# Summary report

# of the

# IEA Programme

# on

# District Heating and Cooling, including the integration of Combined Heat and Power

ANNEX VII

2002-2005

***Compiled by***

***SenterNovem***

***IEA-dhc@senternovem.nl***

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# General Preface Annex VII

## Introduction

The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries and reduce the dependency on oil and other fossil fuels. Thirty years later, the IEA again drew attention to serious concerns about energy security, investment, the environment and energy poverty. The global situation is resulting in soaring oil and gas prices, the increasing vulnerability of energy supply routes and ever-increasing emissions of climate-destabilising carbon dioxide.

The IEA's World Energy Outlook1 "Reference Scenario" 2004 projects that, in the absence of new government policies or accelerated deployment of new technologies, world primary energy demand will rise by 59% by 2030, with 85% of that increase from the use of coal, oil and natural gas. However, these trends are not unalterable. The World Energy Outlook "Alternative Policy Scenario" shows that more vigorous government action and accelerated deployment of new technologies could steer the world onto a markedly different energy path, where world energy demand would be 10% lower and carbon-dioxide emissions 16% lower.

## DHC makes a difference

One of the key technologies that can make a difference is District Heating and Cooling.

DHC is an integrative technology that can make significant contributions to reducing emissions of carbon dioxide and air pollution and to increasing energy security.

The fundamental idea of DHC is simple but powerful: connect multiple thermal energy users through a piping network to environmentally optimum energy sources, such as combined heat and power (CHP), industrial waste heat and renewable energy sources such as biomass, geothermal and natural sources of heating and cooling.

[1] The annual *World Energy Outlook* presents long-term projections for supply and demand of oil, gas, coal, renewable energy sources, nuclear power and electricity. It also assesses energy-related carbon dioxide emissions and policies designed to reduce them. The annual World Energy Outlook has long been recognized as the authoritative source for global long-term energy market analysis. This flagship publication from the IEA is produced by the agency's Economic Analysis Division with input from other internal and external energy experts as required. For more information see http://www.worldenergyoutlook.org/.

The ability to assemble and connect thermal loads enables these environmentally optimum sources to be used in a cost-effective way, and also offers ongoing fuel flexibility. By integrating district cooling carbon-intensive electrically-based air-conditioning, rapidly growing in many countries, can be displaced.

As an element of the International Energy Agency Programme, the participating countries undertake co-operative actions in energy research, development and demonstration.

One of the programmes that has run for more than 25 years is the Implementing Agreement ‘District Heating and Cooling including the integration of Combined Heat and Power’.

**Annex VII**

In May 2002 Annex VII started.

Following is a list of the recent research projects (annexes) undertaken by the District Heating & Cooling Implementing Agreement. Ten countries participated from Europe, North America and Asia: Canada, Denmark, Finland, Germany, Korea, The Netherlands, Norway, Sweden, United Kingdom, and United States.

| Project title | Company | |
|---|---|---|
| A comparison of distributed CHP/DH with large-scale CHP/DH | Parsons Brinckerhoff Ltd<br>Formerly PB Power Ltd – Energy<br>Project leader:<br>Paul Woods | 8DHC-05.01 |
| | | |
| Two-step decision and optimisation model for centralised or decentralised thermal storage in DH&C | SP Swedish National Testing and Research Institute<br>Project Leader:<br>John Rune Nielsen | 8DHC-05.02 |
| | | |
| Improvement of operational temperature differences in district heating systems | ZW Energiteknik<br>Project leader:<br>Heimo Zinko | 8DHC-05.03 |
| | | |
| How cellular gases influence insulation properties of district heating pipes and the competitiveness of district energy | Danish Technological Institute<br>Project leader:<br>Henning D. Smidt | 8DHC-05.04 |
| | | |
| Biofouling and microbiologically influenced corrosion in district heating networks | Danish Technological Institute<br>Project Leader:<br>Bo Højris Olesen | 8DHC-05.05 |

| Project title | Company | |
|---|---|---|
| | | |
| Dynamic heat storage optimization and Demand Side Management | Fraunhofer Institut Umwelt-, Sicherheits-,<br>Energietechnik UMSICHT<br>Projectleader: Michael Wigbels | 8DHC-05.06 |
| | | |
| Strategies to manage heat losses – Technique and Economy | MVV Energie AG Technology and Innovations management<br>Project leader: Frieder Schmitt | 8DHC-05.07 |
| | | |

**Benefits of membership**

Membership of this implementing agreement fosters sharing of knowledge and current best practice from many countries including those where:

- DHC is already a mature industry
- DHC is well established but refurbishment is a key issue
- DHC is not well established.

Membership proves invaluable in enhancing the quality of support given under national programmes. Participant countries benefit through the active participation in the programme of their own consultants and research organisations. Each of the projects is supported by a team of experts, one from each participant country. As well as the final research reports, other benefits include the cross-fertilisation of ideas which has resulted not only in shared knowledge but also opportunities for further collaboration.

New member countries are very welcome – please simply contact us (see below) to discuss.

