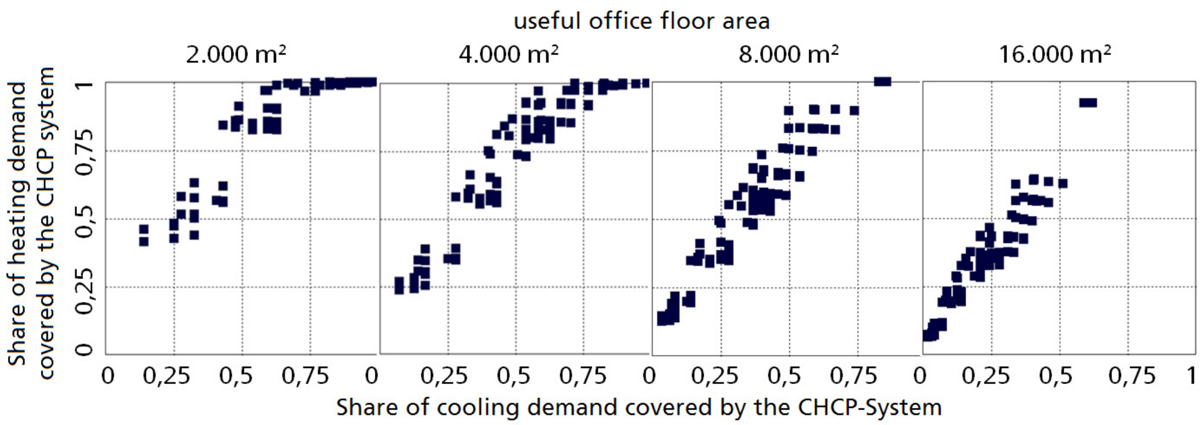

Figure 64 Shares of the heating and cooling supply by the CHCP, for different building sizes. Black marks represent each one of the CHCP-systems performing CHP thermal powers from 10 to 300 kW.

Building description for the market sectors

The building shell of office buildings is similar to the one of residential buildings (in the categories multi family houses and large multi family houses). In Germany the residential building stock is well documented (IWU,2003) (IWU,2007). IFEU/ebök, 2003, delivers local data and is an example for the many investigations carried out for German cities to find out the energetic optimization potential in the building stock, which are often based on IWU, 2003.

From these data, we derived a segmentation of the multi family residential building stock in two classes of building age, and complemented these with a third one representing newly built buildings or refurbished buildings.

Table 37 Segmentation of the multi family residential building stock, using data of Münster, NRW and proposed segment for newly built or refurbished buildings (according to very good thermal standard).

year of construction	**share** (city of Münster)	**heating demand**
≤ 1968	56%	150 – 250 kWh/m²a
> 1968	44%	70 – 120 kWh/m²a
newly built or refurbished		ca. 50 kWh/m²a

Figure 65 and Figure 66 give a more detailed analysis of the share and thermal performance of building age classes of multi family houses in Münster. Obviously, such a detailed segmentation is much too highly resolved for the purpose of this market study.

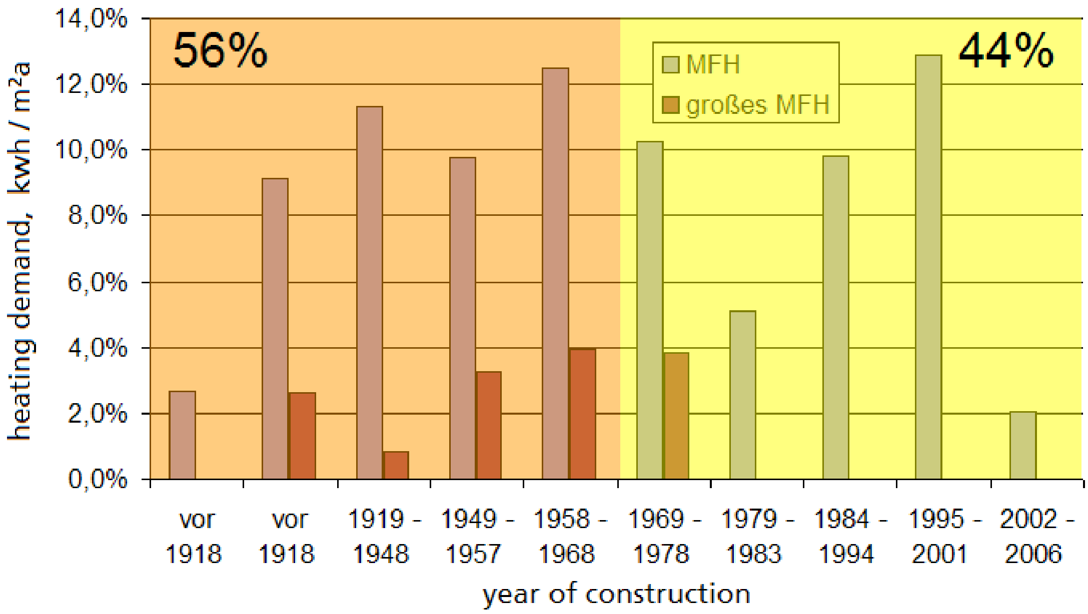

Figure 65 Share of age categories of multi family houses (MFH) an large MFH in Münster; Germany.

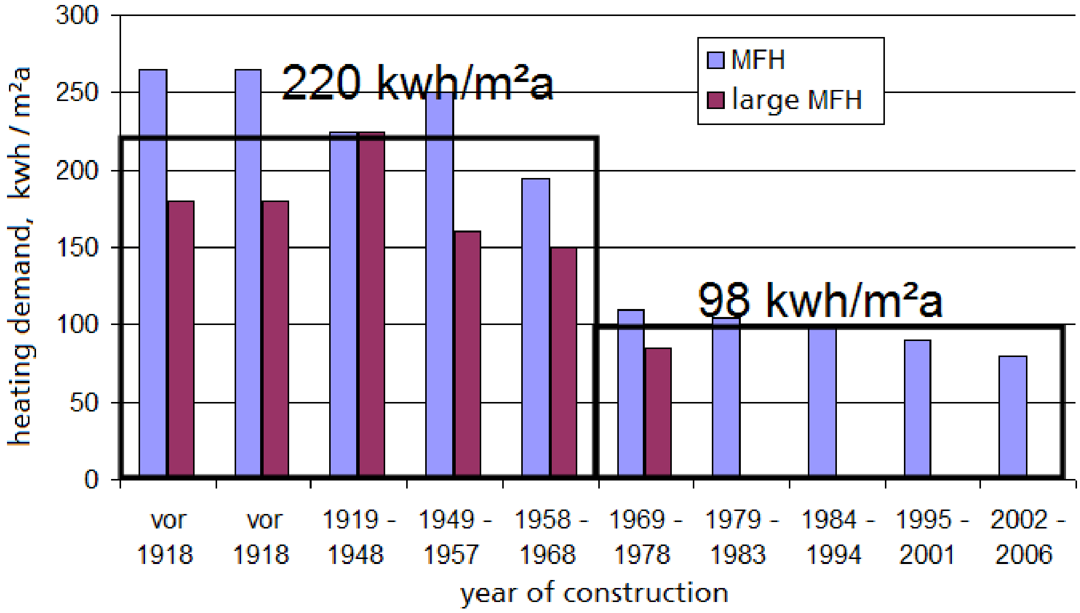

Figure 66 Yearly heating demand of multi family houses (MFH) and large MFH in Münster, Germany, with average values for buildings constructed before and after end of 1968.

Definition of representative office building shell characteristics

As mentioned above, we assumed office building shells to be similar to multi family residential building (MFH) shells. There are two important caveats using this approach: all given heating demand data are given for residential buildings under residential use. Following the approach and assuming similar building shells, different operations of the buildings lead to different heating and cooling demands, which were calculated.

The second and even more important question is the transferability of the residential building stock characteristics to the office building stock. E.g., buildings with concrete skeleton kernel and facades with glazing shares larger than 50% are typical for office buildings constructed since the 1970s, however they are not equally represented in the residential building stock.

Hoffmann, 2007, examines the German office building stock with respect to the applicability of passive cooling. Here a good evaluation of the available statistical data and also a very useful summary of building properties is given.

It was decided to base the set of parameters to be varied on a building shell which was close to the constructed-after-1968 segment of residential multi family houses, sporting an overall U-value (with respect to the useful area) of 1.00 W/m²K. The calculations were carried out for office buildings with useful areas of 2000, 4000, 8000, and 16000 m². Variations were calculated for office buildings of 8000 m² and overall U-values (with respect to the useful area) of 1.60 W/m²K and 0.45 W/m²K respectively. As the less insulated building shell could represent buildings of the pre 1969 era, the better insulated building shell comes closer to current building standards realized at new constructions or refurbishments. Key characteristics of all set of parameters used in the market analysis calculations are listed in Table 39.

Description of the building operation schemes

Ranged approximately in the constructed-after-1968 class concerning the building envelope, we defined the operation schemes of a representative office building, and scaled them to 4 sizes of the building.

Definition of a representative office building (4 sizes):

- building:
  - functional zones: 4 zones (office rooms, conference room, floors, central IT hardware room)
- operation:
  - temperatures: (20) 21°C in winter; 24 (26)°C in summer
  - ventilation: mechanical, heat recovery (average 60%)
  - internal loads: 188 Wh/(m² d) (on working days) 52 kWh/(m² a)
  - warm water: 4 kWh/(m² a)

- resulting energetic key numbers:
  - heating demand: 74 kWh/(m² a)
  - cooling demand: 38 kWh/(m² a)

The operation scheme allows to scale the input data according to arbitrary office floor areas.

To compare, Table 38 shows a classification of office buildings by their internal loads SWKI, 2001, cited by Hoffmann, 2007:

Table 38 Internal loads (Wh/m²ngad, nga is useful gross area) of single/small group office buildings and large room office buildings According to [SWKI 95-3, 2001], cited by Hoffmann, 2007.

	Internal Loads, offices with 1 – 6 persons per room		**Internal Loads, offices with more than 6 persons per room**	
	Wh/(m^2_{nga}d)	kW/(m^2_{nga}a)	Wh/(m^2_{nga}d)	kW/(m^2_{nga}a)
low	143	52	142	52
mean	264	70	198	72
high	191	96	286	104

Based on the standard building shell description, the internal load scheme of the 8000 m² office building was varied in two ways, resulting in internal loads of 26 kWh/(m²a) and 104 kWh/(m²a).

So the parameter variations we carried out our calculations for represent buildings with low and high internal loads in SWKI, 2001-categories and – in the case of internal loads of 26 kW/(m²a) – with very low internal loads. While the "low" standard seems to be close to German planning guide lines and regulations, the "very low" variations represents future energy saving high efficient electronics which indeed could be installed as an alternative strategy to active cooling.

In Table 39, the key characteristics of all set of parameters used in the market analysis calculations are listed:

Table 39 Characteristics of representative German office buildings and variations simulated.

	representative office building	better insulated	less insulated	lower internal loads	higher internal loads
total useful area, m²:	**2.000, 4.000, 8.000, 16.000**	8000 (only for this size parameter variations with regard to the building and operation energy standard have been carried out)			
U-value with respect to useful area, W/(m²K)	1.00	**0.45**	**1.60**	1.00	1.00
internal loads, kWh/(m² a)	52	52	52	**26**	**104**
heating demand, kWh/(m² a)	74	44	107	80	63
cooling demand, kWh/(m² a)	38	38	39	26	63

Yearly Simulation of representative buildings

The calculation of one year's electric, heating an cooling load is carried with a custom load simulation tool ("Load Generator"). In Figure 67**,** the loads for the 2000 m² representative office building are depicted.

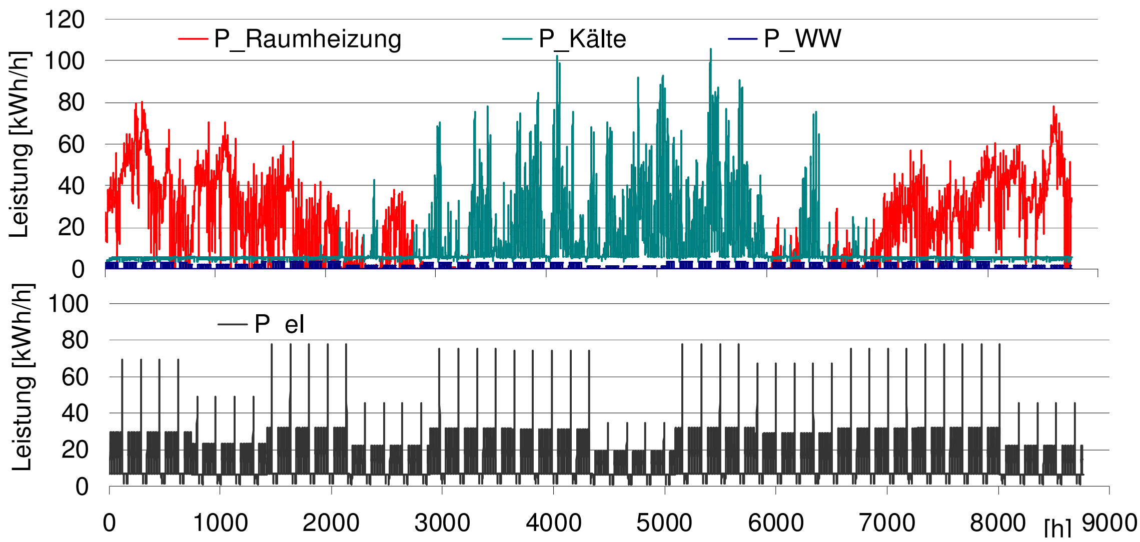

Figure 67 Yearly thermal and electric loads for a representative office building of 2000 m² floor area (hourly data).

Calculation of fuel demand and electricity production

Feeding the Polysmart Energy and Financial Simulation tool with the load profiles, the tool calculates the hourly

- share of the heating demand covered by the CHCP system
- share of the cooling heating demand covered by the CHCP system
- share of the electricity demand covered by the CHCP system, respectively share of the electricity produced by the CHCP system which is used by the building's operation.

Figure 64 shows the shares of the heating and cooling demand which can be covered by the CHCP systems in the cases of office buildings with floor areas of 2.000 m², 4.000 m², 8.000 m² and 16.000 m².
Corresponding data are the hourly heating and cooling energy provided by the auxiliary heater and cooler and the electricity purchased from / delivered to the grid.

Calculation of the economic performance of CHCP systems

From all these resulting fuel and electricity demand and production data, and the economic data like prices, fees, taxes, incentives etc., the economic performances of each system are calculated in terms of the benefits by surplus investment ratio for a technical live time of 15 years. All payments and income are rated with an appropriate interest rate of 5%, depending on the date of the cash flow. Table 40 shows further cost and feed in conditions relevant for the operation of CHCP systems in Germany.

Table 40 Cost and feed in conditions relevant for the operation of CHCP systems in Germany in 2008.

Delivery costs	
Electricity	16.05 €-cent/kWh
gas	5.41 €-cent/kWh
feed in conditions for electricity production	
basic compensation (EEX 2008)	5.77 €-cent/kWh
CHP-bonus, first 10 years	5.11 €-cent/kWh
Bonus for avoided grid usage	0.80 €-cent/kWh
tax benefits (refund of energy taxes for natural gas)	5,77 €-cent/kWh

As shown in Figure 68, currently energy price augmentation rates in Germany are 5.3% for gas and 2.3% for electricity.

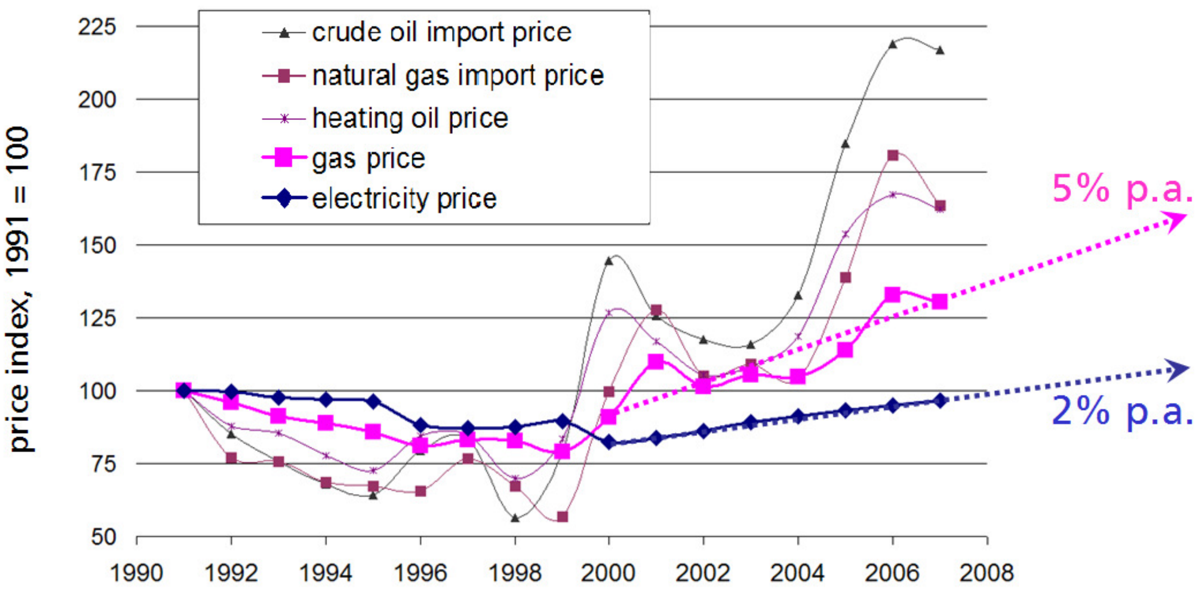

Figure 68 Selected energy price data in Germany, corrected for inflation. Source: German ministry for economics (BMWi).

In order to draw the picture of future economic performance of the CHCP-systems in dependence on different energy price augmentation scenarios, the economic calculations were carried out for augmentation rates of 2%, 5% and 8% for electricity and gas. We calculated using every combination of gas and electricity price augmentation rates, but augmentation rates for electricity is not higher than the one for gas. The resulting benefits by surplus investment ratios are depicted in the following figures.

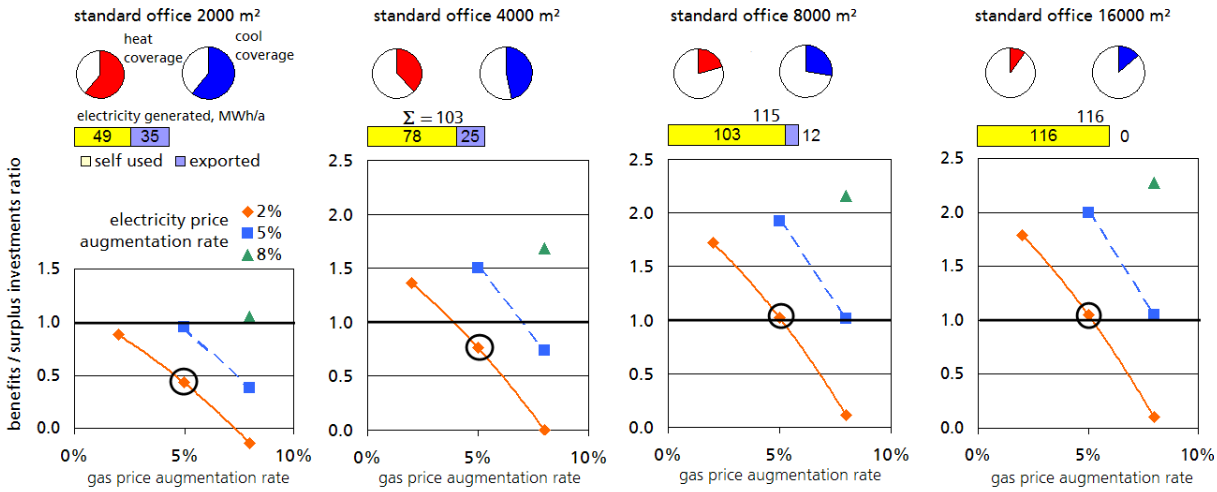

Figure 69 Benefits / surplus investment ratio in dependence on annual gas and electricity price escalation for representative German office buildings of 2.000, 4.000, 8.000 and 16.000 m² useful areas, and for the best performing µ-CHCP system over a live time of 15 years. The results for an annual electricity augmentation rate of 2% and an annual gas price augmentation rate of 5% are marked. The pie-charts show the CHCP system's coverage of heat (including heat for TDC operation) and cool demand. The bar graphs show the amount of electricity produced by the CHP, self used inside the office building and sold to the grid respectively. Values on the y-axis above 1 indicate an economically viable solution and values below 1 a non-viable solution.

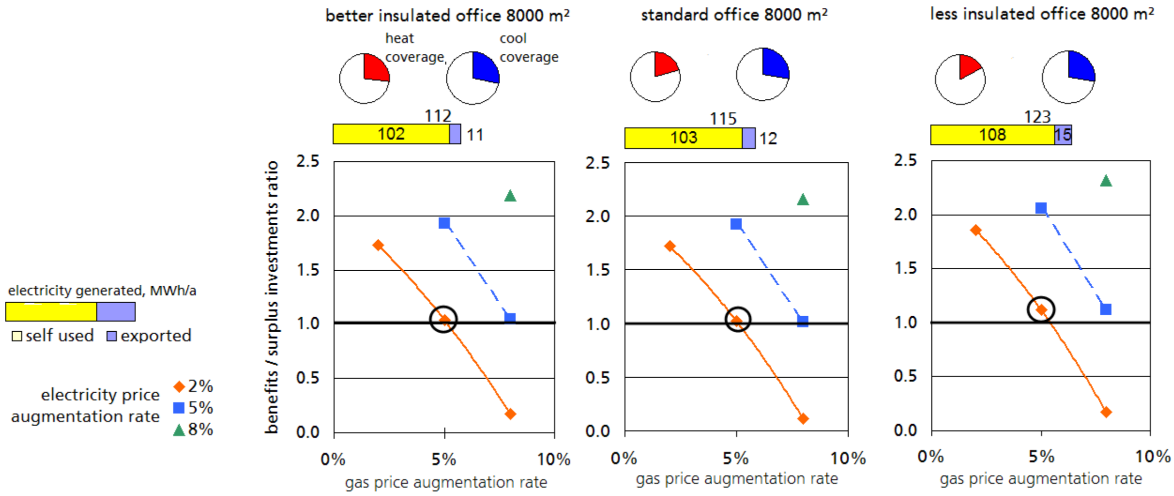

Figure 70 Benefits / surplus investment ratio in dependence on annual gas and electricity price escalation for German office buildings of 8.000 m² useful area, and with different building shell insulations than the representative version for the best performing µ-CHCP system over a live time of 15 years. The results for an annual electricity augmentation rate of 2% and an annual gas price augmentation rate of 5% are marked. The pie-charts show the CHCP system's coverage of heat (including heat for TDC operation) and cool demand. The bar graphs show the amount of electricity produced by the CHP, self used inside the office building and sold to the grid respectively. Values on the y-axis above 1 indicate an economically viable solution and values below 1 a non-viable solution.

