Large or small-scale CHP/DH – a comparison

Mr. Jens Overgaard, Head of Department, Energy Systems, Rambøll

Mr. Paul Woods, Technical Director, Energy Services Division, Parsons Brinckerhoff Ltd. UK

Mr. Oliver Riley, Project Engineer, Energy Services Division, Parsons Brinckerhoff Ltd. UK

An important element of the International Energy Agency (IEA) research and development programme is the implementing agreement "District Heating & Cooling including the integration of Combined Heat and Power".

The implementing agreement has run for more than 25 years and a number of projects have been developed under the programme, which saw the end of the latest phase or "annex" earlier this year. The projects of the latest annex, Annex VII, were presented at an End-of-Annex seminar in June at the Euroheat & Power Congress in Berlin.

Among the projects was a study with the title "A comparison of distributed CHP/DH with large-scale CHP/DH". The study was undertaken by Parsons Brinckerhoff Ltd (UK) together with Ramboll (Denmark), W-E, (The Netherlands), VTT (Finland) and University of Sussex (UK), assisted by Canmet (Canada).

The scope of the study was to analyse two scenarios for the development of combined heat and power (CHP) combined with district heating (DH). The first of the two scenarios was based on large-scale CHP/DH, seen in countries in Scandinavia, Eastern Europe and South Korea. The second scenario was based on distributed CHP/DH with a large number of small units, seen in the Netherlands and the UK, and even in smaller Danish communities, usually better known for large-scale CHP/DH. Models were to be analysed with respect to economic worth, environmental benefits and other key figures.

A generic city
In order to cover the whole range of CHP from the individual household installation to the city-wide CHP/DH scheme, the study compared CHP/DH systems at four different scales. Each of the four different systems was to supply a generic city with heat and electricity.

It was the intention to define a city that could represent an average international city. The size of the city in terms of population was determined after comparing data for the 500 largest cities in Europe. It was chosen to model the city itself using data from three UK cities, ranging from 250,000 to 500,000 in population.

Information about area of land (km^2), building type and floor space was available for each postal district of each of the UK cities, allowing the project team to estimate the demand for heat and electricity. The information also made it possible to define a variation in energy demand so that the inner city had a higher density than the rest of the city.

Variations in heat demand over the year and over a 24-hour period were considered, and heat demand and electricity demand profiles were included in the model. It was assumed that the city had access to a gas transmission network and a national electricity grid. In fig. 1 the theoretical heat load profile for the whole city is illustrated.

Four models
When supplying the heat and electricity to meet the energy demand of the generic city, the range of options introduced with the two different scenarios was shaped using four different models.

Each of the four models was characterised by the CHP technology selected and consequently by the size and the layout of the district heating system or in one model the lack of a DH system. The models were:

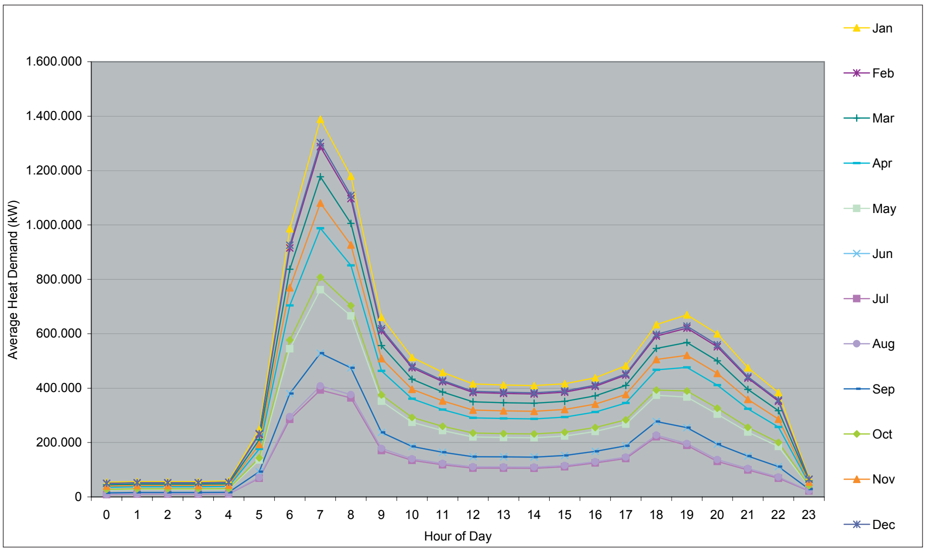
Model A – City-wide
Model B – District
Model C – Local
Model D – Building

In all four models the fuel was natural gas.

