Beyond Low Energy Buildings: Developing Sustainable Infrastructure Strategies

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Summary

Whilst consulting engineers endeavour to reduce the energy consumption in buildings through good design practice there is a limit to the impact that can be made to the overall savings in carbon emissions. What is needed is to develop infrastructure strategies that reduce the dependency on inefficient centralised power stations, with their inherent generation and distribution losses. We have been able to demonstrate to clients planning to construct large buildings or a mixed-use projects that installing combined heat and power (CHP) plant and district heating provides a more sustainable development with economic, operational and environmental benefits. District cooling schemes have also been appraised as part of an integrated services approach. Fundamentally, this strategy also makes carbon savings that could not be achieved by looking at building design features alone. We see the potential for a large growth in local energy centres where new projects, which are of sufficient size, can form their own independent energy supply companies. As a case study we are able to present the feasibility study proposals for the Royal William Yard development in Plymouth.

1. Introduction

There is a range of techniques that a designer can apply to reduce the energy consumption of a building. These measures include improved fabric insulation levels, the application of good daylight design, efficient ventilation systems, heat recovery, the specification of efficient luminaires and appropriate controls. The resulting difference in energy consumption between a well designed/operated building and an ordinary building can be dramatic. Comparisons of energy consumption figures show that a good practice building normally has half the energy consumption of a similar average building (1). A best practice project that uses innovative passive design techniques can go even further. For example, the passive design techniques exploited in the Elizabeth Fry Building at the University of East Anglia reduce heating energy demand to only 25% of typical similar building (2 & 3). However, there is a limit to the cost-effective measures that can be taken to further lower the energy consumption and thus carbon dioxide emissions resulting from a construction project.

2. Thinking outside the box

It has become a cliché to suggest that to get the best ideas a designer must 'think outside the box' but sometimes it is appropriate to look beyond the building and review the nature and origin of the energy supplies delivered to the project. We should ask what environmental impact has been created in order to get these utility services to the boundary of our site. Fundamentally, can there be a more environmentally benign approach to delivering the infrastructure services?

Most of the electricity generated in the UK has a primary fuel efficiency of 35%-45%, that is to say, most of the energy available in the primary fuel is rejected as waste heat. Furthermore, a large proportion of the power stations in the UK use gas turbines, fuelled by natural gas, which is a premium, relatively clean fuel. This is an energy source that also has a range of other extremely useful applications for which its characteristics are difficult to replace. For large volumes of this fuel to be exploited purely for power generation at such low overall efficiencies could be argued to be a flagrant use of a limited natural resource.

There is a way of getting more utilisation of our primary fuels and that is by co-generation, otherwise know as combined heat and power (CHP). Figure 1 shows a schematic comparison of the conventional energy supply scenario and the distributed energy approach, which links a number of buildings together using an energy centre. By recovering and utilising the heat produced from the electricity generation process, CHP plant can have a total fuel conversion efficiency of over 80%, as shown in Figure 2.

All reasonably sized projects, say greater than 1,000 m^2, can consider CHP as a partial or total replacement for traditional utility energy supplies (micro-CHP technologies, when they have become more developed may make even smaller scale projects feasible).

There are already many successful CHP/ community heating projects in the UK that are delivering cost effective on-site heat and power. Such projects include many university, hospital, leisure centre and industrial sites but there are also increasingly housing and mixed-use developments such as the Sheffield City Heat and Power scheme, and the Greenwich Millennium Village and Barkantine scheme in East London (5). However, generally the market penetration is small in the UK. CHP provides only around 5% of the power generation in the UK, by comparison the Netherlands, Denmark and Finland each use CHP to supply more than 35% of their electricity generation, as shown in Figure 3.

The global impact of the inefficiency of traditional power generation is enormous. It has been estimated that the overall worldwide waste of energy arising from central power stations is about the same as the total amount of energy consumed by the global transport sector (6).