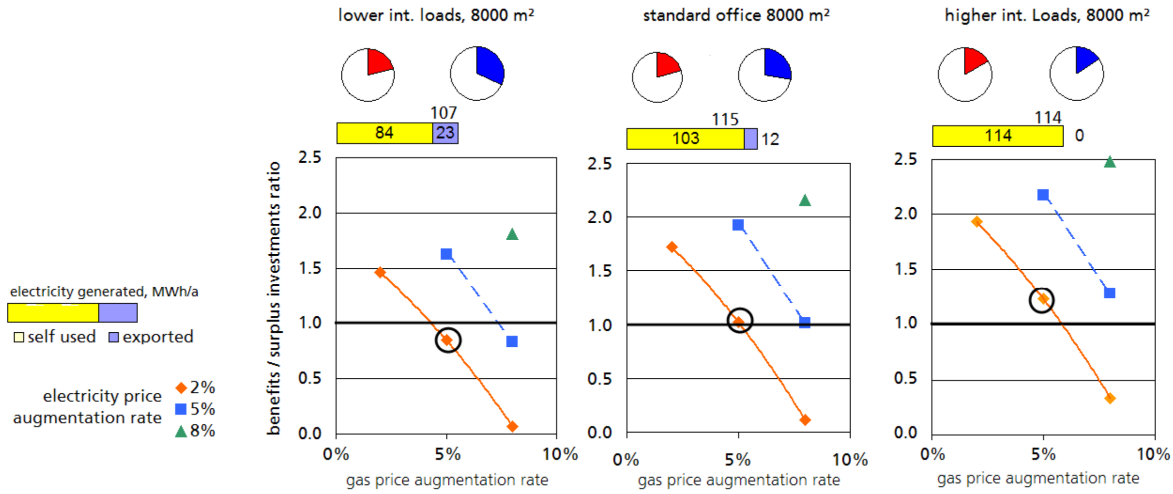

Figure 71 Benefits / surplus investment ratio in dependence on annual gas and electricity price escalation for German office buildings of 8.000 m² useful area, and with different internal loads for the best performing µ CHCP system over a live time.

As shown, our investigations show a major dependency of the economic viability of CHCP systems on future energy price development, mainly the ratio of electricity and fuel prices. In a given gas and electricity price scenario however, economic benefits depend on the amount of produced electricity, mainly if it is directly used in the building saving electricity costs.
The results given rely on one specific µ-CHCP-system which is the best performing one of the currently available systems in all simulated cases, indepedant on size and loads, due to its high efficient components. It consists of a CHP with an electrical output of 17 kWel and a thermal output of 32kWth and a TDC with a cooling capacity of 15 kWc. The nominal total efficiency of the CHP is presumed to be 92%, the electrical efficiency 32%. The CHP produces a supply temperature of 90℃. This is used by the TDC to produce a cooling temperature of 11℃. The TDC works with a thermal COP of 0,71 at ambient temperatures below 30℃. The parasitic electrical consumption of the TDC for recooling is quite low: 1,2 kWel respectively 8% of the cooling capacity.

In Figure 72, the calculated primary energy savings achieved with currently available µ-CHCP systems compared to state-of-the art conventional heating boilers and compression chillers are plotted against their coverage of the total heat demand. E.g. covering 50% of the total heat demand, the ecologically best performing systems can save approximately 20% of primary energy. On the other hand, depending on their efficiency numbers (and size matching) the application of worse performing CHCP systems can even cause an additional consumption of primary energy.

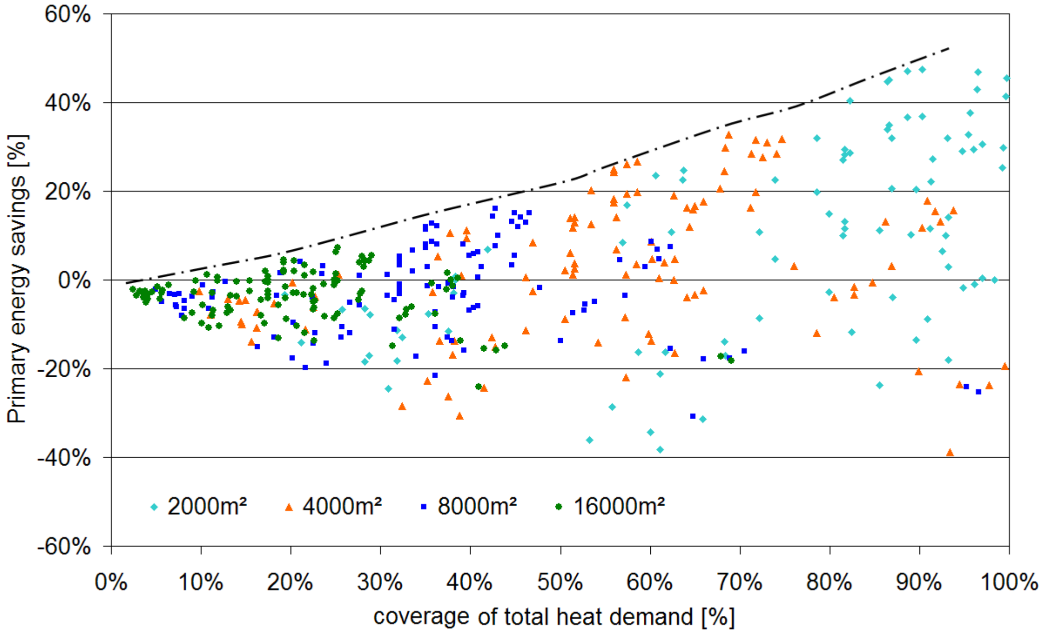

Figure 72 Primary energy (PE) savings vs. coverage of total heat demand (including heat for TDC operation) of currently available µ CHCP systems applied to represent¬ative German office buildings of different sizes. The dashed-dotted line indicates the maximal PE.

Applied to average German office buildings, only micro-CHCP systems with high efficient components perform well enough to achieve economical and ecological benefits. Economic viability is mainly dependant on the future electricity and fuel price ratio. Extrapolating the 2000 to 2007 energy price development, economic viability is only achievable, if heat and cool demand coverage is less than 25%.

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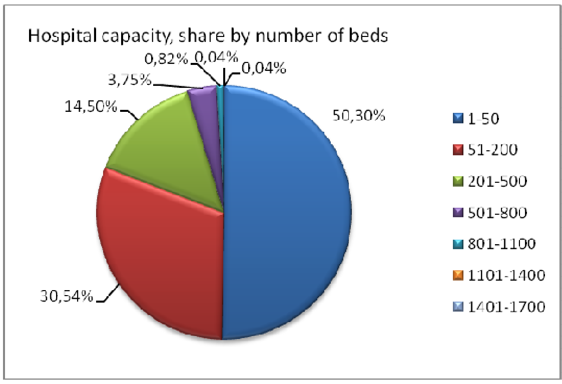
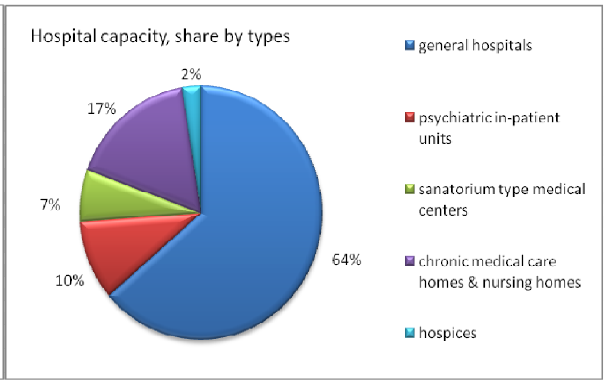
The hospital sector in Poland

Total capacity

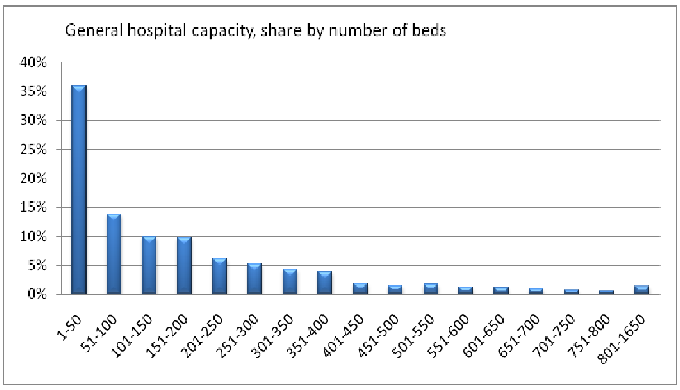
At the beginning of the year 2008, the hospital sector in Poland accounted for about 280,000 beds. The hospital sector is characterized by a diversified architecture in respect of overall heat-transfer coefficient, by a diversified floor area in regard to the number of beds and by a diversified share of specializations. These features cause difficulties when it comes to do a clear specification of the investigated sector. For the purpose of elaborating a hospital sector characterization, health care units were categorized according to two aspects: by number of beds per building and by type of hospital. Concerning the number of beds, the largest shares are covered by 3 categories: 50% are hospitals with a maximum of 50 beds, 31% are hospitals accounting for an amount of beds between 51 and 200, and 14% are hospitals containing between 201 and 500 beds. Among health care unit types, general hospitals prevail, representing a 64% of the total. Chronic medical care and nursing homes represent as well a meaningful share within the total hospital capacity, namely a 17% of the total. The minor groups include psychiatric in-patient units, sanatorium type medical centers and hospices.

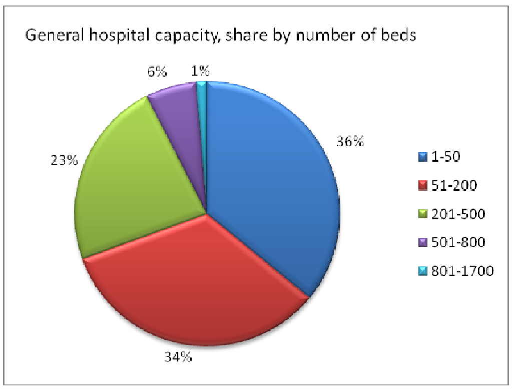


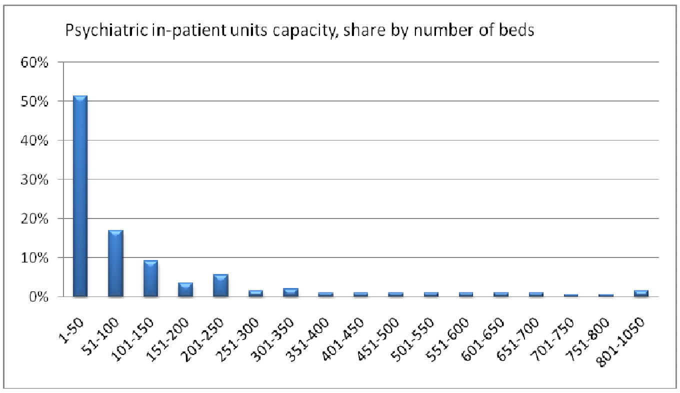


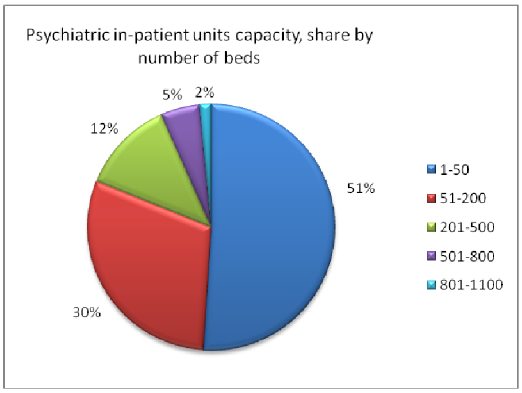
General hospitals are the biggest buildings and 64% of the units have over 50 beds. Moreover, a significant number of psychiatric in-patient units and sanatorium type medical centers are rather large buildings, accounting for a 49% and a 88% of units with more than 50 beds, respectively.

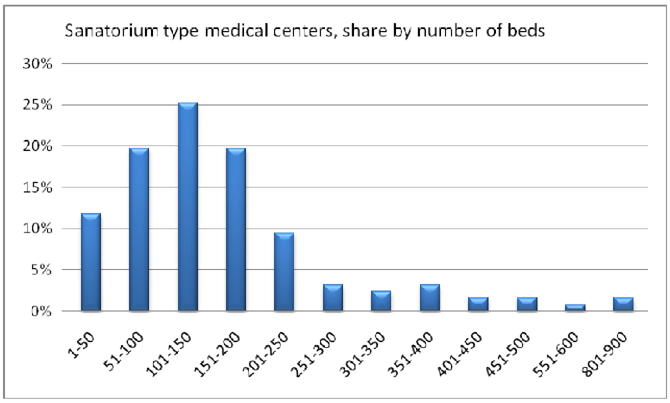
A large number of chronic medical care & nursing homes belong to small units, accounting for amounts of beds up to 50, namely the 67%. Hospices are the smallest type of health care units, and in 98% of the cases, the units have less than 50 beds.

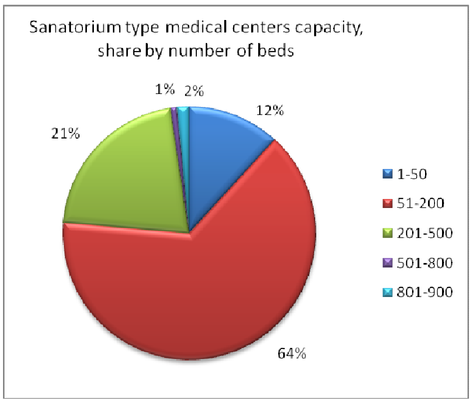




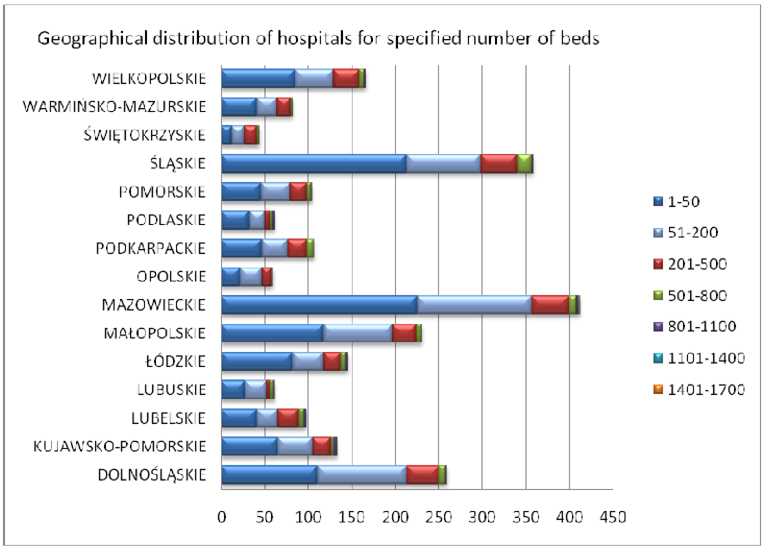








The majority of hospitals are located in the following regions in Poland, called *voivodeships* (and as such referred to from now on): mazowieckie (located in the Centre of Poland), śląskie, dolnośląskie and małopolskie (located in the South). In every *voivodeship*, hospitals having less than 50 beds, and those having between 51 and 200 beds are predominating. However, hospitals having between 201 and 500 beds are a significant group as well.



Market trends

The growth and drop of number of beds and buildings for different types of hospitals between years 2004-2007 is presented in the table below [1, 3]. According to statistics the number of general hospitals -which are the predominant type of hospitals in Poland- have been decreasing about a 1-2% per year. It is visible that the amount of chronic medical care &

nursing homes have increased, which relates to the lengthening average of life expectancy [2]. Thus, a further growth of health care units mainly oriented to elder people can be expected.

Type of units	Growth (drop) of number of beds	Growth (drop) of number of units
general hospitals	(5%)	(5%)
psychiatric in-patient units	(8%)	2%
sanatorium type medical centers	(6%)	(9%)
hospices	0%	30%
chronic medical care homes	34%	29%
nursing homes	6%	3%

Many hospitals in Poland are in a bad technical state. Health care capital expenditure has increased from 0,26% of PKB in 2003 to 0,35% in 2006 [1, 3], and a further growth can be assumed to take place.

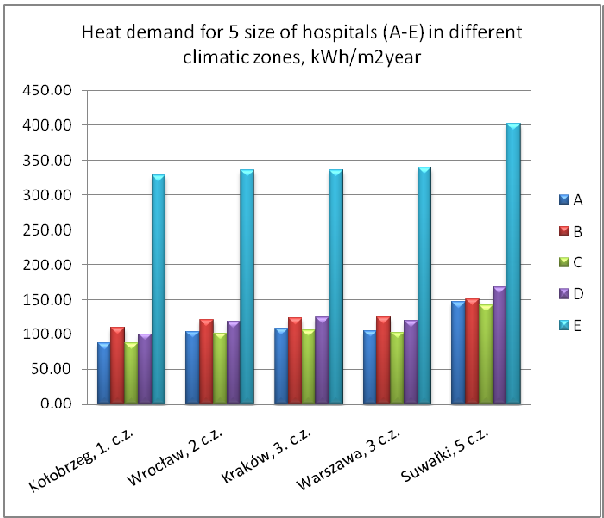
Energy needs

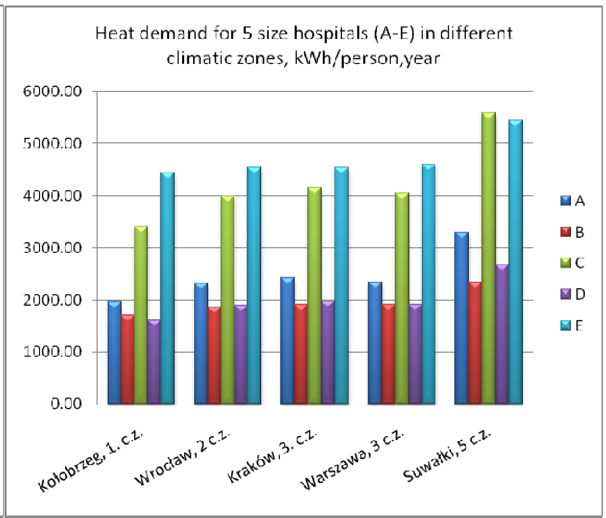
The following figures have been calculated on the basis of energy audits provided by NAPE. Five sizes of hospitals from the group of general hospitals and psychiatric in-patient units, were taken under consideration. The symbols of the hospitals, the corresponding sizes in respect of number of people and beds, the location and the U-values are shown in the table below:

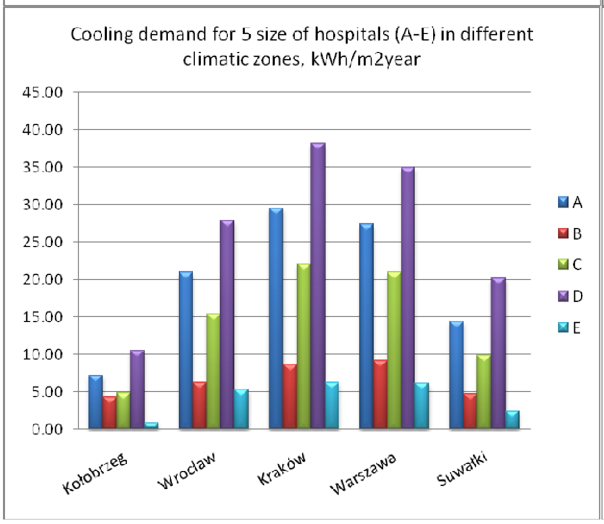
Hospital	Number of people	Number of beds	Location (climatic zone)	U [W/K m^2floor area]
A	250	51-200	North-West (2)	2,41
B	450	201-500	Centre (3)	1,83
C	514	501-800	Centre (3)	2,28
D	873	801-1100	North-East (4)	3,06
E	1540	1401-1700	Centre (3)	3,46

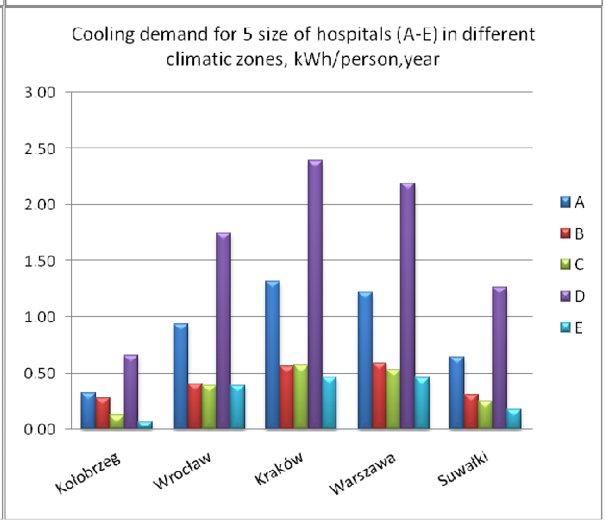
The surveyed information is related to: maximum number of people making use of the hospital (which does include both the number of beds and that of employees), weekly occupation, floor surface, electricity and hot water consumption, and heating and cooling demand. Each unit has been theoretically located in five different climatic zones that are representative for those which can be found in Poland during winter. The first zone is the warmest region, the fifth zone is the coldest one.
The specific energy demand strongly depends on the characteristics of each hospital, which differ not only on the building size and on the quality of the thermal insulation, but also on the type of care health units located on its inside, which may involve hot water consumption among other things.
The specific heat and cooling demand varies for different climatic zones. Annual heat demand for the smallest hospital (A) ranges between 88 kWh/m^2 in the 1st climatic zone and 147 kWh/m^2 in the 5th climatic zone, corresponding to 2.0 and 3.3 MWh/person respectively. Generally, for every hospital in its real location the annual heat demand varies from 100 to 350 kWh/m^2 approximately (namely 2.0 to 4.5 MWh/person respectively). The variability (in percentage) of heating demand as a function of the climatic zone for every hospitals is not very pronounced.
The cooling demand by region is more variable, and it changes even by a few hundreds of pp among different regions of Poland. The annual cooling demand for hospital A ranges from 7 kWh/m^2 in the zachodniopomorskie *voivodeship* (i.e. the North-West part of Poland) to 30 kWh/m^2 in the małopolskie *voivodeship* (the South), corresponding to 0.3 and 1.3 kWh/person. In general, annual cooling demand for every hospital in its real location ranges

between 5 and 35 kWh/m^2 (namely 0.5 and 2.2 kWh/person). As it can be obwerved in the following graphs, the greatest energy demand for space cooling is located in the South (0.5-2.4 kWh/person) and in the Centre (0.5-2.2 kWh/person) of Poland, it is lower in the South-West (0.4-1.7 kWh/person) and the North-East (0.2-1.3 kWh/person) and it achieves its lowest values in the North-West (0.1-0.7 kWh/person).