"Model A – City-wide" was a scheme with a single large-scale combined cycle gas turbine plant (CCGT) located at the perimeter of the city. The size of the plant would be of the order of 500 MWe. The DH system was characterised by a heat transmission network covering the entire city and supplying a number of distribution networks, at what was called district level. These distribution networks would in turn supply building complexes via a local network.

"Model B – District" was a scheme with a limited number of smaller CCGT plants with one plant located in each district of

Figure 1. Combined (month/day) undiversified heat load profile for entire city.



the city. The size of these plants was in the range of 30 MWe to 100 MWe. There was no DH transmission network, but heat was supplied from each plant via separated distribution networks to the local networks of the district.

"Model C – Local" was a scheme based on a larger number of spark ignition gas engines (SIGE) CHP plants, each of them supplying heat through a local network. The size of the plants was in the range of 1 MWe to 30 MWe.

"Model D – Building" was a scheme where each building or small building complex had its own CHP unit, typically a SIGE or a micro-turbine. There would be no DH network in connection with this scheme. The size of the units was thought to be in the range of 750 We to 1 MWe.

As a reference or alternative model, a non-CHP option with individual gas-fired boilers was assumed. In this model the assumption was that electrical power for the city was produced by a large-scale CCGT and supplied via a national grid.

DH network design

The DH network design was critical for the assumptions that were to be made, not least because of the significant investments. The considerations taken by the project team clearly reflect the importance of network design in real-world projects, where it can mean the difference between failure and success of a project.

Heat mains were modelled in three stages, corresponding to the transmission network, the distribution networks and the local networks. The schematic layout of the city-wide system is illustrated in fig. 2, but it should be noted that this diagram shows the principle and it is not an exact representation of what was actually modelled. The corresponding layout of the district and the local systems will be the same without the distribution network or the distribution and the local networks, respectively.

A number of assumptions were made regarding the installations included in the overall cost of each system. The factors having an influence on the cost of installing heat mains in a given area were also considered, allowing for differences in operating temperatures and pressures, complexity of existing services and traffic control, length of mains to supply all the required loads and measures to supply the peak heat demand. Pre-insulated pipe systems were assumed for all mains with quality of pipes and other specifications to meet EN 253.

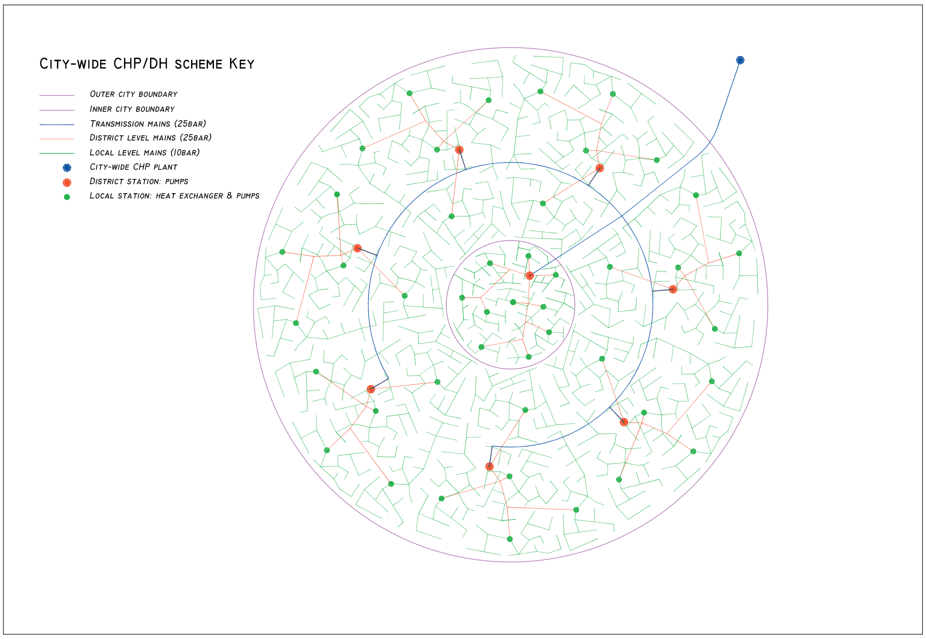
Comparing the models

The four schemes were compared using a discounted cash flow method over the whole life of each model. In this life cycle cost evaluation, the total capital cost took account of all costs for CHP production units, DH systems and customer connections. The operating costs related to the four models were also included.