3. Sizing and Operational Issues

The energy centre, which is effectively replacing the traditional inefficient power station, can be positioned in one of the occupied buildings or as a stand-alone construction, on or near the site to be served. Typically, the CHP plant is a gas-fired reciprocating engine or gas turbine and will be sized to serve at least the base heat load requirement (such as the domestic hot water demand). The heat to power output ratio is approximately 2:1 but it does depend on the size of the CHP unit. Larger units tend towards a larger proportion of electricity output.

Some projects may use the CHP plant to meet a large proportion of the site electricity demand and the resulting heat output may thus exceed the base hot water load. This situation is viable when the CHP plant generates electricity more cheaply than the tariff charged by the conventional utility company. The penalty in this scenario is that the surplus heat has to be rejected to the environment, unless there is of course a useful application for the heat such as space heating or absorption cooling (i.e. tri-generation system). Mixed-use developments tend to even out the energy demands, thus optimising load factors and improving the overall efficiency of the plant.

4. Discussion of Energy Sources and Sustainability Aspects of Decentralised Energy Schemes

One of the key features of distributed energy schemes is that a wide range of energy sources can be considered. At the moment the balance in tariffs favour natural gas as the preferred fuel for most CHP applications but where a natural gas network is not available LPG may be appropriate. In the longer term when natural gas becomes more depleted other fuel sources for co-generation such as biomass (wood chips and pellets), biogas, landfill gas and refuse will be more economic, especially as taxation is likely to be stacked in favour of renewable energy sources. Alternative thermal energy sources for district heating will become more prominent including large scale solar collectors, which have been tried on a district scale in Sweden and Denmark (7). In addition, aquifer thermal energy storage looks like it could have a significant role in future distributed energy schemes where the local geology is appropriate. There are already over 100 distributed energy projects using this technique in Netherlands with operations in almost every major city (8). In a typical aquifer thermal energy application for commercial buildings the district heating is provided by a heat pump using the ground water as a low temperature heat source. In summer the ground cold store is used directly for cooling, thus avoiding the need for compression chillers.

The flexibility of being able to change the primary fuel source in a local energy centre to suit changing economic and resource availability conditions, means that investing in more distributed energy networks now will effectively improve the security of supply of power, heat and cooling in the future. Conversely, continuing to design developments that are dependant on the grid for general power supply, compressor chillers for cooling and limited natural resources for heating means that there will be greater technical barriers later to adapt buildings to cope with different fuel availability scenarios. It is worth pointing out that 'security of supply' is seen as one of the UK Government's core energy policy objectives, as outlined in their recent Energy White Paper (9). Distributed energy schemes are seen as a means of attaining this objective.

The benefits of having CHP with associated distributed energy systems can be summarised by looking at the three aspects of sustainability i.e. economy, environment and society. All aspects should be considered in an appraisal:

a) Economic Benefits:

- Lower whole-life cost scenario compared to supplying project with conventional utilities.
- Lower energy costs for end-users (although this is sensitive to tariff fluctuations)
- Lower end-user maintenance costs (especially when comparing the maintenance and gas safety inspections required for a multitude of small boilers against a centrally managed plant)
- Financially attractive to leasing companies who will consider capital funding of the project in return for 15-30 year operating lease agreement.

b) Environmental Benefits:

- Reduced depletion of fossil fuel resources
- Lower carbon dioxide and NOx emissions (depends on fuel mix)
- Greater opportunity to utilise alternative energy sources such as biomass, solar and refuse.

c) Societal benefits:

- More affordable heating means less risk of ‘fuel poverty’
- Increased security of energy supply
- Virtually trouble-free heating system from the perspective of the end-user
- Construction of the energy centre and the distribution network improves local employment and training opportunities and engenders community pride/local empowerment.