City	*Voivodeship*	Zone of Poland
Kołobrzeg	zachodniopomorskie	North-West
Wrocław	dolnośląskie	South-West
Kraków	małopolskie	South
Warszawa	mazowieckie	Centre
Suwałki	podlaskie	North-East

The annual demand for domestic hot water strongly depends on a certain hospital, and it ranges from 17 kWh/m^2 to 126 kWh/m^2, corresponding to 684 kWh/person and 1700 kWh/person respectively.
The average electric energy consumption is of 84 kWh/m^{2}year in every hospital.

Sector segmentation

On the basis of the collected information, the hospital sector in Poland has been divided into clusters. The following overview has been made with regard to the aim of the study, i.e. evaluating the potential benefits of micro-CHCP.

Both general hospitals and psychiatric in-patient units have been taken into consideration. They represent about the 64% and 10% of the total respectively. Chronic medical & nursing homes have more pp of the total than psychiatric in-patient units, but almost 70% of buildings have less than 50 beds and will therefore not be examined. Sanatorium type medical centers and hospices are the smallest groups (7% and 2%, in that order), additionally hospices are probably too small for micro CHCP as well as the majority of chronic medical & nursing homes do.
In this category, four prototypical sizes have been identified which are defined by the number of beds. Such categorization is based on the share of sizes from the total: 31%, 14%, 4% and 1% respectively. Hospitals accounting for less than 50 beds have been excluded, since they are probably too small for micro CHCP, although they constitute the largest group.

Category	Size	Size filter
General hospitals & psychiatric in-patient units	250 people	between 51 and 200 beds
	450 people	between 201 and 500 beds
	514 people	between 501 and 800 beds
	873 people	between 801 and 1100 beds

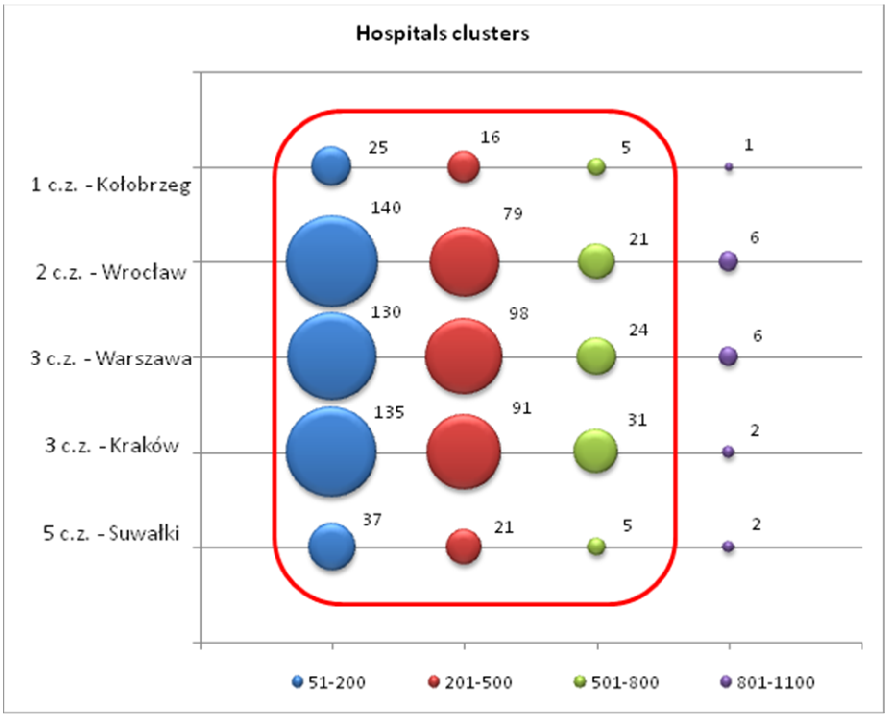
The climate conditions have strong influence on the heating and the cooling load. Five winter climatic zones in Poland have been used. Each segment is characterized by its own geographical filter, as shown in the table below.

Voivodeships	Geographical filter
zachodniopomorskie, pomorskie	1. climatic zone - Kołobrzeg
dolnośląskie, kujawskopomorskie, lubuskie, wielkopolskie	2. climatic zone - Wrocław
lubelskie, łódzkie, mazowieckie, świętokrzyskie	3. climatic zone - Warszawa
małopolskie, opolskie, podkarpackie, śląskie	3. climatic zone - Kraków
podlaskie, warmińsko-mazurskie	5. climatic zone - Suwałki

By combining the size with the climate segments, all of the hospital sectors have been divided into twenty clusters. The number of hospitals for each cluster has been estimated according to the available statistics on hospitals capacity. The first climatic zone includes the smallest number of hospitals due to a lack of data for the zachodniopomorskie *voivodeship*. It is expected that the number of objects in the 1st climatic zone shall be comparable as the ones in the 5th climatic zone are.

	51-200 beds	201-500 beds	501-800 beds	801-1100 beds
	250 people	450 people	514 people	873 people
1 c.z. - Kołobrzeg	25	16	5	1
2 c.z. - Wrocław	140	79	21	6
3 c.z. - Warszawa	130	98	24	6
3 c.z. - Kraków	135	91	31	2
5 c.z. - Suwałki	37	21	5	2

Once the characteristics of each cluster have been specified for the sake of size and climate, an assessment of micro-CHCP attractiveness for a given cluster is made possible. The decisive value parameter is the need for cooling. Micro CHCP can find application in hospitals located in every climatic zone, but it should be noticed that the cooling demand in the 1st climatic zone is the lowest one. Hospitals with a number of beds ranging between 801 and 1000 have not been taken into consideration, because they represent a very small cluster in comparison with others. A graphical classification of the proposed clusters is shown in the graph below, where the figures besides the bubbles represent the corresponding number of prototypical hospitals in each group.



Load profiles

The data input for the load generator has been sourced from energy audits provided by NAPE. First, the calculation mode - using known and fixed heating and cooling demands as input - has been used in the counting of hospitals in every given region; later on, the mode that uses effective U-values and sensitivities on solar radiation has been used for the same hospital in other climatic zones. The weekly and yearly schedules for occupation, ventilation, hot water consumption and internal loads were approximated in the following way:

	1-6	7	8	9-17	18	19-24
Monday	70	80	95	100	90	70
Tuesday	70	80	95	100	90	70
Wednesday	70	80	95	100	90	70
Thursday	70	80	95	100	90	70
Friday	70	80	95	100	90	70
Saturday	60	80	80	80	80	60
Sunday	60	80	80	80	80	60

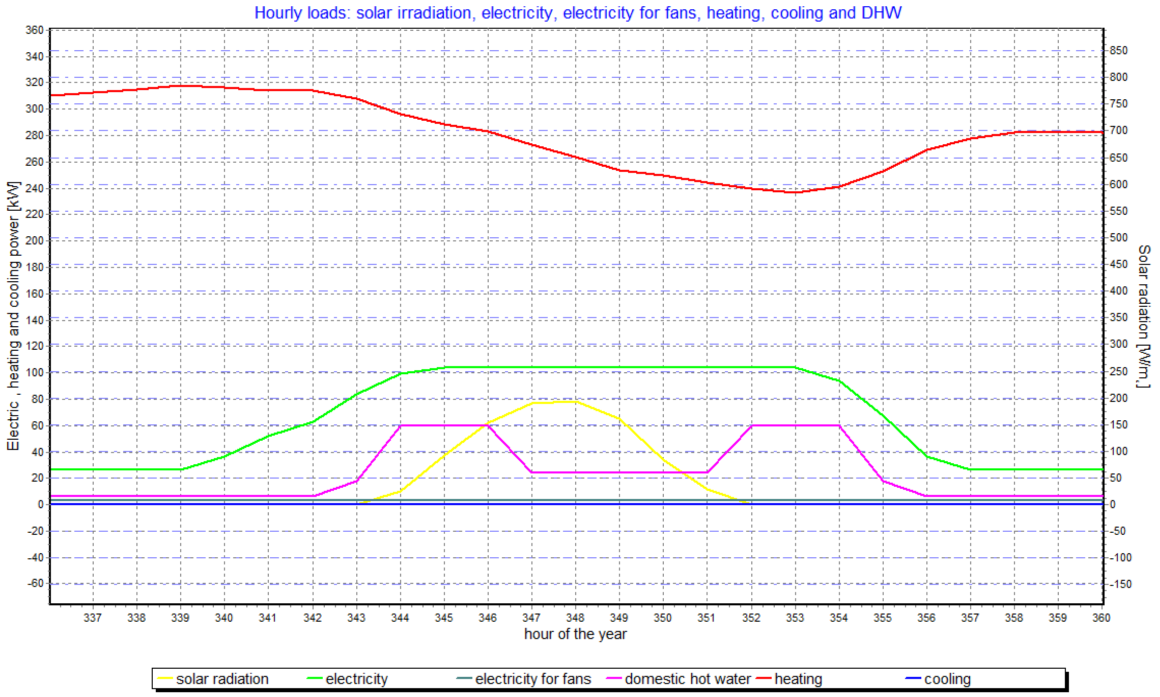
The relevant inputs for each climatic zone of the three prototypical hospitals is shown in the following table:

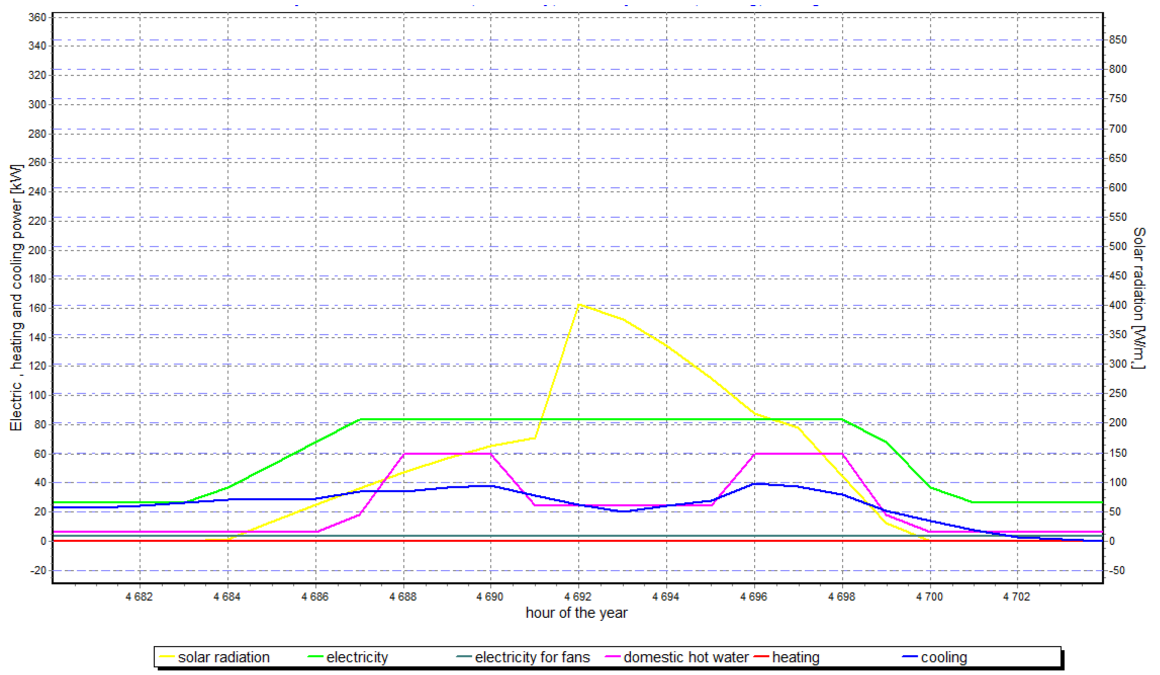
Number of beds	51-200	201-500	501-800
Number of persons	250	450	514
Floor area, m^2	5600	6957	20099
Minimum room temp., ^oC	16	20	16
Maximum room temp., ^oC	24	24	24
Maximum relative humidity, %	70	60	70
Maximum hot water consumption, l/h	750	1025	688
Effective U-value, W/Km^2floor area	2,41	1,83	2,28
Solar sensitivity factor, %	49,41	2,73	41,02
Maximum air change rate, 1/h	1,0	0,7	1,1

Ventilation heat recovery value, %	50	50	50

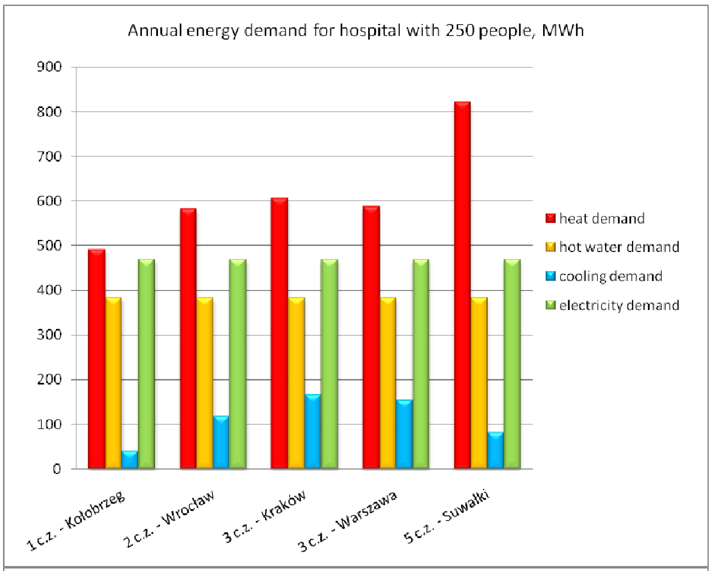
Internal gains and domestic hot water consumptions are assumed to vary with occupation (see table above). Maximum hot water consumption values are presented above for every type of hospital. Maximum internal loads have been assumed to be at the same level for every cluster, i.e. 15 W/m^2.

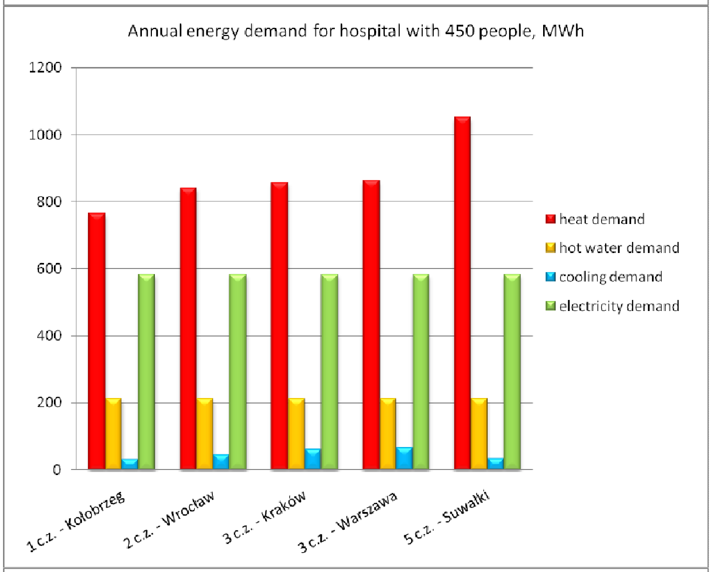
Examples of the resulting hourly profiles in a typical winter day (i.e., 15 January, hours of the year rangin from 336 to 360) and a typical summer day (i.e., 15 July, hours of the year ranging from 4680 to 4704) for the case of a hospital with 450 beds located in the 3rd climatic zone (Warszawa, the Centre) are shown hereafter.

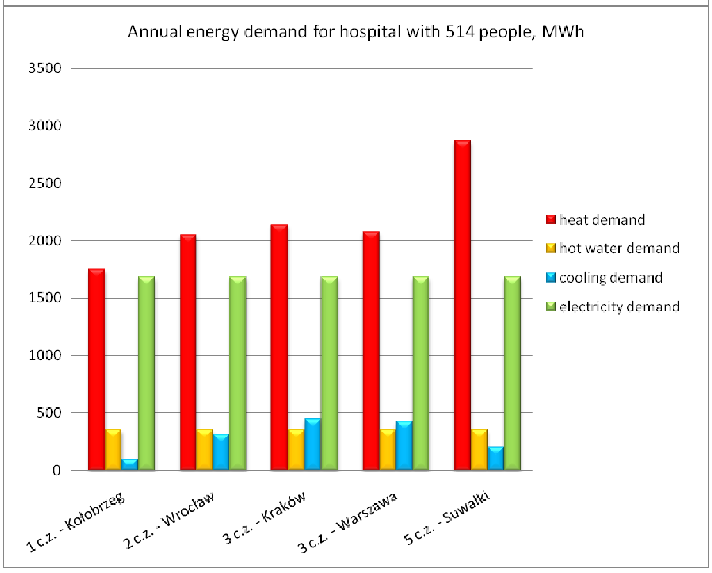




The simulated annual loads for heating, domestic hot water, cooling and electricity are shown in the following plot.







The output load curves from the load generator were all very similar in shape, and generally just the peak values change from one hospital to another. The results were cross-checked with the initial data available from the energy audits and the accuracy was surprisingly good, yielding an average tolerance of +/- 5%.

Energy prices and incentives

The main energy distribution sources in Polish hospitals are district heating and electricity from the grid. In hospitals -especially in those with surgical wards- the energy backup is necessary, and it is mostly provided by LPG or heating oil. In locations where district heating is not available, heat is generated from natural gas.
The most important features which determine the price of energy are the destination of uses (non-domestic for hospitals) and the ordered power (or thermal power).
Based on the specific demand per m^2 of useful floor area in hospital, the annual consumption of district heating and electricity can be estimated for the 3 types of hospitals considered so far.

Hospital size		Specific per m^2 annual consumption		Total per hospital annual consumption	
People	Beds	District heating [kWh/m^{2}year]	Electricity [kWh/m^{2}year]	District heating [MWh/year]	Electricity [MWh/year]
250	51-200	111	84	620	470
450	201-500	126	84	880	580
514	501-800	108	84	2180	1680

Electricity

Electricity prices for final consumers are fixed by two utilities:

- energy distribution service (officially regulated price),
- energy seller (liberalized price).

In the liberalized market, the cost of energy changes in a 5-10% depending on the units, fuel type and fuel prices [5]. Differences in production costs depending on the fuel type or generation techniques are compensated by a certificate system (described in 'CHP regulation and promotion', hereafter).
The total electricity price is mainly defined by the sum of the unit price, the distribution tax and the VAT (22%). The prices and taxes are fixed at a central and a local level in the following order: in 2007 the unit price of electricity was about 3.04c€/kWh and the additional distribution tax averaged 3.26c€/kWh. A part of the taxes is fixed depending on the ordered power and another part varies depending on energy consumption. Hospitals are characterized by an electricity ordered power over 40 kW. Distribution taxes apply only when electricity is purchased from the grid.
The average total electricity price excluding VAT for sectors with ordered power over 40 kW, has been calculated [4, 6, 14] and its steady growth during the last years is reported:

Electricity price	Year		
c€/kWh	2005	2006	2007
Total price before VAT	5.02	5.14	5.31

Electricity prices also depend on the tension level of the grid a plant is connected to (MT stands for medium tension, LT for low tension) and the time zone (zones correspond to both periods during and beyond a peak, and to those during day-time and night-time). In order to show the differences among prices corresponding to every time zone, the example prices of electricity for consumers with ordered power over 40 kW in 2007 are presented as follows [4].

year 2007	MT, c€/kWh	year 2007	LT non domestic, c€/kWh
During a peak (8-11, 18-21)	5.67	Day-time (6-21)	6.34
Beyond a peak (11-18, 21-8)	4.17	Night-time (21-6)	5.04

VAT on electricity has been set to 22% for all users.

District heating
The total district heating price equals the sum of the distribution tax -which is liable to regulation- and the unit price of heat, which is set at a regional level. Unit prices are differentiated by fuel for heat generation. In 2007, average unit prices varied between 1.68 and 2.32c€/kWh and distribution taxes between 0.49 and 1.18c€/kWh, depending on the region [7]. The total prices of district heating are very diversified. In 2006 the smallest price amounted to 0.60c€/kWh, the greatest to 4.8c€/kWh, depending on the utility company [14]. The total average district heating price excluding VAT has been calculated [7, 8, 9, 10, 14] and its steady growth during the last years is reported as follows:

District heating price	Year		
c€/kWh	2005	2006	2007
Total price before VAT	1.76	1.80	1.89

VAT on district heat has been set to 22% for all users.