The different scenarios were assumed to be developed over a 7-year period, during which the build-up of the CHP supply, the DH network and the heat connection would move from zero to 100 %. For "Model D – Building" the development was assumed to be linear for both capital cost and heat connection. The three other models were then assumed to develop at different rates, reflecting the complexity of each system in relation to model D.

Fig. 3 and fig. 4 show the development in capital cost and heat connection respectively for the four models. The diagrams indicate that model D gives the highest rate of heat connection early in the 7-year build-up period, and at the same time the rate for capital cost is the lowest when compared with three other models.

Figure 2. Schematic layout of DH network in city-wide scheme.



Two comparisons were made, the first one being an economic comparison where the lifetime cost of supplying heat and electricity to the city was calculated. The second one was an environmental comparison where the energy balances for the four models were used to calculate the corresponding CO_2 emissions.

As a follow-up on the environmental comparison, the report discusses the possible use of renewable fuels and heat sources. It is argued that the use of biomass or household waste in CHP production will be of relevance only in large-scale systems, such as model A and model B of this study.

The project team made a large number of estimates and assumptions and although they were thought to be typical for Western European countries, a sensitivity analysis was carried out on four key issues, which were:

- Heat density
- Cost of imported gas and power
- Cost of capital – discount rate
- Cost of DH networks

The project team is aware that local conditions may have an important influence on the parameters. The report therefore recommends that similar studies in individual countries should use local costs and energy data. On the other hand, the project team is convinced that the trends of the results are universal and that the conclusions have a general value.

Results

The results of the economic calculations are summarized in the net present value (NPV) for the city's energy need. The NPV for each of the four models and the non-CHP alternative is shown in fig. 5 as a negative value because it represents a cost. In the calculation of the NPV it was assumed that the discount rate was 3.5 %; the lifetime of the overall system was 32 years; there was no financial benefit from carbon savings; and energy prices were constant.

The comparison shows "Model A – City-wide" to be the only economically viable CHP scenario. The result can be explained by the fact that the city-wide system has the highest efficiency and a comparatively low capital cost CCGT plant, which more than compensates for the higher costs of a city-wide DH system.

The report discusses an assumed variation in the gas price, depending on the size of the customer; and an alternative analysis with no variation in gas price over the four models was carried out. The result was presented in the report, but the ranking was unchanged and the conclusion was the same.

Conclusions

At the outset of this study, the project team met for a kick-off meeting in Helsinki. In a discussion paper issued before the meeting, four different theoretical conclusions to the findings of the study were presented to show the range of possibilities.

At one end of the range the conclusion began with the following statement: “The new technologies of mini and micro CHP offer significant advantages over all other CHP/DH approaches. The cost of even a small district heating network is so high that it cannot be offset by improvements in efficiency or lower costs of larger CHP systems.”

At the opposite end of the range, the first paragraph of the conclusion began: “The study has shown that despite the potential offered by the new technologies the most cost-effective energy supply for any city will be the construction of a large-scale district heating system supplied with heat extracted from a major power station… The higher energy efficiencies and lower capital costs of large-scale fossil-fuel power stations have been shown to more than off-set the costs of developing the large-scale district heating network.”

The last conclusion is much in line with the recommendations of the report from the study, where the conclusions are in favour of large-scale systems. However, some caution should be taken, because these systems are likely to require a high degree of regulation.

The report itself comments on the results for all four models, and conclusions on the advantages and disadvantages of each model are given in terms of economy and environment. The report also introduces and discusses a number of other issues of relevance for each model, such as alternative heat sources, fuel flexibility, etc. Returning to the scope of the study and the analysis of the two basic scenarios represented by the four models, the simple conclusion seems quite clear: Large-scale CHP/DH systems hold more economic and environmental advantages than distributed CHP/DH.