5. The impact of the Energy Performance of Buildings Directive

A recently introduced driver for change is the new European Directive, 2002/91/EC, on the energy performance of buildings (10). Each government in the European Union must put the necessary laws and regulations in place to comply with this directive by 4 January 2006 (11). The objective of the directive is to improve the energy performance of buildings and thus help the EU achieve its Kyoto commitment to control carbon emissions. Article 5 of the new directive is of interest here because it states that for new buildings with a useful floor area over 1,000m^2 governments should ensure that, before construction starts, formal consideration should be given to the following energy systems:

- CHP
- District heating/district cooling
- Heat pumps
- Decentralised energy supply systems based on renewable energy.

The full implementation of this directive in the UK remains to be seen but certainly if the objectives are met, we are likely to see more central government planning guidance requiring large projects to make the appropriate assessments of the case for CHP and distributed energy schemes. The Mayor of London has already stated, in his draft Energy Strategy, that combined heat and power capacity in London should double by 2010, compared to its capacity in 2000 (12). The Mayor expects the London Development Agency to do all it reasonably can to promote and facilitate CHP and community heating projects. As an early indication of the new policies we are already noticing, as consultants, that large projects are at risk of having their planning application rejected, or at least severely questioned, if the developer has given insufficient consideration to sustainability.

6. Case Study: Royal William Yard, Plymouth

As a case study of the feasibility of CHP and district heating/cooling we can study the Royal William Yard project in Plymouth where we are working as consultants for the South West Regional Development Agency (SWRDA). The project is a former naval stores and food production facility built between 1824 and 1834. The navy ceased to use the site after the Second World War and the regional development agency took control of the site in 1998. All of the buildings have been designated as Heritage Listed or Scheduled Ancient Monuments. The site covers an area of nearly 77,000m^2 and includes ten buildings, providing approximately 48,000m^2 of floor space. The buildings will be used for residential, office, retail, leisure and exhibition space. (Refer to Figures 4 and 5 for photographic images of the site)

The infrastructure proposed for the development, which shall begin construction during autumn 2003, is to include district heating, district cooling and an 11kV network. At a later stage it is proposed to build the energy centre in the annex of one of the existing buildings on the site. The whole development will not be fully occupied until around 2008 due to the fact that major repair works are still needed on some of the buildings before they can be fit-out but at least two buildings will be completed and occupied by the end of 2004. This phasing of occupation means that the full demand will not be established from the outset. Nevertheless, it has been decided to install the distribution system in a common service trench in the first phase of works so that disruptive trenching works do not have to be made at a later date. The plant will be modular so that as new buildings in the development come 'on line' the capacity of the energy centre to generate heating, cooling and electricity can increase accordingly.

We have carried out a life-cycle cost appraisal for the project, which we have taken, for the sake of simplicity, to be 25 years. The total installed capital cost for a site-wide distributed energy scheme, including plant, is estimated to approximately £3m. The plant comprises a series of gas-turbine CHP units (with total electrical output of 500kW), gas-fired boilers or heat pumps for top-up heating and absorption cooling plant to deal with commercial chilled water demand. As a comparison we took the base case to be grid supplied electricity and central gas-fired boilers as the heat source in each building.

In order the assure the users of the CHP scheme that they will pay less for their energy than standard customers the operator will need to set the tariffs to a defined amount less than a basket comparison of standard tariffs. We have assumed this to be set around 10% less than standard tariffs. Thus, a typical large residential user at Royal William Yard is predicted to pay £630/year for power, hot water and heating using the CHP scheme compared to £700/year using conventional sources.

What the financial analysis shows is that the income from the sale of electricity, heat and cooling from the energy centre allows the initial cost to be recouped within approximately 10-12 years, thereafter giving a net income to the operator. This may seem like a relatively long payback period but with a proposed 25-30 year energy supply lease there is a net financial gain for the energy management company even after interest payments have been made on the capital. It has already been stated that the development of the site will be phased over several years and the full income from energy sales is not achieved until there is full occupation. The long period of development does pose a risk factor and the client must take this into account before it commits to the full implementation of the energy centre.