Natural gas
The total natural gas price equals the sum of the unit price of gas and the distribution taxes, the latter being liable to regulation. In 2007 the average unit price was 2.72c€/kWh and the distribution tax 0.68c€/kWh [4, 15]. There are no tax breaks.
The average total natural gas price excluding VAT has been calculated [4, 15] and its steady growth during the last years is reported as follows:

Natural gas price	Year		
c€/kWh	2005	2006	2007
Total price before VAT	2.39	3.05	3.40

VAT on natural gas has been set to 22% for all users.

CHP regulation and promotion

Presently, the implementation of the EU directive on cogeneration in the country is based on the obligatory purchase of certificates of origin from highly efficient CHP and investment subsidies. Other mechanisms of support such as tax breaks are not considered in Poland.
Since the 1st of July 2007, all energy companies dealing with power generation and selling power to final customers are obliged to purchase the certificates of origin of highly efficient CHP. Certificates originate from CHP units which have had a positive opinion of an accredited unit and have obtained certificates from the Energy Regulatory Office, based on the PES indicator (described hereafter). Proprietary interests following from certificates are negotiable and so are the commodities of the energy exchange (Polish Power Exchange). In the case of CHP, two types of certificates exist: a 'yellow' one for gas-fired CHP or CHPs with installed electric power below 1 MW (small-scale power plants), and a 'red' one for other types of CHP. Prices of certificates at the end of 2007 amounted to 2.52c€/kWh and 0.38c€/kWh respectively [13]. If energy utilities do not obtain the certificates, they have to pay a substitute-charge: in 2007 it was of 2.54c€/kWh for gas-fired CHP or CHPs with installed electric power below 1 MW and 0.39c€/kWh for other CHPs [4]. In 2009 energy utilities trading power are obliged to sell energy from CHPs in a share of total as follows: 2,9% from gas-fired CHP or CHPs with installed electric power below 1 MW and 20,6% from other CHPs, otherwise to pay the substitute-charge. Until 2012 - last year of validity of this support mechanism - these fractions will rise appropriately: 3,5% and 23,2%. Presently, no information is available on eventual incentives after 2012.

The Decree [11] defines 'highly efficient cogeneration' as the combined production of electricity and heat which provides:

a) energy savings not less than 10%,
b) energy savings for CHP plants with installed electric power below 1 MW,

in comparison with separate production of electricity and heat at reference efficiencies.

The PES indicator compares the primary energy consumption of a highly efficient cogeneration plant and the consumption of a conventional separate generation of electricity and heat:

$$PES = \left(1 - \frac{1}{\frac{\eta_{qc}}{\eta_{refc}} + \frac{\eta_{qe}}{\eta_{refe}}} \right) \cdot 100$$

where η_{qc} and η_{qe} are efficiencies for heat and electricity generation respectively, η_{refc} and η_{refe} are reference efficiencies for heat and electricity generation respectively, defined separately.

The reference values for electric efficiency are shown in Table 41 and are a function of the fuel type and the year when the plant is put into commissioning. These efficiencies are subject to corrections related to the average outside temperature of the year and the grid losses. The efficiency must be reduced by 0,1 pp for every Celsius degree of average outside temperature below 15°C, and increased in opposite conditions. The efficiency correction by means of the outside temperature is defined by the following equation:

$$\eta_{refe\ to} = \eta_{refe\ pal} + 0{,}1 \cdot (15 - t_o)$$

where $\eta_{refe\ pal}$ is the reference efficiency for electricity generation, defined in Table 41.

Corrections related to grid losses are defined by the following equation :

$$\eta_{refe} = \eta_{refe\ to} \cdot \sum_{i=1}^{n} U_i Z_i$$

where U_i is the share of electric flux at a given voltage level and Z_i are multipliers defined in Table 42.

Table 41 Reference values for electric efficiency used to calculate the PES in the Decree [11].

Electric efficiency for PSE calculation [%]												
Type of fuel		Year of putting into commissioning										
		≤1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006-2011
Solid	Hard coal, coke	39,7	40,5	41,2	41,8	42,3	42,7	43,1	43,5	43,8	44,0	44,2
Solid	Lignite, lignite briquette	37,3	38,1	38,8	39,4	39,9	40,3	40,7	41,1	41,4	41,6	41,8
Solid	Peat, peat briquette	36,5	36,9	37,2	37,5	37,8	38,1	38,4	38,6	38,8	38,9	39,0
Solid	Fuel wood, wood waste	25,0	26,3	27,5	28,5	29,6	30,4	31,1	31,7	32,2	32,6	33,0
Solid	Agricultural biomass	20,0	21,0	21,6	22,1	22,6	23,1	23,5	24,0	24,4	24,7	25,0
Solid	Biodegradable municipal waste	20,0	21,0	21,6	22,1	22,6	23,1	23,5	24,0	24,4	24,7	25,0
Solid	Non-renewable municipal and industrial waste	20,0	21,0	21,6	22,1	22,6	23,1	23,5	24,0	24,4	24,7	25,0
Solid	Oil shale	38,9	38,9	38,9	38,9	38,9	38,9	38,9	38,9	38,9	38,9	39,0
Liquid	Oil (diesel oil, heating oil), LPG	39,7	40,5	41,2	41,8	42,3	42,7	43,1	43,5	43,8	44,0	44,2
Liquid	Biofuels	39,7	40,5	41,2	41,8	42,3	42,7	43,1	43,5	43,8	44,0	44,2

	Biodegradable waste	20,0	21,0	21,6	22,1	22,6	23,1	23,5	24,0	24,4	24,7	25,0
	Non-renewable waste	20,0	21,0	21,6	22,1	22,6	23,1	23,5	24,0	24,4	24,7	25,0
Gaseous	Natural gas	50,0	50,4	50,8	51,1	51,4	51,7	51,9	52,1	52,3	52,4	52,5
	Refinery gas, hydrogen	39,7	40,5	41,2	41,8	42,3	42,7	43,1	43,5	43,8	44,0	44,2
	Biogas	36,7	37,5	38,3	39,0	39,6	40,1	40,6	41,0	41,4	41,7	42,0
	Coke-oven gas, top gas, others waste gases, waste heat recovered	35,0	35,0	35,0	35,0	35,0	35,0	35,0	35,0	35,0	35,0	35,0

Table 42 Values for multipliers correction due to grid losses in the Decree [11]. (*) excluding fuel wood, wood waste and biogas (Z=1).

Voltage	Multiplier	
	Electricity putting to electric power system	Electricity selling to direct power line or used for internal load
> 200 kV	1	0,985
100-200 kV	0,985	0,965
50-100 kV	0,965	0,945
0,4-50 kV	0,945	0,925
< 0,4 kV	0,925	0,860

The reference values for thermal efficiency are shown in Table 43 and are a function of fuel and agent type.

Table 43 Reference values for thermal efficiency used to calculate the PES in the Decree [11].

Thermal efficiency for PSE calculation [%]			
Fuel type		Agent type	
		Process steam / hot water heating	Direct utilization of waste gases
Solid	Hard coal, coke	88	80
	Lignite, lignite briquette	86	78
	Peat, peat briquette	86	78
	Fuel wood, wood waste	86	78
	Agricultural biomass	80	72
	Biodegradable municipal waste	80	72
	Non-renewable municipal and industrial waste	80	72
	Oil shale	86	78
Liquid	Oil (diesel oil, heating oil), LPG	89	81
	Biofuels	89	81
	Biodegradable waste	80	72
	Non-renewable waste	80	72
Gaseous	Natural gas	90	82
	Refinery gas, hydrogen	89	81
	Biogas	70	62
	Coke-oven gas, top gas, others waste gases	80	72

Another kind of incentives relevant for some cogeneration plants are tradable 'green' certificates, which function in a similar way as 'yellow' and 'red' one but are related to the power generation from renewable sources, not only in cogeneration. In 2009 energy companies trading with power have been obliged to sell 'green' energy in a share of 8,7% of the total, and it is expected that until 2017, namely the last year of validity of this support mechanism, this fraction will rise up to 12,9%. Substitute-charges amounted to 5.27c€/kWh, certificate prices – 5.20c€/kWh [13].

In the near future 'white certificates' will be introduced as support mechanisms. They are energy efficiency certificates. Qualified companies can sell 'white certificates' in a quantity proportional to the amount of primary energy saved, receiving a rebate.

Tariff and incentives scenario for micro-CHCP

Polish tariffs and economic incentives on cogeneration in the current legislation and in future scenarios are examined below. Three scenarios are investigated: business as usual (prices based on 2007), strong political support and moderate political support.

Business as usual

The existing incentives to highly efficient cogeneration in Poland are the following:

- priority for electricity sales to the grid,
- obligation of acceptance of electricity generated in highly efficient CHP plants connected directly to a power system operator,
- 'yellow' certificates (for gas-fired CHP or with installed electric power below 1 MW): 2.5c€/kWh (till 2012) [13],
- 'green' certificates (for power plants based on renewable fuels): 5.2c€/kWh (till 2017) [13],
- increase of district heating prices net of taxation at a yearly rate of 3%,
- increase of natural gas prices net of taxation at a yearly rate of 3%.

The prices of electricity sold to the grid depend on the type of fuel and units, but differences most often do not exceed a 10%. Electricity prices are independent of time zones.

Table 44 Prices of electricity sold to the grid during 2007, before VAT=22% [12].

Type of CHP	c€/kWh
Gas-fired CHP or with installed electric power below 1 MW	2.91
Others CHP	2.76
Competitive market	2.80

Prices of electricity purchased from the grid depend on the following parameters: the tension level of the grid the plant is connected to (MT stands for medium tension, LT for low tension), value of ordered power (boundary value is 40kW); the time zone (zones divided as periods during and beyond a peak, and during day-time and night-time). Average values of the Polish electricity market, connected with greater demands as in hospitals, are summarized in Table 45.

Table 45 Average prices of electricity purchased from the grid during 2007, before VAT=22% [4].

	MT, c€/kWh		LT non domestic, c€/kWh
During a peak (8-11, 18-21)	7.94	Day-time (6-21)	8.89
Beyond a peak (11-18, 21-8)	5.84	Night-time (21-6)	7.06

Natural gas is the fuel rarely used in power industry (share in electric energy production 2%). By reason of gas is the fuel most often utilize in micro CHCP, its costs are summarized in Table 46.

Table 46 Average prices of natural gas during 2007, before VAT=22% [4, 15].

	Industrial (medium size), c€/kWh (LHV)	Domestic, c€/kWh (LHV)
Natural gas average price	2.79	3.40

Strong political support

In addition to the incentives already established by the present legislation, the “strong political support scenario” considers the following ones:
- ‘yellow’ certificates: 2.8c€/kWh,
- ‘white’ certificates: 12€/toe (in a 2 years),
- ‘green’ certificates: 5.6c€/kWh,
- partial rebate of 40% of investment costs with a maximum of 2,200,000 €,
- increase of district heating prices net of taxation at a yearly rate of 5%,
- increase of natural gas prices net of taxation at a yearly rate of 5%,
- increase of electricity prices net of taxation according to the following equation:

Electricity price = 3.0642 x (Natural Gas price x Share in el. en. production + Hard Coal price x Share in el. en. production) + 0.0337 [€/kWh]

High value of subsidies, originated from UE funds, follows from low GNP in Poland.

In Poland, electricity prices are very slightly conditioned by natural gas prices, because electricity generation is mainly based on coal (only 2% of power plants are based on natural gas [4]). Electricity prices are instead strongly dependent on CO2 emission allowances prices (method of allocation unbeneficial for units and there is great lack of emission allowances), obligation of obtaining ‘green’, ‘yellow’ and ‘red’ certificates (in ‘green’ electricity increase an obligatory share of agro biomass -which is difficult in combustion- what will lead to a rise of electricity prices). Most of the power plants in Poland date from the seventies, and nowadays the process of power plants rebuilding has began -related to free CO2 emission allowances for new units-. Regarding such conditions (new investments, obligatory share of certain types of energy and compulsory quantity of CO2 emission allowances) the increasing tendency of electricity prices is difficult to predict, especially depending on one parameter. Nevertheless, an attempt to develop an equation of the price of electricity depending on natural gas has been made.

There is no reverse metering in Poland, but power system operators are obliged to accept electricity generated in highly efficient CHP plants connected directly to the operator. The Polish Energy Exchange, as indispensable element of the liberalized energy market, offers a chance for an objective market energy price definition.

Moderate political support

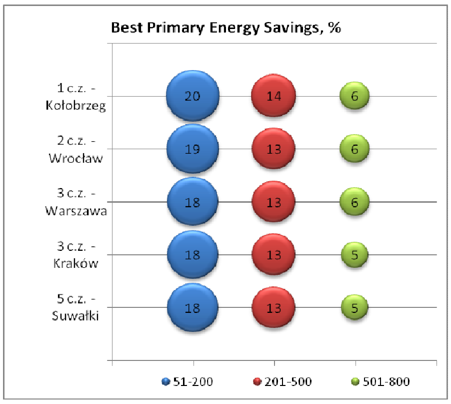
Moderate political support is an average between the two previously described scenarios. The moderate political support considers the following parameters:
- ‘yellow’ certificates: 2.5c€/kWh (till 2012),
- ‘white’ certificates: 12€/toe (in a 3 years),
- ‘green’ certificates: 5.3c€/kWh (till 2017),
- partial rebate of 30% of investment costs with a maximum of 2,200,000 €,
- increase of district heating prices net of taxation at a yearly rate of 4%,
- increase of natural gas prices net of taxation at a yearly rate of 4%,
- increase of electricity prices net of taxation according to the following equation:

Electricity price = 3.0642 x (Natural Gas price x Share in el. en. production + Hard Coal price x Share in el. en. production) + 0.0337 [€/kWh]

Economic attractiveness

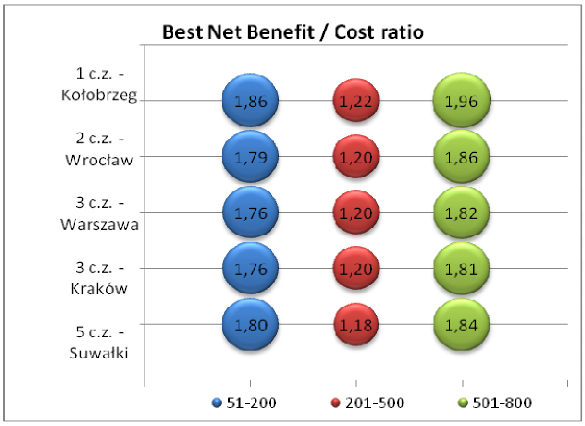
The PolySMART Energy and Financial Assessment Tool has been used to calculate the energy and financial performance of micro-CHCP in the Polish hospital sector. The best achievable primary energy savings vary between 5 and 20%. Savings are considerably higher for hospitals accounting for a number of beds between 51 and 200, due to the following reasons:
- when CHCP units cover the largest share of energy demand, the primary energy savings are higher,

- the maximum power of micro-CHCP is limited to about 50 kWe, 100 kWt and 50 kWc, which makes it impossible to cover the total heat demand of all of the considered hospitals characterized by heating peak loads above 300 kW in each cluster. Within the same hospital category, primary energy savings are larger in the 1st climatic zone (North-West area), which is the warmest region in winter, and cooling demand in summer is the lowest one.
The most usually installed heating system in Poland is based on district heating (reference efficiency=88% for units supplied by hard coal according to the Decree [11]), instead of gas boilers (reference efficiency=90% [11]), as set in the PolySMART Energy and Financial Assessment Tool. Therefore, PES values might be higher in reality (by about 1 pp).



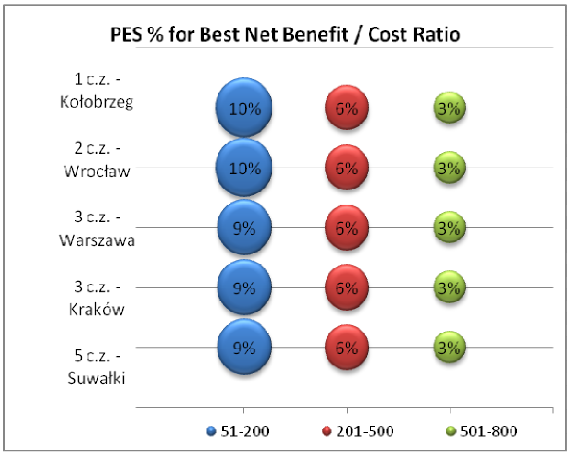
For all cases the summary table of the optimal size in terms of B/C ratio is reported below. In this regard the best are the greatest hospitals. The worst in terms of B/C ratio are medium hospitals with number of bed between 201-500. It is caused by the fact, that this type of hospitals has very low cooling demand in comparison with others demands. In Poland hospitals of this size were build before world war. They are poviat hospitals. In overwhelming majority they are old buildings of massive construction (U=1,83 W/m^{2}K in comparison to small-size U=2,41 W/m^{2}K and large-size U=2,28 W/m^{2}K).
The investment in CHCP in medium type of hospitals is unprofitable in scenario ‘business as usual’ and ‘moderate support’.

	Best B/C ratio								
	Business as usual			**Moderate support**			**Strong support**		
Localization	**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**
1 c.z. - Kołobrzeg	1.08	0.69	1.21	1.14	0.68	1.24	1.86	1.22	1.96
2 c.z. - Wrocław	1.03	0.68	1.14	1.08	0.67	1.15	1.79	1.20	1.86
3 c.z. - Warszawa	1.01	0.68	1.12	1.05	0.67	1.11	1.76	1.20	1.82
3 c.z. - Kraków	1.01	0.68	1.11	1.04	0.67	1.10	1.76	1.20	1.81
5 c.z. - Suwałki	1.03	0.66	1.13	1.08	0.65	1.12	1.80	1.18	1.84



Primary energy savings were calculated, in each cluster, for the system that promises the highest profitability. The corresponding values are lower than the maximum achievable primary energy savings in all cases. In particular, primary energy savings are significant only for small size hospitals.

	Best PES for best B/C ratio								
	Business as usual			Moderate support			Strong support		
Localization	**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**
1 c.z. - Kołobrzeg	10%	6%	3%	10%	6%	3%	10%	6%	3%
2 c.z. - Wrocław	10%	6%	3%	10%	6%	3%	10%	6%	3%
3 c.z. - Warszawa	9%	6%	3%	9%	6%	3%	9%	6%	3%
3 c.z. - Kraków	9%	6%	3%	9%	6%	3%	9%	6%	3%
5 c.z. - Suwałki	9%	6%	3%	9%	6%	3%	9%	6%	3%

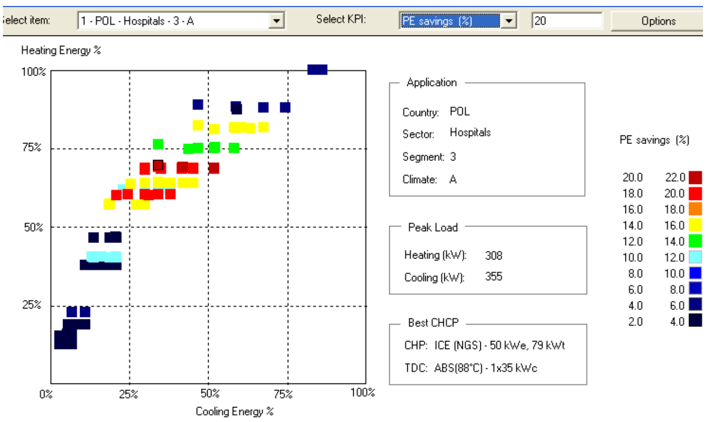


Heating, cooling and electricity demand is covered by CHCP in the degree as showed in the table below. The largest share of cooling demand is covered in medium-size hospitals, because of the lowest cooling demand in relation to overall energy demand.

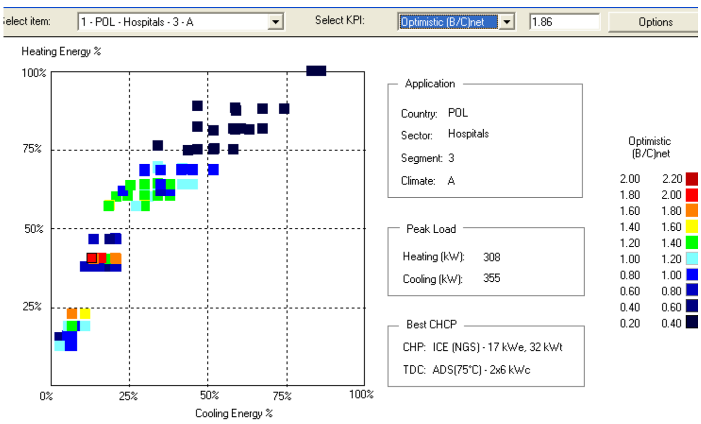
		Energy supplied to the user for best B/C ratio								
		Business as usual			Moderate support			Strong support		
Localization		**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**
1 c.z. - Kołobrzeg	H:	41%	30%	20%	41%	30%	20%	41%	30%	20%
	C:	13%	61%	5%	13%	61%	5%	13%	61%	5%
	E:	27%	18%	8%	27%	18%	8%	27%	18%	8%

		Energy supplied to the user for best B/C ratio								
		Business as usual			Moderate support			Strong support		
Localization		**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**	**51-200**	**201-500**	**501-800**
2 c.z. - Wrocław	H:	38%	29%	19%	38%	29%	19%	38%	29%	19%
	C:	12%	39%	4%	12%	39%	4%	12%	39%	4%
	E:	26%	18%	8%	26%	18%	8%	26%	18%	8%
3 c.z. - Warszawa	H:	38%	29%	19%	38%	29%	19%	38%	29%	19%
	C:	11%	26%	4%	11%	26%	4%	11%	26%	4%
	E:	26%	18%	8%	26%	18%	8%	26%	18%	8%
3 c.z. - Kraków	H:	38%	29%	18%	38%	29%	18%	38%	29%	18%
	C:	11%	30%	4%	11%	30%	4%	11%	30%	4%
	E:	26%	18%	8%	26%	18%	8%	26%	18%	8%
5 c.z. - Suwałki	H:	33%	25%	15%	33%	25%	15%	33%	25%	15%
	C:	11%	49%	4%	11%	49%	4%	11%	49%	4%
	E:	27%	18%	8%	27%	18%	8%	27%	18%	8%

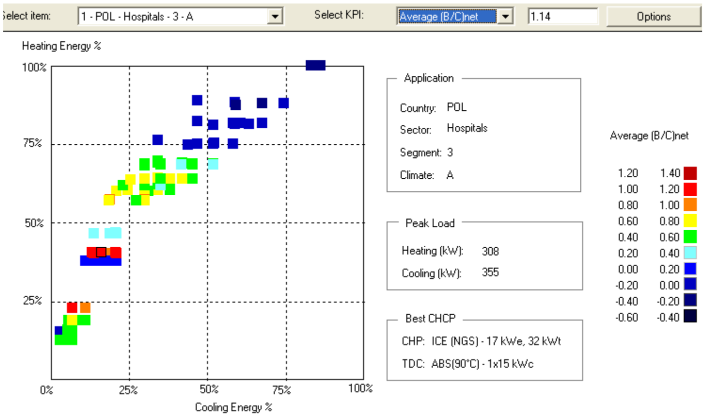
Following the maximum B/C ratio and the coverage of heating, cooling and electricity demand, the most interesting cluster is the hospitals with number of beds between 50-200 (53% share). Therefore below graphs of PES and B/C ratio for hospitals with number of beds between 51-200 in three economic scenarios are presented.