For further information please contact:
Rambøll
Att.: Mr. Jens Overgaard
Teknikerbyen 31
DK-2830 Virum
Phone +45 4598 6000
Fax +45 4598 6700
jo@ramboll.dk

Parsons Brinckerhoff Ltd. UK
Att:. Mr. Paul Woods or Oliver Riley
Parnell House
25 Wilton Road
London SW1V 1LW
United Kingdom
Phone 0117 9339300
Fax 0117 9339253

Figure 3. Capital cost lead-in.

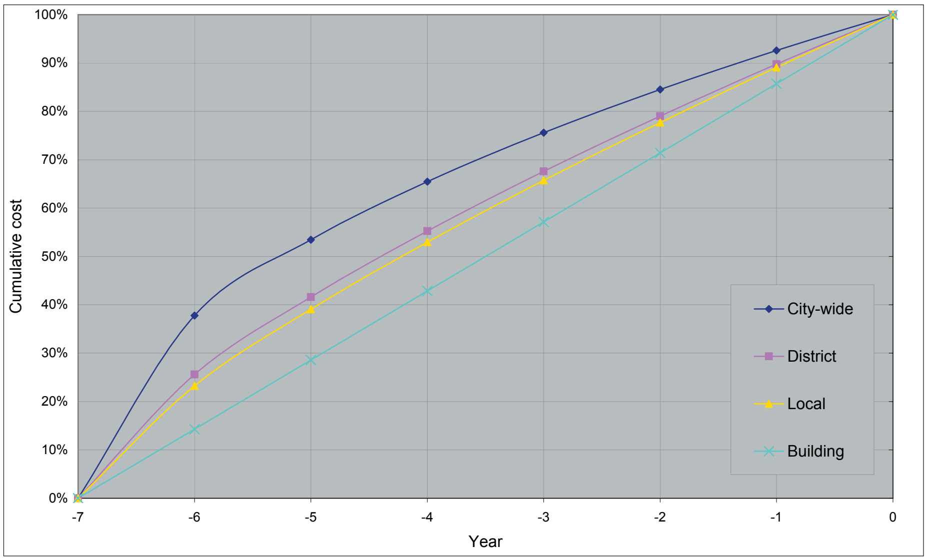


Figure 4. Heat connection lead-in.

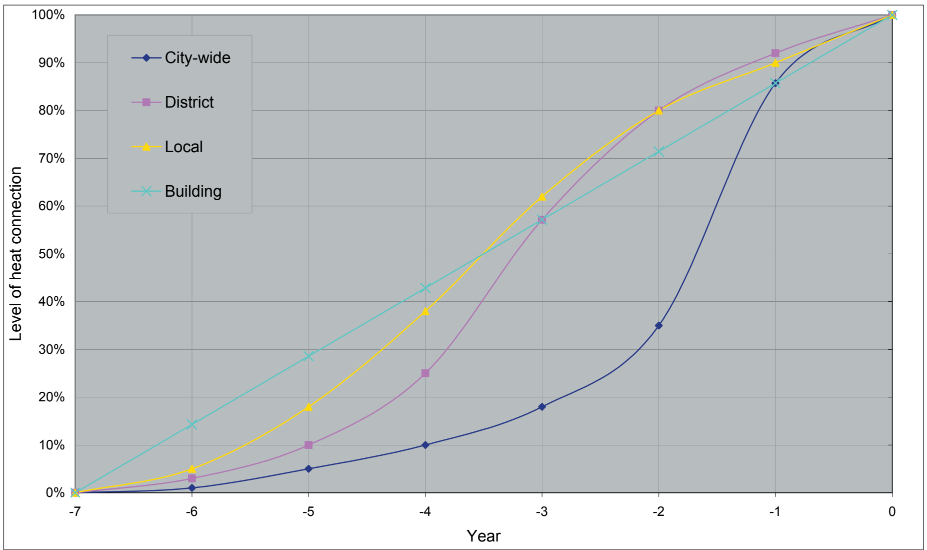


Figure 5. Net present value (NPV) for the four models and the alternative.