Sensitivity analysis shows that the economic advantage of CHP tends to generally get better when fuel prices increase. For example, if the price of gas, the default fuel for the CHP plant, inflates at the same rate as the price of centrally generated electricity the margins for the CHP scheme get better because CHP customers do not face the full burden of the increases in the import electricity tariff. In the analysis at Royal William Yard, an average fuel inflation of just 2% applied to both gas and electricity makes the payback period one year shorter and improves the net present value at the end of 25 years by £300,000, equivalent to 10% of the initial investment. It is easy to see, using this sensitivity analysis, that the relatively low market share of CHP in the UK will increase as national fuel tariffs increase and it must be acknowledged that relatively cheap electricity price in the past decade is undoubtedly one of the main causes for lack of CHP expansion in the UK in recent years. Indeed, a comparison of international energy tariffs partly explains why Netherlands and Denmark have a much greater penetration of CHP than we do; their energy costs are significantly higher than the UK. (There are of course other reasons why these countries have a better share of CHP, including the fact that they have not been constrained by the same institutional barriers that the UK has).

The predicted carbon dioxide savings at Royal William Yard, compared to the conventional scenario are calculated to be approximately 0.75 million tonnes per annum. Figure 6 compares the estimated carbon emissions and also includes the consideration of a heat pump in the energy centre for top-up heating extracting heat from local harbour sea water With an annual system coefficient of performance of 4 it results in lower carbon emissions per unit of heat energy output than a gas-fired boiler, even including the CO_2 output arising from the electricity used to drive the heat pump. This strategy needs to be investigated further. (Note that we have assumed standard government values for the carbon weighting of gas and electricity use and have not taken into account the issue of displacing marginal centralised plant with different carbon weighting). The final make-up of plant is still to be determined and will depend on capital cost considerations as well as operational costs.

7. Conclusions

A low primary energy approach (and thus low carbon approach) to a project should not be limited to the design of the building and its services but should also include an appraisal of the infrastructure systems. Combined heat and power generation, district heating, district cooling and associated private wire systems can significantly reduce primary energy consumption. Life-cycle costing can be used to assess the economic viability of local distributed energy systems. In the case of the Royal William Yard mixed-use development in Plymouth, the proposed distributed energy system shows that users can benefit from energy costs that are 10% lower than the conventional infrastructure scenario, and carbon dioxide emission savings of 0.75 million tonnes per annum can be achieved. The new European Directive on the Energy Performance of Buildings, as well as a range of planning guidance and policy instruments, are likely to be key drivers for change.

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Figure 1. Comparison of conventional and CHP distribution schematics