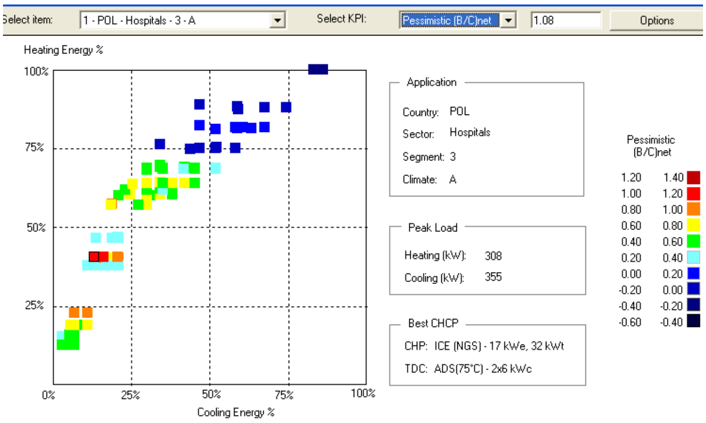
PES for hospitals with 51-200 number of beds located in the 1. climatic zone (Kołobrzeg)



B/C ratio in the strong support scenario for hospitals with 51-200 number of beds located in the 1. climatic zone (Kołobrzeg)



B/C ratio in the moderate support scenario for hospitals with 51-200 number of beds located in the 1. climatic zone (Kołobrzeg)



B/C ratio in the business as usual scenario for hospitals with 51-200 number of beds located in the 1. climatic zone (Kołobrzeg)

To summarize, profitability in the bussiness as usal and moderate support is little. Only the strong support scenario shows an attractive value of the profitabily index.

The total potential primary energy savings are presented in the following table. Savings vary between the minimum, corresponding to the best net benefit/cost ratio in each cluster, and the maximum technically achievable.

Hospital type	Maximum PES	Best B/C net	PES for best B/C net	PE need	min PES	max PES
	%	-	%	kTOE	kTOE	kTOE
51-200 beds 1 c.z. - Kołobrzeg	20	1,86	10%	100	10,0	20,0
51-200 beds 2 c.z. - Wrocław	19	1,79	10%	10	1,0	2,0
51-200 beds 3 c.z. - Warszawa	18	1,76	9%	109	9,8	19,6
51-200 beds 3 c.z. - Kraków	18	1,76	9%	127	11,4	22,9
51-200 beds 5 c.z. - Suwałki	18	1,80	9%	115	10,3	20,7
201-500 beds 1 c.z. - Kołobrzeg	14	1,22	6%	50	3,0	6,9

Hospital type	Maximum PES	Best B/C net	PES for best B/C net	PE need	min PES	max PES
	%	-	%	kTOE	kTOE	kTOE
201-500 beds 2 c.z. - Wrocław	13	1,20	6%	70	4,2	9,1
201-500 beds 3 c.z. - Warszawa	13	1,20	6%	75	4,5	9,7
201-500 beds 3 c.z. - Kraków	13	1,20	6%	74	4,4	9,6
201-500 beds 5 c.z. - Suwałki	13	1,18	6%	66	4,0	8,6
501-800 beds 1 c.z. - Kołobrzeg	6	1,96	3%	278	8,4	16,7
501-800 beds 2 c.z. - Wrocław	6	1,86	3%	287	8,6	17,2
501-800 beds 3 c.z. - Warszawa	6	1,82	3%	310	9,3	18,6
501-800 beds 3 c.z. - Kraków	5	1,81	3%	366	11,0	18,3
501-800 beds 5 c.z. - Suwałki	5	1,84	3%	317	9,5	15,8
					109,4	**215,7**

It can be assumed that 10% penetration of micro-CHCP would cause savings in the range 10 – 20 kTOE.

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[1] GUS, Podstawowe dane z zakresu ochrony zdrowia w 2007 roku, Warszawa 2008

[2] GUS, Prognoza ludności na lata 2008-2035, Warszawa 2009

[3] GUS, Podstawowe dane z zakresu ochrony zdrowia w 2005 roku, Warszawa 2006

[4] Energy Regulatory Office, www.ure.gov.pl

[5] www.energia-elektryczna.pl

[6] Agnieszka Dobroczyńska, Anna Buńczyk, Anna Daniluk, Samer Masri, Ceny energii elektrycznej w Polsce: sytuacja 2005-2006 - [Sytuacja w elektroenergetyce I i II kwartał 2005-2006, ARE S.A.]

[7] Paweł Bogusławski, Taryfowanie ciepła – wymóg urzędniczy czy ekonomiczna konieczność, Biuletyn Urzędu Regulacji Energetyki, nr 6/2008

[8] Sprawozdanie z działalności Prezesa URE – 2004, Nr 3, May 2005

[9] Sprawozdanie z działalności Prezesa URE – 2005, Nr 3, May 2006

[10] Sprawozdanie z działalności Prezesa URE – 2006, Nr 3, May 2007

[11] Rozporządzenie Ministra Gospodarki z dnia 16 września 2007 r. w sprawie sposobu obliczania danych podanych we wniosku o wydanie świadectwa pochodzenia z kogeneracji oraz szczegółowego zakresu obowiązku uzyskania i przedstawienia do umorzenia tych

świadectw, uiszczania opłaty zastępczej i obowiązku potwierdzania danych dotyczących ilości energii elektrycznej wytworzonej w wysokosprawnej kogeneracji, Dz. U. Nr 185, poz. 1314

[12] Informacja 9/2008 w sprawie średnich cen sprzedaży energii elektrycznej wytworzonej w wysokosprawnej kogeneracji oraz na rynku konkurencyjnym za 2007 rok, www.ure.gov.pl

[13] Polish Power Exchange, www.polpx.pl

[14] Sprawozdanie z działalności Prezesa URE – 2007, Nr 3, May 2008

[15] http://epp.eurostat.ec.europa.eu

[16] Rozporządzenie Ministra Gospodarki z dnia 26 stycznia 2009 r. w sprawie udzielania pomocy publicznej na inwestycje w zakresie budowy lub przebudowy jednostek wysokosprawnego wytwarzania energii

[17] Rozporządzenie Rady Ministrów z dnia 5 maja 1998 r. w sprawie wysokości i sposobu pobierania przez Prezesa Urzędu Regulacji Energetyki corocznych opłat wnoszonych przez przedsiębiorstwa energetyczne, którym została udzielona koncesja

[18] www.mapaprzedsiebiorcy.pl

[19] www.ptpiree.pl/fundusze/index.php

The office sector in Switzerland

Introduction

For space conditioning, cooling often is the dominating factor in office buildings. Due to climate change and increased thermal comfort requirements, cooling becomes even more important (Frank, 2005). While passive methods have their limitations (Artmann, 2007), mechanical cooling leads to increased electricity demands and their respective peak load problems. Besides renewable energy technologies (solar cooling, PV), combined heating, cooling and power (CHCP) or polygeneration is another option for cooling without increasing the electricity demand.
The aim of this study is to evaluate the potential of polygeneration systems for energy savings and the environmental impact reduction in low energy office buildings in Switzerland.

The modeling tool

In the frame of the European project PolySMART, Empa developed an energy and environmental impact assessment tool for polygeneration systems. The CHCP system considered includes a cogeneration unit (CGU) and a thermally driven chiller (TDC), supplemented with a boiler and a mechanical chiller. The tool is mainly designed for office buildings; however, it could be used as well for other building types. It calculates the following impact key figures: primary energy savings, carbon dioxide equivalent savings and savings in terms of eco-indicator points. The latter consists of three midpoint indicators (ecosystem quality, human health and resource depletion). The weighting of these indicators can be specified by the user. In addition, the tool delivers CHCP system related key figures such as CGU operation hours or ratio electricity export to grid vs. electricity demand. CHCP system related inputs taken into account are thermal and electric efficiencies, minimal and maximal thermal power of CGU, and parasitic electrical demand of TDC. Building and occupants related inputs are floor area and hourly demand profiles per square meter for heat (total of space heating and hot water), cold and non-HVAC electric power. The tool was implemented in Excel, with calculations based upon hourly heating/cooling and electrical loads.

Performance assessment metrics

The energetic system performance is determined in terms of non-renewable primary energy (NRPE) demand, in comparison to the reference system, similar to the methodology outlined by Dorer and Weber, 2007. In addition, the greenhouse warming potential was calculated applying the GWP(100a) methodology (IPCC, 2001), and expressed in carbon dioxide equivalents emissions (CDE). The environmental performance was measured using the quantification system “Eco-indicator 99” with the three endpoint indicators “resource depletion*” (RD)*, “ecosystem quality” (EQ) and “human health” (HH). The environmental indicators were calculated on the basis of the NRPE demand. Relative savings were calculated in the same manner as the energy performance indicators, i.e. the same reference systems were used. The aggregation of the endpoint indicators into a total environmental impact indicator (Eco-Total) was made using equal weighting factors. Some of the results are shown by the mixing triangle diagram developed by Hofstetter, 1998, allowing a system comparison for all weighting combinations. Inventory data used for all environmental performance indicators has been the *Ecoinvent 2.0* database (Ecoinvent 2007). Nevertheless, customized inventory data was needed in this study as, for natural gas, the *Ecoinvent* database contains datasets referring either to heating value of the natural gas supplied or to the heat produced by the CGU. The former datasets do not include emissions due to natural gas combustion. The latter datasets are based on efficiencies of the CGU which were assumed in the process of building up the inventory data. As in this study varying values of CGU efficiencies have been used, a dataset for natural gas including combustion was required referring to the fuel’s heating value. This customized dataset was calculated by adding the fuel's impact prior to combustion and the impact of the combustion emissions. Herein the combustion data was taken from a data set for a state of the art gas boiler. Thus, due to the cleaner combustion in boilers compared to combustion in most of today available CHP systems, the environmental performance results obtained represent a potential benchmark for future systems with improved combustion.

The performance of building integrated polygeneration in terms of energy savings and environmental impact reduction are evaluated for small, well insulated office buildings by means of a simulation based case study.

The micro-polygeneration system assumed comprises a natural gas driven micro-cogeneration (CGU) unit, a thermally driven cooling (TDC) unit and a back-up boiler. A number of cases with different combinations of capacities and efficiencies of CGU and TDC unit are analyzed and compared to the reference system –which includes a gas boiler and grid electricity. The office building considered complies with advanced building standards. Cooling and heating is provided by thermo-active building systems (concrete core pipe systems). The building loads are determined as 1h-values with the whole-building simulation program TRNSYS, using standard occupancy and electric demand profiles specified by Swiss standards. Energy carriers are natural gas as fuel and grid electricity considering three different generation mixes: Swiss, European and combined cycle power plant.
The system performance is determined energetically in terms of non-renewable primary energy demand, and environmentally in terms of CO_2-equivalent reduction and the endpoint indicators according to Eco-Indicator 99 (resource depletion, ecosystem quality and human health). The calculations are based on the latest release of the internationally recognized LCA-inventory database *Ecoinvent*.

The current study focuses on a simple performance assessment assuming average efficiencies based on measured performance data or on manufacturer's data. The aim of the study is to get indications on the potential of energy savings and environmental impact reduction. Future work should focus on detailed modeling considering part load characteristics and control.

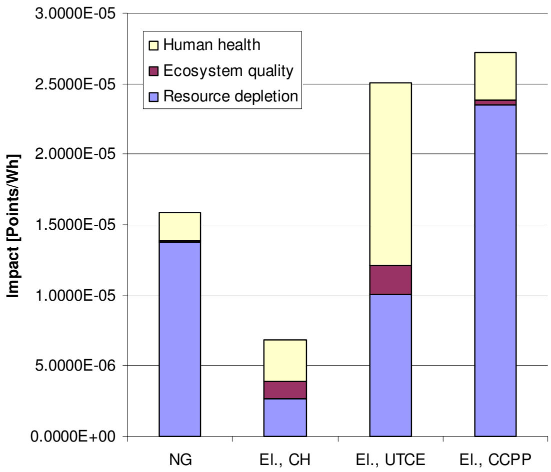


Figure 73 Endpoint indicators for natural gas and electricity mixes.

Polygeneration systems

Natural gas driven CGUs with thermal capacities in the range of 1 to 30 kWth and efficiencies (LHV) of 60% thermal and 30% electric for the standard case were assumed. The capacity of the TDC was assumed to fully comply with heat power supplied from the CGU. The standard COP for the TDC was 0.63, with variations from 0.55 to 0.95. For the CGU and TDC analyzed, average efficiencies based on measured performance data or on manufacturer's data were used. Several operation modes for heating and cooling demand driven operation and a modulation capacity within predefined power range were considered. A thermal efficiency of 0.98 for the gas boiler and a COP of 3.0 for the mechanical chiller were assumed. The locally generated electricity was either directly used or exported into the grid. The reference system for all cases comprises the gas boiler and the mechanical chiller, and grid electricity according to the selected mix.

Building

An office building complying with advanced building energy standards was used for the study (Table 47). Space cooling and heating are provided by a thermo-active building system (concrete core pipe system) (Lehmann et al., 2007). Ventilation was assumed to be thermally neutral. The assumed pattern of internal heat gains during the day are specified incorporating the three components, lighting, occupants and equipment using (i) standard full load values given in SIA 2024, and (ii) realistic simultaneity or utilization factor patterns (no occupancy on week-ends assumed).
Space heating and cooling loads were then determined as 1h-values for two types of room spaces (i.e., normal and corner rooms), using the whole building and plant simulation tool *TRNSYS* (TRNSYS, 2005), and then aggregated for the whole building by defining the number of spaces and floors, assuming similar conditions in the adjacent rooms. For the building size given in Table 47, the annual heating loads amount to 40MWh/a (16.6 kWh/m^2/a), cooling load to 46 MWh/a (19.1 kWh/m^2/a) and electric demand for office appliances and lighting to 44 MWh/a (18.4 kWh/m^2/a). Monthly average values are shown in Figure 74. In summer and winter, sun protection was activated for each façade separately, (i) upon direct solar incidence on the façade, or (ii) if the product global irradiation (on the façade) times the g-value of the glazing exceeds 90 W/m^2. Artificial lighting ranged from 25 to 100% according to considered illumination.

Table 47 Characteristics of considered office room types and building.

Room	
Space	
length	3.33 m
width,	6.00 m
height,	3.00 m
	20 m^2
Orientation	West (normal office) ; south and west (corner office)
Façade area/ glazed area	21/7.5 m^2 (per façade side for corner office)
Solar heat gain coefficient (g)	
- glazing alone	
- glazing with sun-shading	0.41 -
	0.08 -
U-value of façade	0.65 W/(m^2 K)
Internal heat gains	Standard values according (SIA 2024)
Building, number of	
Corner offices	4
Normal offices	8
Floors	10
Building	
Total floor area	2400 m^2

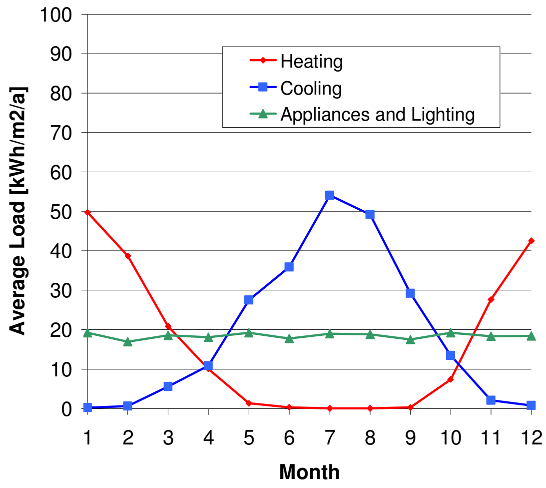


Figure 74 Simulated loads for the building analyzed.

Results

Sizing of the CHCP

One main factor influencing operation parameters was the size of the CGU (Figure 75). When varying the CGU size (quantified as maximal thermal output) from 1 to 30 kW, the total annual CGU operation time decreased from 89 to 27%. Assisted operation decreased in the same power range from 86 to 10%. With the exception of small power sizes cooling required higher assistance than heating.

During roughly 10% of the year, the CGU operated in the 'heating with CGU only' mode within a broad range of CGU sizes, for cooling the time percentage was more proportional to the CGU size, this 10% relative time value was only attained at CGU sizes towards 30 kW.

Electricity export occurred for CGUs of at least 5 kW and reached its maximum closely to 30 kW. CGUs located at the lower or upper end of the power range analyzed might be inappropriately sized considering economical aspects (initial costs versus benefit) and might therefore play a minor role in market.

Operation without a TDC unit (cogeneration) resulted in substantially lower CGU operation time and electricity export (see 2nd diagram in Figure 75).

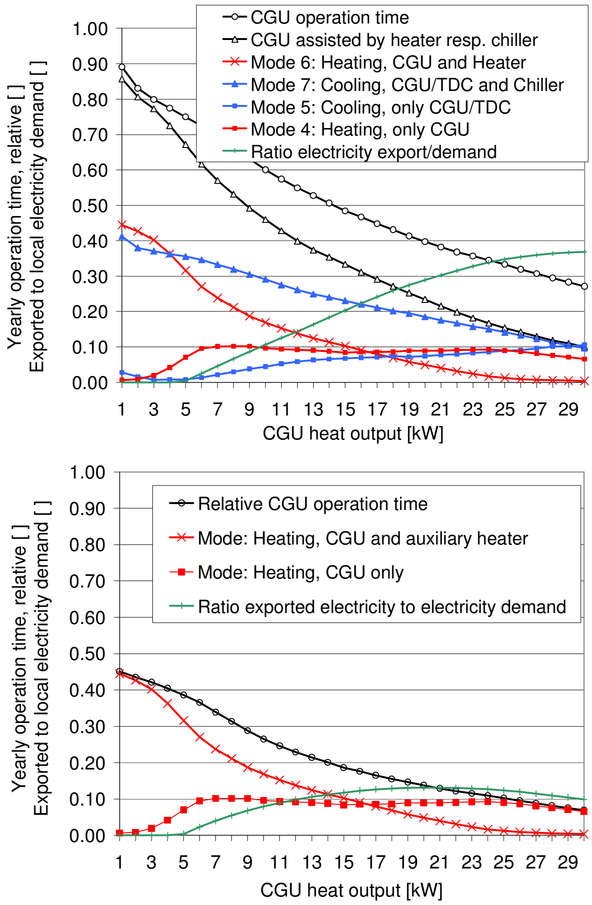


Figure 75 Operation indicators for polygeneration (1st diagram) and cogeneration (2nd diagram).

Performance of CHCP

The performance of the CHCP system was analyzed for different electricity mixes assuming a CGU size of 15 kW maximum heating output, and compared to the reference system (gas boiler and chiller only).
NRPE demand results were comparable to the reference for the Swiss mix, 12% lower for the UCTE mix and 12% higher for the CCPP.
Emitted Greenhouse gas equivalents are substantially higher than for the reference with Swiss electricity mix.
Considering all environmental impacts, polygeneration showed a high total impact, up to the double compared to the reference in the Swiss mix case with equally weighted endpoint indicators. This high impact is mainly due to the endpoint indicators “ecosystem quality” and “human health” whereas the indicator “resource depletion” has an attenuating effect. The performance of the cogeneration system shows a similar picture but with minor variations to the reference (2nd diagram in Figure 76).

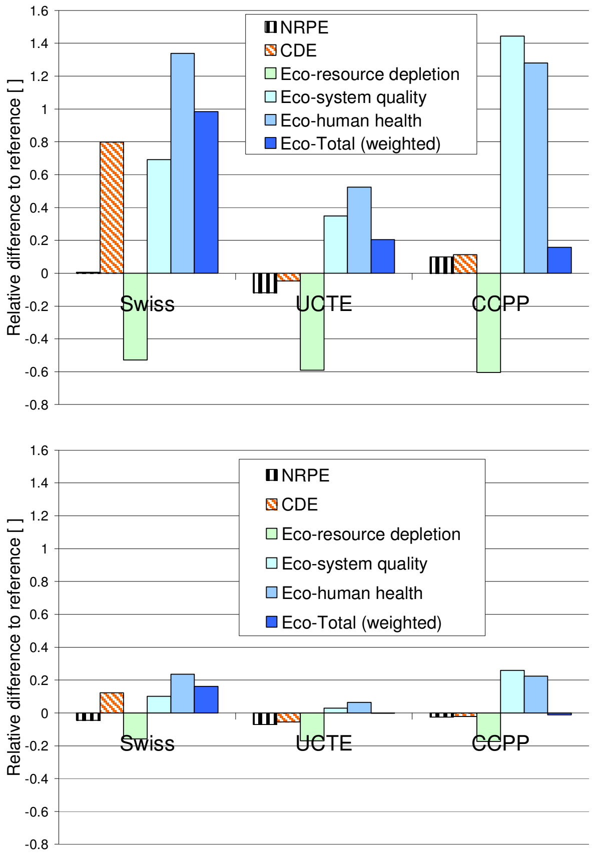
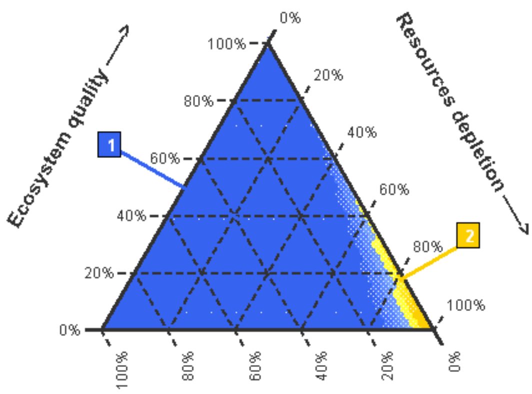


Figure 76 Performance results for different electricity mixes considering polygeneration (1st diagram) and cogeneration (2nd diagram).

The total environmental impact is based on weighting assumptions for the three endpoint indicators. Figure 77 shows for each possible weighting whether the reference system or the polygeneration system has a better total performance.
For the Swiss mix for most possible weightings the reference system performed better, for UCTE and CCPP the reference system was also performing better for a wide range of weightings.



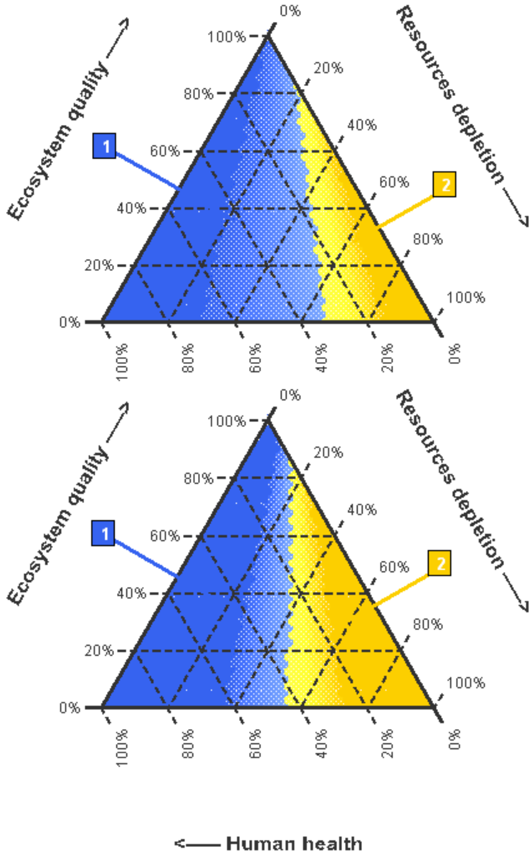
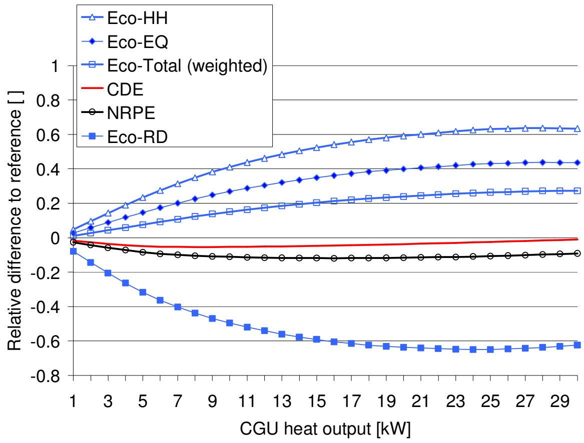


Figure 77 Total environmental performance for different electricity mixes (1st diagram: Swiss mix, 2nd diagram: UCTE mix, 3rd diagram: CCPP grid electricity). System 1 refers to the reference values, system 2 to polygeneration. Fully colored area represents a performance of at least 35% better than the other system.

Sensitivity on sizing and efficiencies

Figure 78 to Figure 81 show the system performance as a function of the CGU size and the system efficiencies, as relative difference values to the reference case. Positive relative differences indicate a higher impact value for the polygeneration or cogeneration system, compared to the reference system.
Figure 78 shows the system performance as a function of the CGU size. Within a broad power range the performance indicators NRPE, CDE and Eco-Total showed a rather flat curve. Thus the sizing of CHCP is not very critical in terms of these indicators. This is particularly valid for the case of cogeneration.



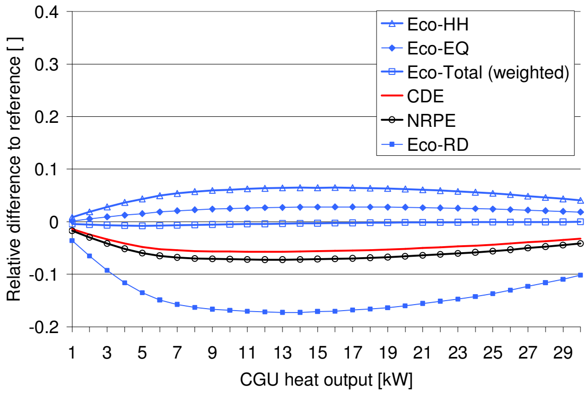


Figure 78 Performance results as a function of CGU size, UCTE electricity mix, for polygeneration (1st diagram) and cogeneration (2nd diagram)

Figure 79 shows polygeneration performance results as a function of the electrical efficiency of the CGU. NRPE performance increased with electrical efficiency for all electricity mixes. Advantageous results compared to the reference were obtained for efficiencies equal or higher than 31% for the Swiss mix, than 17% for the UCTE mix and than 46% for electricity generated by combined cycle power plants.

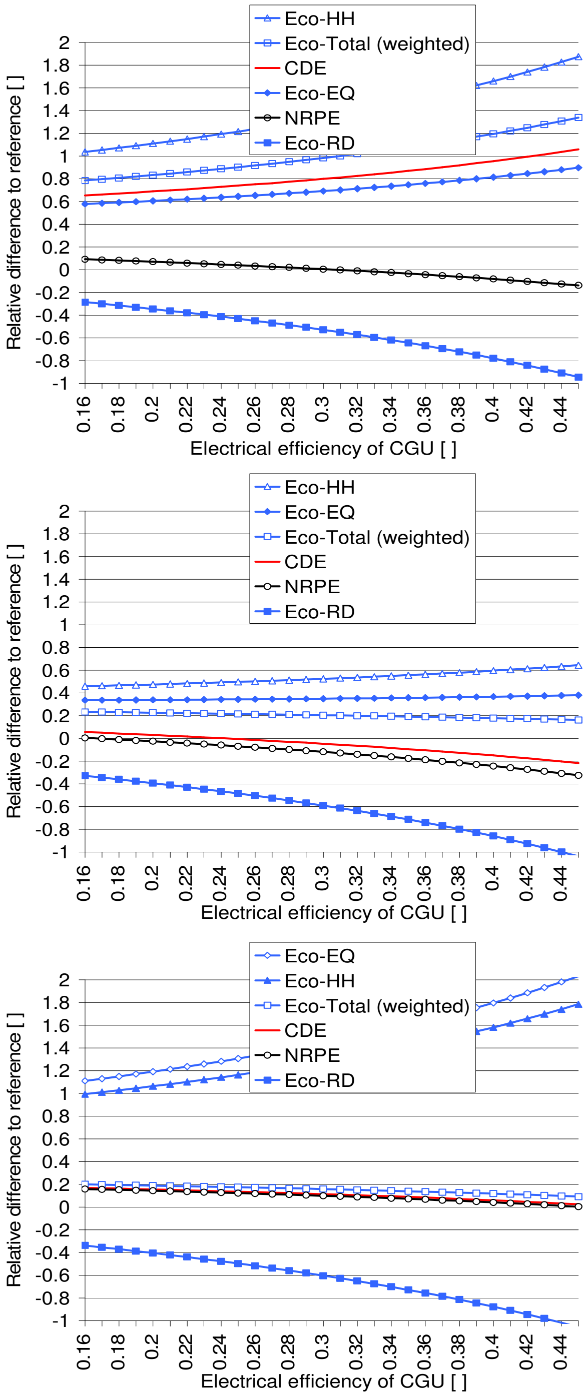


Figure 79 Polygeneration performance indicators relative to reference as a function of the electrical efficiency (LHV) of CGU for different electricity mixes (1st diagram: Swiss, 2nd diagram: UCTE, 3rd diagram: CCPP). The results correspond to CGU size of 15 kW (heat output). The total CGU efficiency (LHV) was kept constant at 0.9.

The performance in terms of CDE decreased with electrical efficiency both for the UCTE and CCPP mixes but increased for the Swiss mix. This also holds for the total environmental performance. However, total environmental performance was worse than the reference value for all three electricity mixes and the whole investigated efficiency range. Further, it can be noticed that the relationships between performances in terms of NRPE, CDE and Eco-Total depend on the electrical efficiency of the CGU.
For a heat driven operation mode, as chosen in this study, the annual operation time is independent of the thermal electrical efficiency of the CGU. However, the TDC efficiency influenced the performance indicators. The variation was higher for the Eco-Total values than

for the NRPE and CDE values. Even for high efficiency values the Eco-Total performance for polygeneration was significantly lower than for the reference system.

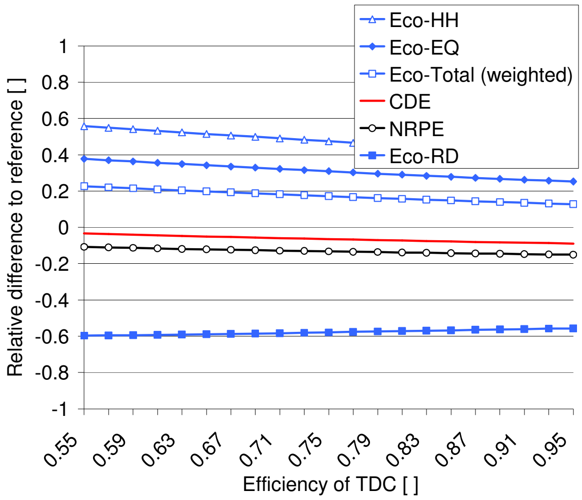


Figure 80 Polygeneration performance indicators relative to reference for UCTE electricity mix. The results correspond to a CGU size of 15 kW (heat output)

In the case that only NRPE and CDE performance indicators ar considered, significant reductions can be observed for the UCTE mix. This is illustrated in Figure 80. The electrical efficiency of the CGU yielded a much greater influence than the efficiency of the TDC unit (Figure 81).

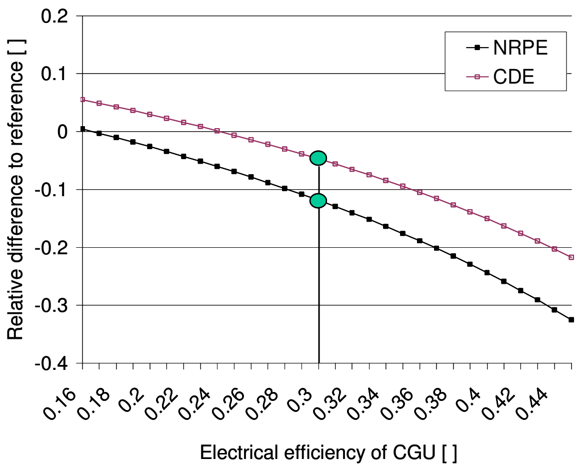


Figure 81 Polygeneration NRPE and CDE performance indicators relative to reference as a function of CGU electrical efficiency (LHV), for UCTE electricity mix. The results correspond to CGU size of 15 kW (heat output) and a TDC efficiency of 63%.

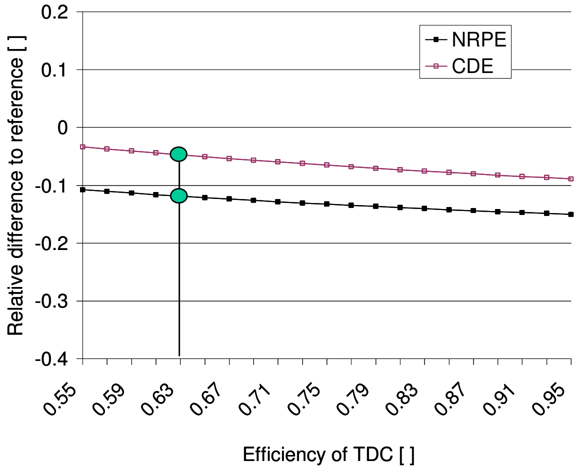


Figure 82 Polygeneration NRPE and CDE performance indicators relative to reference as a function of TDC electrical efficiency, for UCTE electricity mix. The results correspond to CGU size of 15 kW (heat output) with an electrical efficiency of 30% (LHV).

Conclusions

A simple performance assessment of polygeneration systems in an office building in terms of energetic and environmental indicators (in comparison to systems with gas boiler and mechanical cooling), and in terms of operational aspects was realized.
The study shows that the operation time of the CGU unit can be significantly increased when coupled to a TDC unit.
In terms of non-renewable primary energy equivalents, a reduction was found in all polygeneration cases with CGU electrical efficiencies (LHV) equal or higher than 17% for the UCTE mix, higher than 46% for electricity generated by combined cycle power plants, and higher than 31% for the Swiss mix.
NRPE reductions were much more influenced by the electrical efficiency of the CGU than by the efficiency of the TDC unit.
Carbon dioxide emissions were only reduced by polygeneration in the cases of UCTE electricity mix and for CGU electrical efficiencies (LHV) equal or higher than 25%.
The findings for the environmental performance of polygeneration are based on equally weighted Eco-indicator 99 endpoint indicators. Values for the three endpoint indicators show a different picture. Thus, a different weighting for each of the endpoint indicators would lead to a contrary finding, e.g. if only human health impacts would be considered.
With equally weighted endpoint indicators, the total environmental performance was below the reference for all three electricity mixes and for the whole efficiency range investigated, even though advantageous assumptions were made concerning combustion emissions.
Future work should focus on detailed modeling considering part load characteristics, heat/cold storage capacity and control.

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Market opportunities and challenges

Prospective customers

In light of the presented case studies, micro-CHCP is likely to find application where the electricity demand is relatively high as compared to the heating and cooling demand, and the electricity base load is such that the electricity exported to the grid is limited. Moreover, suited applications must be characterized by smooth profiles of the heating and cooling demand, in order to maximize the operation hours of the micro-CHCP system with the minimum possible system capacity. Since the marginal energy and financial savings are more attractive for heating than for cooling, a convenient application should have a larger heating than cooling demand.
Finally, the micro-CHCP should cover only a limited fraction -of about 50%- of the heating and cooling demand so that the investment becomes economical. As such, the micro-CHCP system must be complemented by auxiliary heaters and coolers.

According to aforementioned reasons, prospective customers could be preferably found among:

- Medium size hotels (< 200 rooms)
- Small hospitals (< 200 beds)
- Office buildings (< 4000 m^2)
- Small industries
- Small supermarkets

It is important to underline that, due to emergency and safety reasons, the possibility provided by the CHCP plant to self-generate electricity constitutes an added value for this type of customers.

Generally speaking, applications in the households sector appear more difficult at the present stage of technology. In single family houses, the benefit to cost ratio of micro-CHCP is seldom attractive because the investment is relatively higher, a large part of the self-generated electricity is injected to the grid, the driving thermal load is discontinuous, relatively high costs must be sustained for the balance of the plant (storages, auxiliaries) and the room needed for heating and cooling storages might not be available. In multi-family houses, the overall thermal and electric load would be such to justify the investment. However, centralized heating and cooling distribution systems are not always present in multi-family houses and the individual metering of heating, cooling and electricity for each dwelling represents an additional bureaucratic burden.

The hotel industry in Europe

The size of the hotel industry in Europe is roughly estimated in more than 110,000 hotels in the EU15, with an average hotel size of 35 rooms (Slattery P., 2003). When only the main hotel chains are considered, the figures become more precise, although chain hotels represent only 10% of the total sector. There exist about 280 companies with more than four hotels each, and nearly 400 hotel brands allover Europe. However, the market is not equally divided among hotel chains: the largest 28 companies detain nearly two thirds of the total rooms whereas the smallest 28 companies only the 0.5%. More than 100 companies have portfolios of less than 1,000 rooms, an average of 6 hotels each and 62 rooms per hotel, limited brand infrastructure and cash flow; all of which results in limited potential for the growth of such companies.
A first classification of chain hotels is provided in terms of market level: the majority of the hotel sector capacity is concentrated in the mid-market, with about 45% of total rooms and an average size of 133 rooms:

Market level	Number of hotels	Average rooms per hotel	Rooms %
Deluxe	159	153	1.9%
Up-Market	1919	187	28.1%
Mid-Market	4332	133	45.1%
Economy	3196	76	19.0%
Budget	1069	70	5.9%

Hotels are further classified according to the range of facilities they provide. The following classification is reported:
- Resort (bar, restaurants, conference rooms, indoor and outdoor leisure)
- Full featured (bar, restaurants, conference rooms, indoor or outdoor leisure)
- Basic featured (bar, restaurants)
- Limited featured (restaurant)
- Rooms only

Hotel facilities	Number of hotels	Average rooms per hotel	Rooms %
Resort	786	220	13.5%
Full featured	2947	177	40.8%
Basic featured	3014	95	22.4%
Limited featured	2259	82	14.5%
Rooms only	1669	67	8.7%

According to the mentioned classification, about 40% of the chain hotels provide full feature facilities.

Finally, hotels can be classified according to their size or number of rooms:

Hotel size	Number of hotels	Average size	Rooms %
More than 1,000 rooms	13	1124	1.1%
200 - 999 rooms	1619	314	39.8%
50 - 199 rooms	6700	100	52.5%
17 - 49 rooms	2163	38	6.4%
Less than 17 rooms	180	11	0.2%

The available statistics show that micro-CHCP has the potential to find application in about 50% of the chain hotels in EU15, for a total of nearly 7,000 installations. Considering the totality of the hotel sectors, the number of suitable installations can likely increase by a factor of 10, amounting to 70,000.

The hospital sector in Europe

Hospitals are institutions principally engaged in providing medical, diagnostics and treatment services including the specialized accomodation services required by the inpatients. Hospitals may also provide outpatient health services as a secondary activity. Statistics on the hospital sectors are not easy to interpret due to the large variety of institutions that can be classified as hospitals. For example, health institutions include acute (short-stay) hospitals, primary health care units, psychiatric hospitals, as well as nursing and elderly homes. Moreover, the hospital facilities may be distributed among different buildings, a common situation for large hospitals providing more than 1,000 beds, and hospitals on different sites may merge into one organizational structure. Some national statistics count hospitals trusts (e.g. in the United Kingdom) instead of single sites, others count multi-site hospitals separately although they function as a single organization.

Data on hospitals and beds for different countries available from the WHO European Health for All Database (WHO, 2008) are shown hereafter.

	Number of hospitals	Number of beds	Average size (beds)
Austria	270	64,556	239
Czech Republic	345	83,667	243
Germany	3,359	683,484	203
Italy	1,283	232,168	181
Netherlands	190	78,764	415
Poland	792	196,828	249
Portugal	204	36,563	179
Spain	746	146,202	196
Sweden	81	46,177	570
Switzerland	337	41,196	122

Although the information is too aggregate to be of practical use, a first outlook can be derived about the average hospital size, which ranges from 122 beds (Switzerland) to 570 beds (Sweden). More precise data on the hospitals building stock can be found in national statistics.

Concerning the Italian public health sector, about 70% of the institutions fall in the category of hospitals with less than 400 beds and it can be assumed that about 50% of the institutions have less than 200 beds. The estimate needs to be conservative, since the private sector is most likely characterized by small health care units.

Hospital size	Institutions	Share %
Less than 120 beds	201	31%
120 - 400 beds	273	42%
400 - 600 beds	80	12%
600 - 800 beds	34	5%
800 - 1500 beds	56	9%
More than 1500 beds	10	1%

Similarly to Italy, more than 60% of Austrian hospitals have less then 200 beds, and nearly the totality of private hospitals are small units.

Hospital size	Public institutions	Private institutions	Total	Share %
Less than 200 beds	52	115	167	61%
200 - 500 beds	61	14	75	28%
500 - 1000 beds	18	3	21	8%
More than 1000 beds	8	1	9	3%

Poland is characterized by a large share of small health care units with less than 50 beds. The total number of hospitals with less than 200 beds is estimated in about 630 units.

Hospital size	Institutions	Share %
Less than 50 beds	396	50%
50 - 200	238	30%
200 - 500	111	14%
500 - 800	32	4%

More than 800 beds	16	2%

On the basis of the collected information, a reasonable estimate of suitable micro-CHCP installations in the considered European countries must be in a range from 4,000 to 6,000 units.

Barriers to diffusion

Air quality

One of the main concerns about micro-CHP is the possible impact on air quality. Although micro-CHCP can provide savings of primary energy and the associated CO_2 emissions, fuel combustion generates several types of hazardous emissions which deserve special attention, including:
- carbon monoxide (CO)
- nitrogen oxides (NOx, e.g. NO, NO_2)
- sulfur oxides (SOx)
- particulate matter (PM, e.g. PM10, PM2.5, PM1)
- hydrocarbons (HC, e.g. benzene)

Among the different emission sources, heating systems alone are said to contribute to the total NOx emissions of urban areas in a share variable from 20 to 40%. Consequently, the EU regulation has imposed severe restrictions on the NOx emissions of gas boilers. Nowdays, eco-labelled gas fired boilers in the range below 70 kWt have reached low NOx and CO emission levels, although some concerns exist about the effectively emitted quantity of pollutants during startups, which occur frequently when a heat storage is not installed.