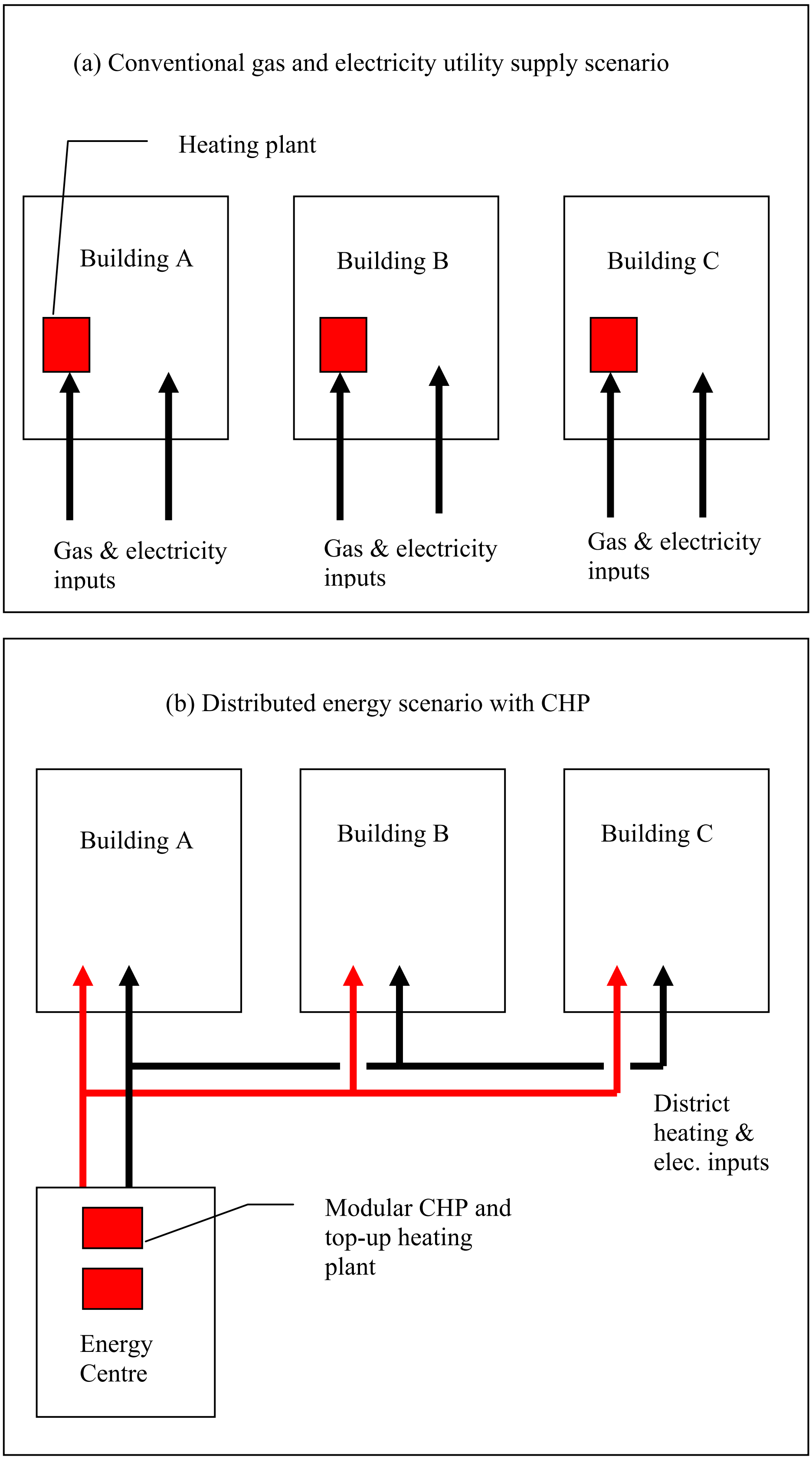
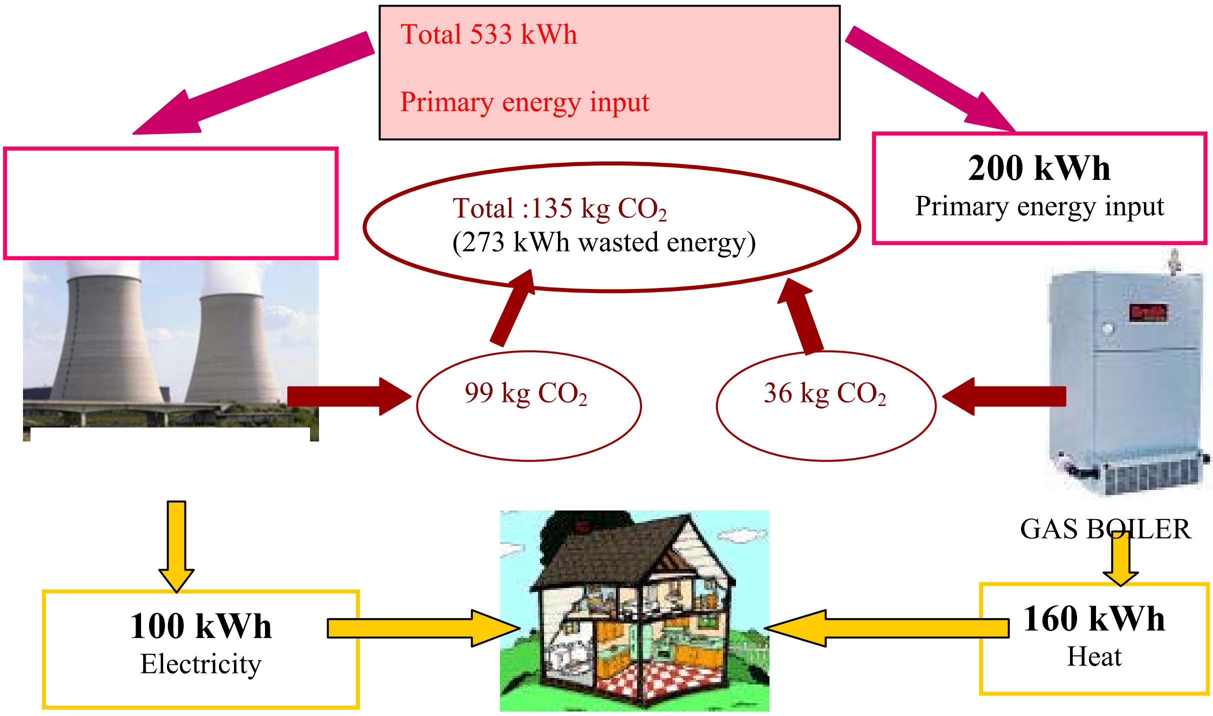