Internal combustion engines are traditionally not the best in terms of NOx emissions, because of the high combustion temperature which is the primary cause of the NOx formation. Newly generated lean-burn engines can achieve both low NOx emissions and high efficiency by increasing the air to fuel ratio in the combustion mix. In order to bring down the flue gases CO and HC concentration, an emission control device (i.e. catalytic converter) is usually recommended.

Stirling engines and microturbines generate NOx emissions in concentrations comparable to those of the most efficient gas boilers. However, their CO emissions can be considerably higher than those of the best gas boilers.

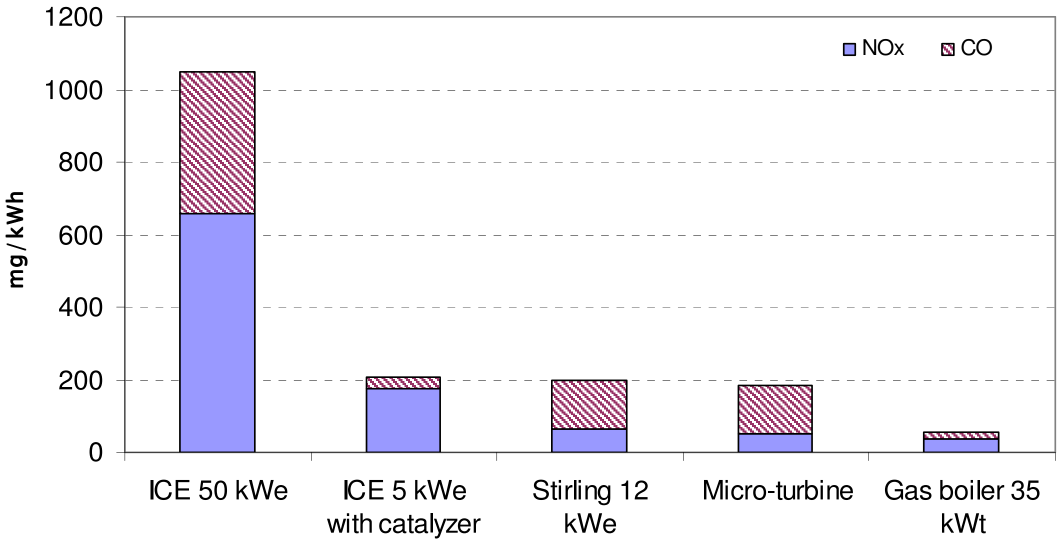

Figure 83 Example values for NOx and CO emissions (mg / kWh of fuel input) of several gas fired micro-CHP technologies, compared to that of efficient condensing gas boilers.

The Stirling engine can be also fuelled by solid biomass. Although biomass fuels such as pellets or wood are CO_2 neutral, concerns exist about the production of fine dusts associated to biomass combustion. Recent advances in the pellet burner technology have lead to a massive reduction of fine dusts emissions. Against fine dusts emissions of about 350 mg/kWh from the old logwood boilers, emissions from newly developed pellet burners can be as low as 30 mg/kWh. By no doubt, pellet technology has the potential to reduce emissions when compared to other biomass technologies. However, it is argued that, when replacing gas boilers, the pellet technology can lead to the opposite effect. This fact, together with the supplying, storage and manual operation requirement, could not encourage the utilization of biomass in small scale systems within high density population urban areas.

In respect to the fine dust regulations, countries like Poland, Italy and Czech Republic have already exceeded the limiting value of exposure to particulate matter in urban areas, set equal to 40 $\mu g/m^3$. This may constitute a barrier to the penetration of distributed generation from fuel combustion in the urban context for such countries.

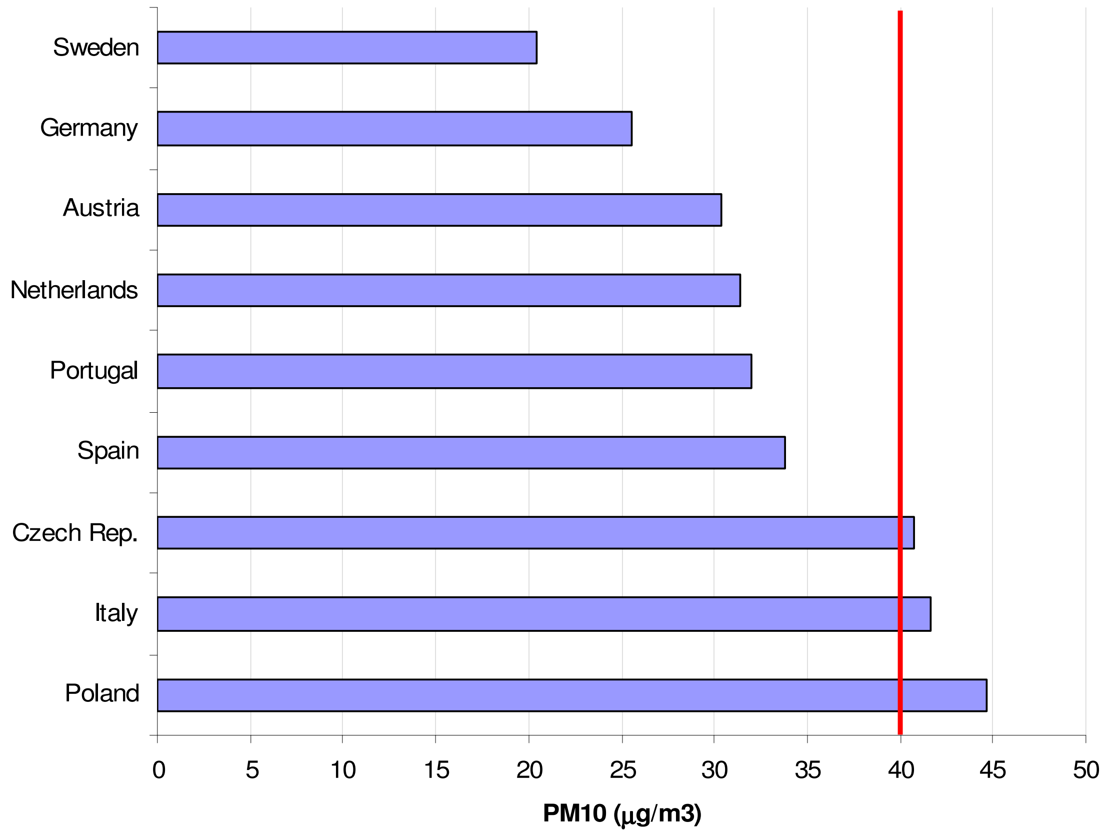

Figure 84 Urban population exposure to air pollution by particulate matter. Source: Eurostat, 2006.

Besides the emission issue, micro-CHPs are considered more hazardous than gas boilers, so that stricter safety measures apply. For example, in Italy a cogeneration unit above 25 kW_e is subject to fire prevention safety rules, though the same would not apply to gas boilers of thermal capacity lower than 113 kW_t.

Another aspect is the cost of administrative tasks, which are made necessary by the fiscal legislation in order to qualify for incentives. For example, in Italy tax breaks can apply to natural gas used in CHP. However, the CHP must prove to be highly efficient, being it required to keep a record of the amount of fuel used and one of the electricity generated. Moreover, taxes are paid over electricity generation and a dedicated electricity counter might be requested due to fiscal reasons.
A similar situation occurs in many other countries such as Portugal, Poland and Spain. On the contrary, grid connection and administrative effort is relatively low in Germany for CHP

units below 50 MWe. When the CHP unit is installed, the unit must be announced and certified by BAFA (Bundesamt für Wirtschaft und Ausfuhrkontrolle). The energy supplier is then forced to connect the unit to the grid and to buy the energy generated in excess. For the abovementioned reasons, it is believed that a CE certification of CHP and TDC units and simplified electricity billing rules can significantly contribute to the reduction of the installation and operational costs of micro-CHCP.

Electricity market

The volatility of energy prices is one big concern, as the profitability of micro-CHCP depends largely on the spark spread of the utilized fuel. In a climate of rapid changes and liberalized markets, energy prices are not easily predictable and only assumptions on future scenarios can be made. In particular,

- Liberalization of the energy sector should create better conditions for the final users. Consequently, customers are likely to shift from the regulated market to the non-regulated market in order to obtain more competitive energy prices as compared to the current situation;
- Energy prices in the non-regulated market are difficult to predict and vary from place to place, depending on the local utility;
- Variable tariff plans, more expensive during daytime and less expensive at nighttime, makes difficult the evaluation of the average energy price;
- Feed-in tariffs are generally much lower than electricity peak purchase prices. This fact penalizes grid-connected micro plants, especially when their electricity surplus is generated during daytime peak hours.

The effect of little variation in electricity and fuel escalation rate have a large impact on spark spread and, by consequence, on the gross margin of micro-CHCP. For instance, assuming electricity prices increase according to a fixed escalation rate, a little variation on the escalation rate for would generate very different results over a useful life period of 15 years.

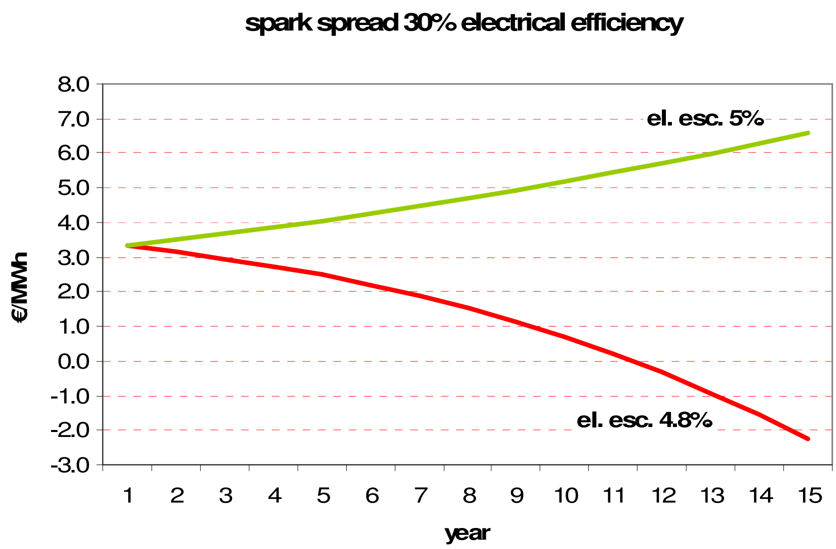

Figure 85: Spark spread over a useful life of 15 years, assuming h_{el}=0.3, fixed escalation rates for gas (e_{gas}=5%) and slightly different escalation rates for electricity (e_{el}=4.8% and 5%)

Indeed, some correlation exists between fuel and electricity prices in a same country. Taking year 2004 as a base year, the historical series of electricity and gas prices show that this correlation was strong in the last few years (see **Figure 86**). Large differences in the incremental variation of the electricity price per unit increment of gas price exist across countries: values like 2.13 in Italy and 2.4 in Netherlands have contributed to the positve marginality of micro-CHCP is such countries, whereas little increment ratios like 0.98 in Germany and 1.24 in Spain have determined a loss in marginality in the recent years.

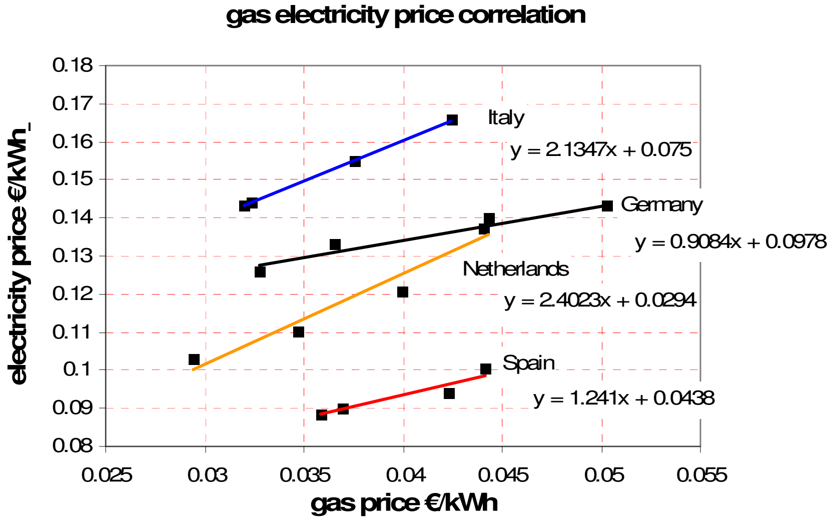

Figure 86: Correlation between gas and electricity price for some EU countries. Source: Eurostat, 2007 (price net of taxation).

In the theoretical evaluation of primary energy savings, the PRF of electricity plays a crucial role. On this regard, the average fossil fuel thermoelectric efficiency has been used in this study. However, it is unlikely that PRF will not vary in the medium term, due to the progressive replacement of old and less efficient power plants by new efficient CCGT power plants, as it has been the case in Italy.

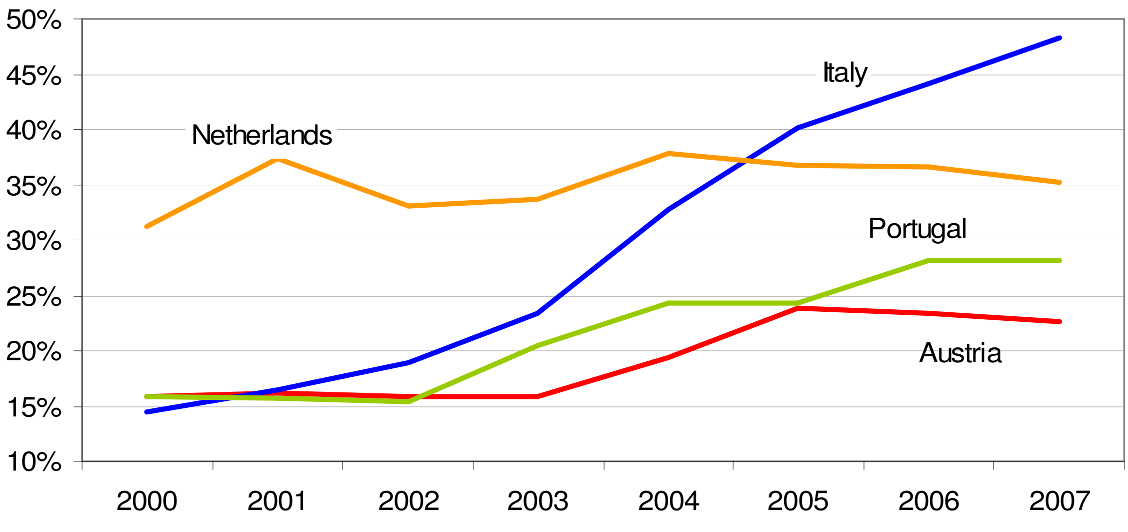

Figure 87: Share of CCGT over total thermal power plants installed capacity for some EU countries. Source: Eurostat b, 2007.

Moreover, the PRF of the marginal electricity, i.e. the electricity replaced with the diffusion of micro-CHCP, will depend also on the dispatching priority to the grid. Micro-CHCP could have in the near future the positive effect of decreasing the peak electricity for the two-fold reason that, in summer, some electricity driven cooling would be replaced by some thermally driven cooling and, at daytime, the micro-CHCP electricity surplus would be fed into the grid. As long as peak load power plants, such as turbogas and hydro pumped storages, are not very efficient, primary energy savings would be obtained more easily. However, as micro-

CHCP penetration increases, the operation hours of mid merit power plants could also be marginally affected. As electricity market liberalization is attracting more and more investments in the mid term plants field, and the CCGT is the standard for what regards mid-merit gas fired plants, at a certain stage penetration could suffer from negative primary energy savings as compared to separate production.

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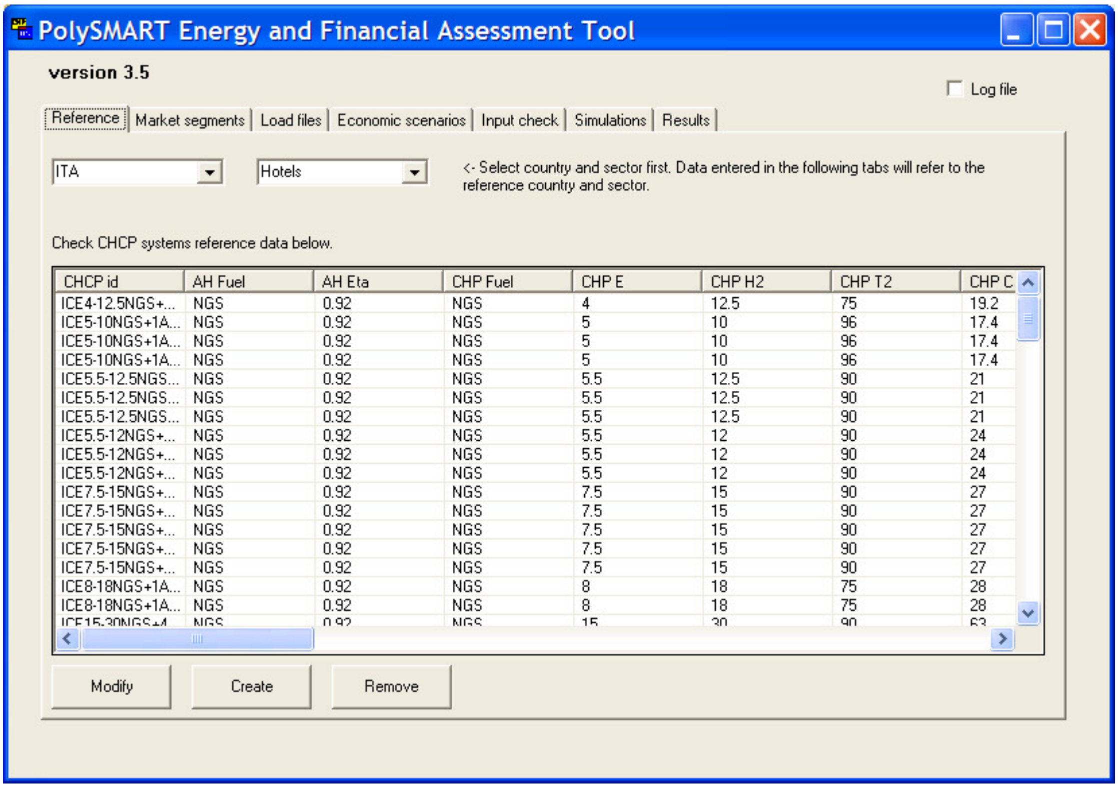
Appendix

Polysmart Energy and Financial Simulation tool

The purpose of the micro-CHCP feasibility tool is to perform simplified energy and economic simulations in order to assess the energy and financial savings potential of micro-CHCP. Both technical and cost parameters of several micro-CHCP systems are provided within the tool. Energy simulations are performed on the basis of the hourly load files, which need to include ambient temperature and humidity, heating demand, domestic hot water demand, cooling demand and electricity demand. By introducing market information such as energy prices and incentives for three pre-defined scenarios (optimistic, average and pessimistic), the tool also performs a simplified scenario analysis providing financial indicators like NPV, payback time and B/C ratio.

Main panel

The main panel consists of 7 datasheets: Reference, Market segments, Load files, Economic scenarios, Input check, Simulations and Results.



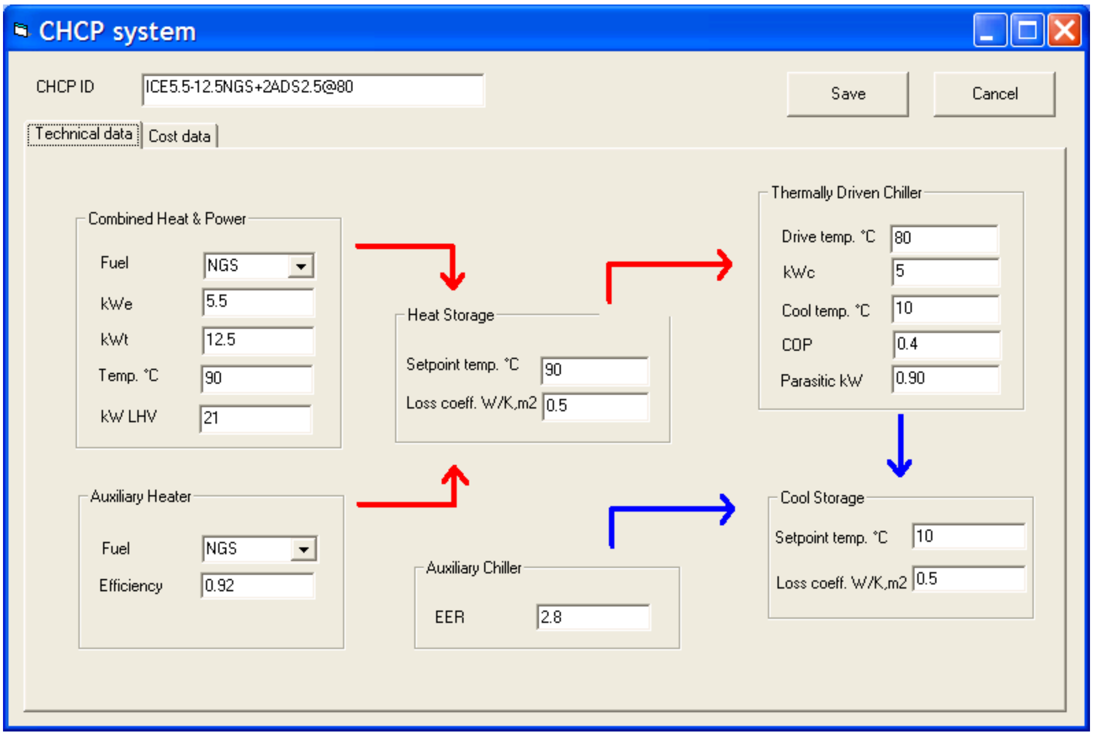
Reference datasheet

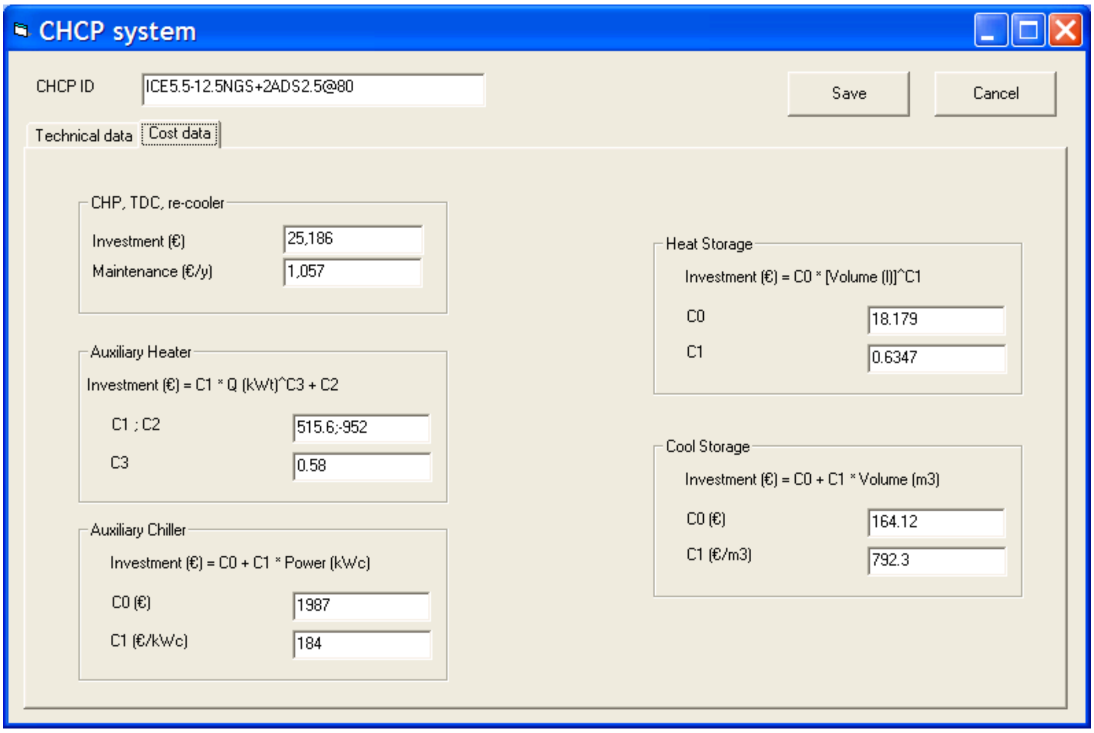
The reference technical and cost parameters of the CHCP systems are managed through the reference datasheet.

Nomenclature

AH = Auxiliary Heater
AC = Auxiliary Cooler
CHP = Cogenerator
CS = Cold Water Storage
CU = Cooling Unit
HS = Heat Water Storage

TDC = Thermally Driven Chiller

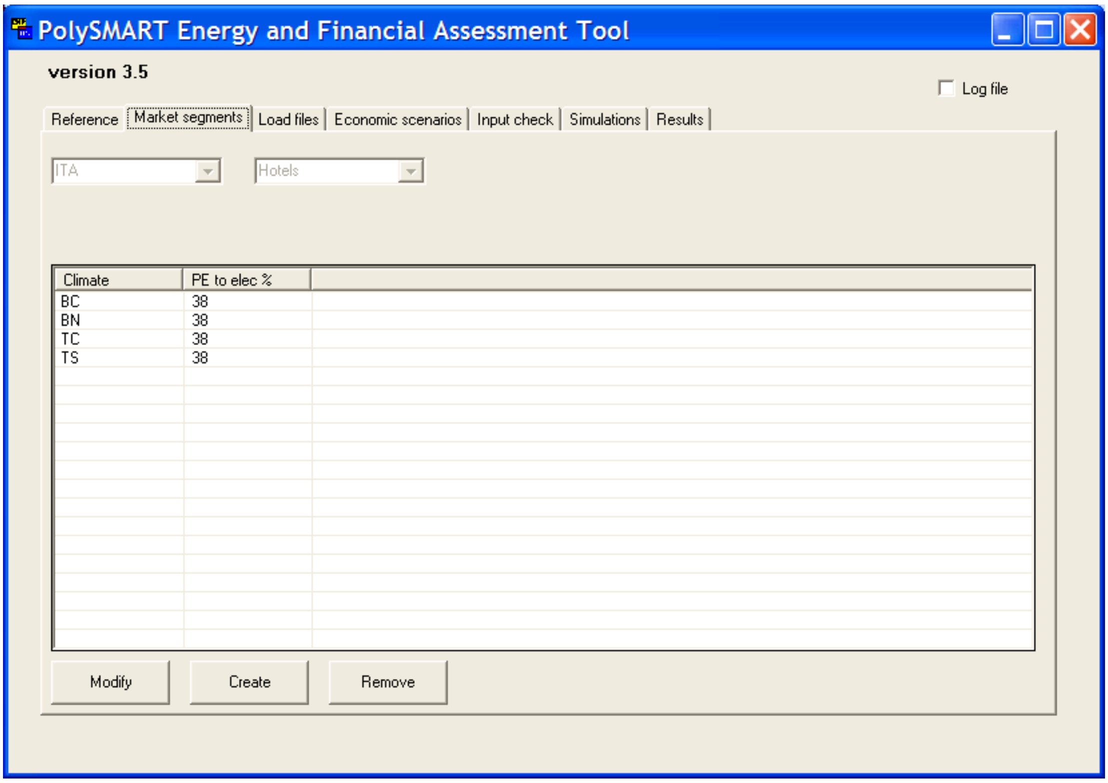




Market segment datasheet

The User may enter the following information:

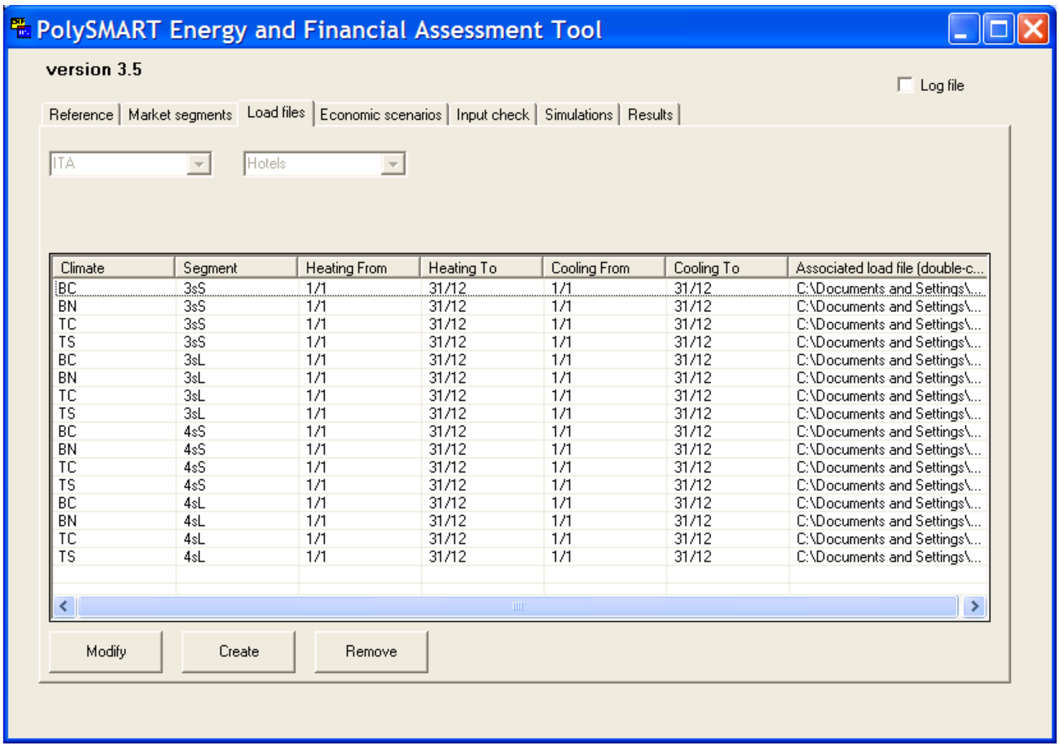
- Climate: the code of climatic zone (e.g. A, B, C, D)
- PE to elec % : primary energy to electricity conversion factor, in percentage, equivalent to $1/PRF_{el}$



Load files datasheet

The load file datasheet allows the User to combine climate and segments into clusters and to enter information about the associated load profile, including:

- Climate: e.g. A, B, C, D as
- Segment: e.g. multi family house, 3 star hotel,
- Heating: heating season from - to date
- Cooling: cooling season from - to date
- Associated load file: name of the load file.



Economic scenarios datasheet

The Economic scenarios datasheet allows the User to enter the energy price and financial condition parameters, including VAT, useful life and discount rate.

Three scenarios are to be defined. For each scenario, the following data are requested:

- Fee €: the CHP connection fee, fixed cost, paid once
- Fee €/kW: the CHP connection fee, cost per kWe installed, paid once
- Subsidy %: percentage of the capital cost covered by the subsidy
- Max subsidy €: maximum subsidy on capital cost
- Yearly Fee: €, annually payed fee

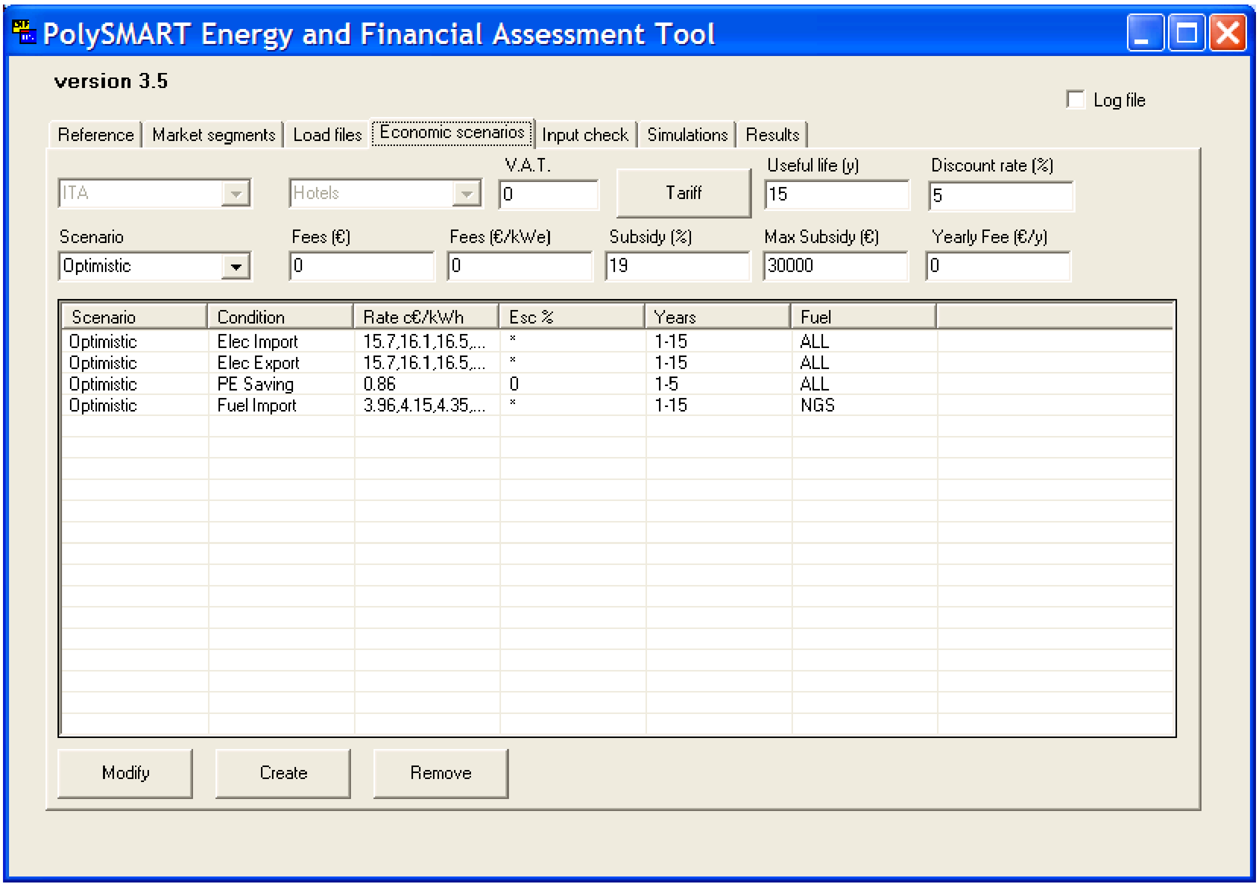
Moreover, rates must be entered. Rates are the conditions which turn a material fact into a financial fact. For instance, the cost of natural gas is the term which turns an import of gas into an expense. Similarly, the white certificate price is the term which turns primary energy savings into revenues.

In the condition form, the following inputs are entered:

- Condition: the condition type, i.e. "Elec. Import", "Elec. Export", "Elec. Gen", "PE Saving", "Fuel Import"
- Rate c€/kWh: the rate (e.g. price, cost, discount) in c€ per kWh of the energy type defined in the condition.
- Esc %: the escalation percentage above inflation
- Years: range of validity in the format y0-y1 where y0 and y1 are integers
- Fuel: the fuel used by the CHP for which the condition applies (any is allowed)

Only pre-defined conditions may be entered:

- "Elec. Import": import of electricity, for which an expense is incurred;
- "Elec. Export": export of electricity, for which revenues are earned.It is possible to enter the tariff plan in the Tariff window;
- "Elec. Gen": generation of electricity, for which revenues can be earned, typically green certificates but also tax deductions from the fuel cost;
- "PE Saving": primary energy savings, for which revenues can be earned (the rate applies to the primary energy saved according to the reference conventional system);
- "Fuel Import": import of fuel, for which an expense is incurred.



Input check datasheet

The "Input check" performs the necessary data integrity control before allowing the user to run a simulation. In case of error, a message is displayed and simulations cannot be performed until all inputs are correct.

Simulations datasheet

When the "Simulations" tab is pressed, the simulation is started and calcualation progress can be monitored. The simulation ends when all load files have been processed.

Results datasheet

The simultion results consit in a summary table and several charts. The summary contains for each load file, the following data:

Technical best

- CHCP Id: the CHCP identifier of the system which performs best under the technical perspective, i.e. which guarantees highest primary energy savings
- FLOH CHP: full load operating hours of the CHP
- FLOH TDC: full load operating hours of the TDC
- PES kWh: primary energy savings in kWh
- PES %: percentage of primary energy savings over total primary energy consumption of the reference conventional system

Economic best

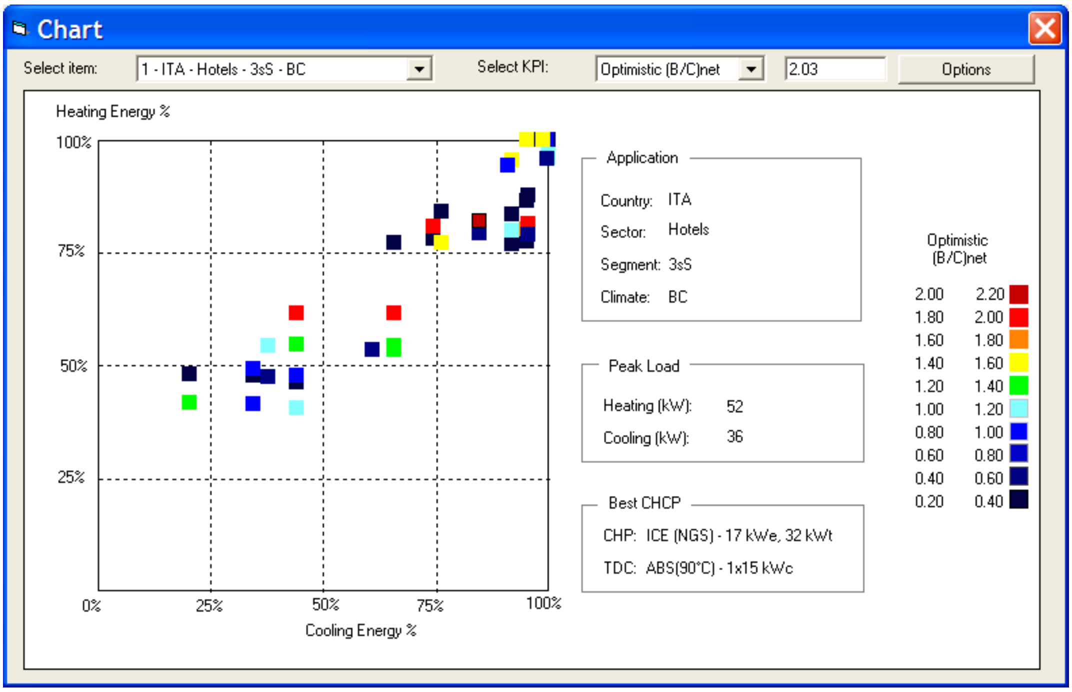
- CHCP Id: the CHCO identifier of the system which performs best under the economic perspective, i.e. which guarantees the shortest payback time
- Investment: the investment cost of the economic best CHCP system

Optimistic scenario
- NPV: Net Present Value for the CHCP system as compared to the reference conventional case, 20 years useful life and 5% discount rate, under the Optimistic scenario
- Payback: Payback time for the CHCP system as compared to the reference conventional case, 5% discount rate, under the Optimistic scenario

Average scenario
- NPV: Net Present Value for the CHCP system as compared to the reference conventional case, 20 years useful life and 5% discount rate, under the Average scenario
- Payback: Payback time for the CHCP system as compared to the reference conventional case, 5% discount rate, under the Average scenario

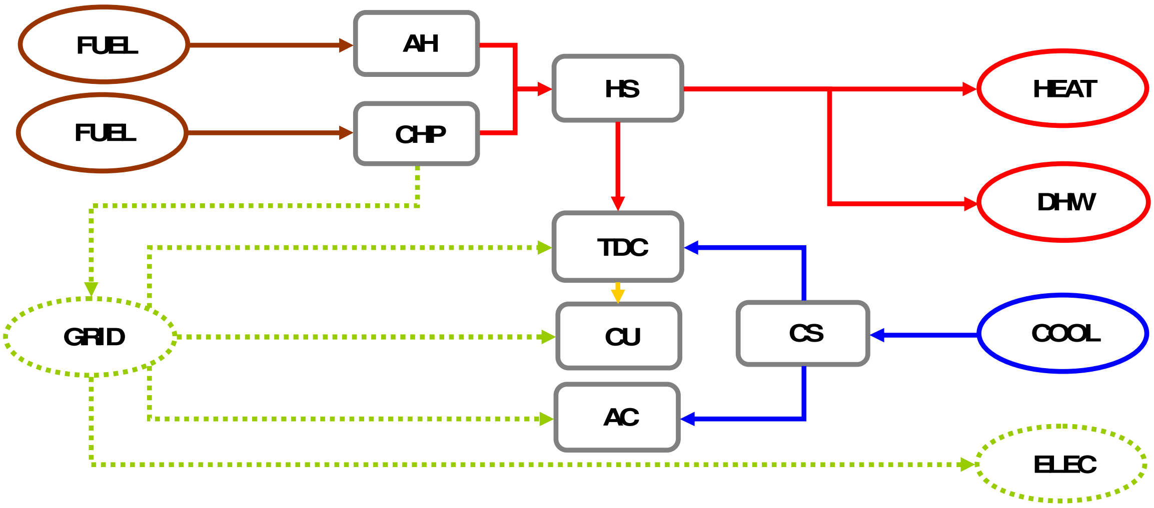
Pessimistic scenario
- NPV: Net Present Value for the CHCP system as compared to the reference conventional case, 20 years useful life and 5% discount rate, under the Pessimistic scenario
- Payback: Payback time for the CHCP system as compared to the reference conventional case, 5% discount rate, under the Pessimistic scenario

Several performance indicators can be further analyzed with the chart window. Each CHCP system is represented as a small colored square. The position indicates how much heating and cooling energy is covered by the CHCP system as compared to the total heating and cooling energy demand, in percentage. The color map indicates the value of the selected performance indicators. The best performing CHCP system is surrounded by a black border.



Simulation logic

The generic CHCP system consists of the following elements: CHP, TDC, re-cooler (CU), auxiliary heater (AH), auxiliary chiller (AC), heat storage (HS) and cool storage (CS).



The sizes of the auxiliaries are automatically calculated based on the peak heating and cooling load at the beginning of the simulation for each CHCP system.

The CHP is driven by the total heating load and the TDC by the cooling load. In order to maximize the CHP operating hours, the system control is set as follows:

- The CHCP system follows always the thermal load
- The CHCP system takes always precedence over the auxiliary systems whenever a heating or cooling load must be satisfied
- It is not allowed to waste thermal energy (dissipation) in order to follow the electrical load
- If the thermal load cannot be met by the CHCP system alone, the auxiliary heater turns on.
- If the cooling load cannot be met by the CHCP system alone, the auxiliary cooler turns on.

The simulation performs an energy balance across the CHCP system boundary based on hourly heating, electrical and cooling loads and CHCP performance parameters, thus determining the following values for each hour of the year:

- the import of fuel for the CHP
- the import of fuel for the auxiliary heater
- the import of electricity
- the export of electricity
- the generation of electricity by the CHP
- the primary energy consumption of a conventional system composed of a boiler, which uses the same fuel of the CHCP auxiliary heater, and an electrical chiller
- the primary energy consumption of the CHCP system
- the primary energy savings as the difference in primary energy consumption between the reference case and the CHCP case