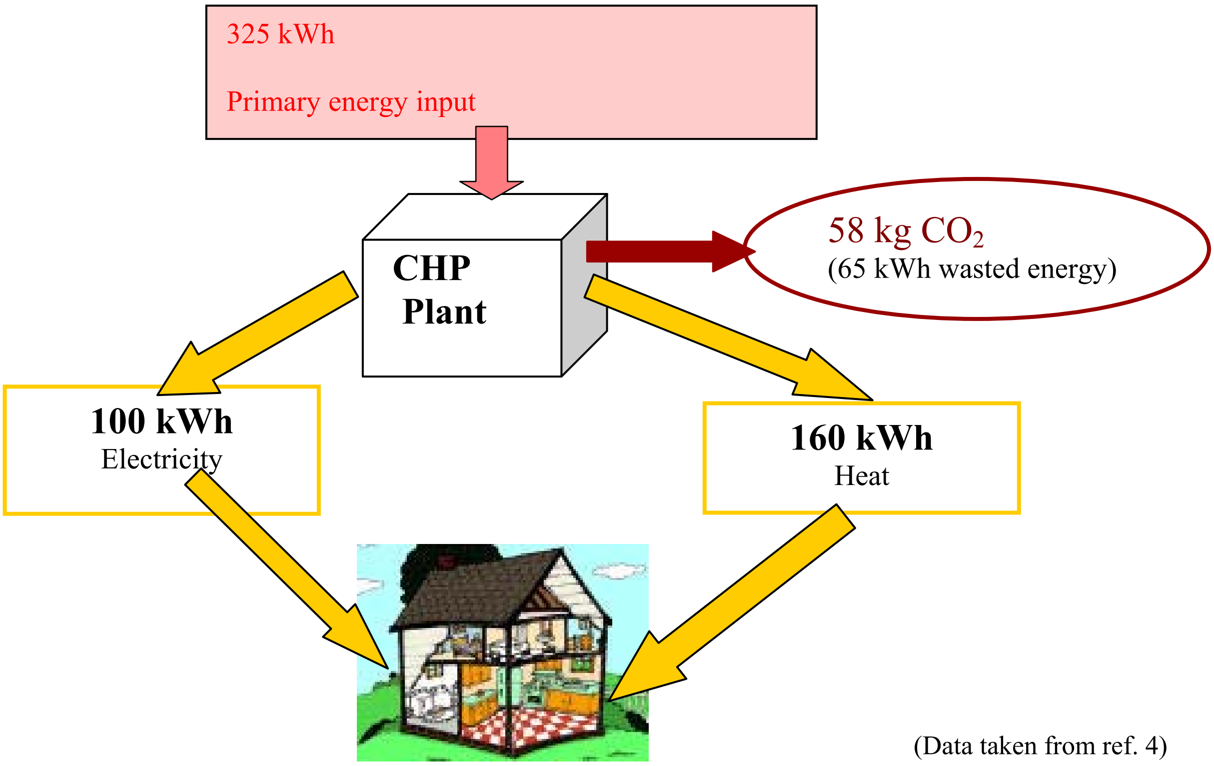
Figure 2: Comparison of CHP and conventional energy conversion efficiencies

(a) Conventional scenario: separate generation of heat and power by boiler and power station respectively



Overall primary energy efficiency ≈ 48 %

(b) CHP scenario: combined generation of heat and power by same plant



(Data taken from ref. 4)

Overall primary energy efficiency ≈ 80 %

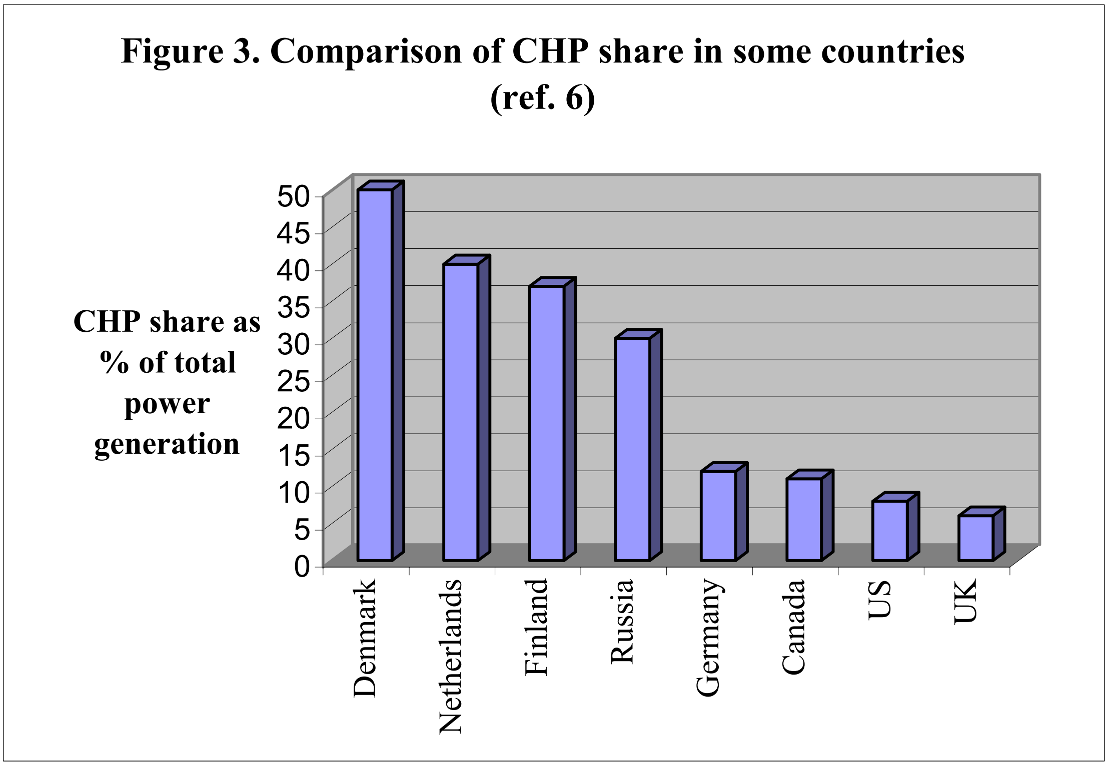


Figure 3. Comparison of CHP share in some countries (ref. 6)
CHP share as % of total power generation
50
45
40
35
30
25
20
15
10
5
0
Denmark
Netherlands
Finland
Russia
Germany
Canada
US
UK

Figure 4. View of Royal William Yard from the harbour, Plymouth

Figure 5. View of one of the buildings at Royal William Yard where CHP and a community heating scheme is proposed

Figure 6. Royal William Yard- comparison of annual carbon dioxide emissions