## Information

General information about the IEA Programme District Heating and Cooling, including the integration of CHP can be obtained from our website www.iea-dhc.org or from:



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|---|---|
| The Operating Agent<br>SenterNOVEM<br>Ms. Marijke Wobben<br>P.O. Box 17<br>NL-6130 AA SITTARD<br>The Netherlands<br>Telephone: +31-46-4202322<br>Fax: +31-46-4528260<br>E-mail: m.wobben@senternovem.nl | IEA Secretariat<br>Energy Technology Collaboration Division<br>Office of Energy Technology and R&D<br>Ms Carrie Pottinger<br>9 Rue de la Federation<br>F-75739 Paris, Cedex 15<br>FRANCE<br>Telephone: +33-1-405 767 61<br>Fax: +33-1-405 767 59<br>E-mail: carrie.pottinger@iea.org |
| | |

# A comparison of distributed CHP/DH with large-scale CHP/DH

**Prepared by**:

Paul Woods (Parsons Brinckerhoff Ltd, UK)
Oliver Riley (Parsons Brinckerhoff Ltd, UK)
Jens Overgaard (Ramboll, Denmark)
Evert Vrins (W-E, The Netherlands)
Kari Sipilä (VTT, Finland)
Professor Richard Stobart (University of Sussex, UK)
Adam Cooke (University of Sussex, UK)

## Summary

District Heating (DH) and Combined Heat and Power (CHP) are now mature and well-established technologies. They are technologies that can deliver lower energy costs, improvements in local air quality and a reduction in CO2 emissions, which will help limit global warming. CHP systems can now be implemented at a wide range of scales from city-wide using District Heating to individual buildings.

Between these two extremes there is a continuum of CHP/DH scales of development. Gas-engines are now being produced at larger sizes up to 8MWe capacity so that, with multiple units, large DH networks can be supplied. In addition, the Combined Cycle Gas Turbine (CCGT) technology is being introduced at progressively smaller scales with a number of designs offered in the 30MWe to 70MWe range.

Energy planners are now faced with such a range of CHP/DH options that there is interest in establishing what scale of CHP/DH would be preferred both with respect to environmental benefits and in terms of overall cost. This report compares CHP/DH systems at four different scales using a generic city model with a population of 350,000. All of the CHP plants were assumed to use natural gas as the main fuel.

The work involved the setting up of models to determine the operation of CHP plant at the different scales to meet the energy demands of the city, using peak boilers and imports or exports from a national electricity grid as required. It was also necessary to estimate the cost of installing DH at each level of scheme and cost correlations with heat density were developed.

The comparison shows that in the whole city case the most economically viable CHP system is the City-wide scenario (at a discount rate of 3.5% real). The City-wide CHP/DH system benefits from a high efficiency, low capital cost, CCGT power plant, which more than offsets the additional costs of constructing a city-wide heat network.

The environmental comparison also shows a clear advantage in moving to the CCGT plant at District or City-wide scale, particularly when compared to the Buildings CHP systems. This is because the CCGT is much more efficient in producing electricity than the smaller units even though electricity and heat distribution losses are higher. Even if all of the buildings were fitted with small-scale CHP systems the overall CO2 reduction would be only 5% compared to a 27% reduction for the City-wide scheme.

It is unlikely that only one CHP solution would be implemented in a given city. For example, in the higher density inner city area, District or Local CHP with DH may predominate and Building CHP could be introduced in the outer city, lower density areas. A city-wide CHP/DH system is most likely to be developed with strong government regulation or legislation in view of the long time scale and the inherent marketing risks for the DH developer.

In the future, these conclusions could change with the advent of fuel cells as, in addition to the low emissions, they offer the prospect of higher electrical efficiencies. At present though, the costs and lifetime of fuel cells are still significant barriers.

This report shows that the overall economic and environmental case for city-wide DH is still strong. In planning new power stations, choosing a location near the edge of a large city could enable major environmental benefits in the future to be realised through District Heating.

# Two-Step decision and optimisation model for centralised and decentralised thermal storage in DHC

**Prepared by**:

Swedish National Testing and Research Institute and Sintef

Mr John Rune Nielsen

Mr Jacob Stang

## Summary

The objective of this project has been to develop a decision and optimisation methodology for optimum dimensioning of centralised or decentralised thermal storage in DH&C systems.

This report presents a methodology for assisting the planning of introducing thermal storage into a DH&C plant. The methodology is divided into the solving of two sub problems; the existence problem, in this report referred to as the step one problem and the dimensioning problem referred to as the step two problem.

The report contains a study on the technical design of the storage and how the shape of the storage affects the efficiency and a survey on short term operational optimisation of DH&C plants as well as a discussion on the storage optimisation problem and how optimisation uncertainties affects the dimensioning.

The methodology for solving the existence problem, i.e. to find out whether a store should be further investigated or not, is presented. The methodology is based on historical data and the main idea behind this decision model is to study periods where the heat load is fluctuating around the maximum capacity of the base heat production. The necessity and appropriate size of storage is evaluated by calculating the demand of energy above and below the actual production limit.

Solving the dimensioning problem is to find the optimum size of heat storage for a given district heating plant. A methodology for solving this problem is presented. Non-linear operational optimisation models from the literature survey are used to determine the optimal operation of the system (dispatch problem) and dynamic programming is employed for finding the optimal size of the storage (unit commitment).

## Conclusions

Minimising the heat loss to the surroundings of a cylinder shaped storage implies an H/D ratio equal to 1,0. However, if the most important issue is to minimise the amount of useless volume the best H/D ratio is 2,0. However some additional height is inevitable due to the space required for diffusers and, if present, also for steam pockets. This is quite consistent with the existing storages in the Nordic countries where a majority of the stores have a H/D ratio range of 1,0 – 2,0.

A simplified method for calculating the economic benefits by using heat storage in different district heating systems is presented and demonstrated. The method is based on historical data. The calculations for some cases show that the method is applicable as a first approach for an investment decision in heat storage.

A methodology for solving the storage dimensioning problem is presented together with a numeric example with a district heat load from a real DH system and where the heat is produced by a back pressure steam turbine CHP in combination with an oil fired heat boiler. For an annual heat load of 712 000 MWh the optimal heat storage volume is approximately 27 000 m3 and the savings are about 3 % of the annual running costs.

# Improvement of Operational Temperature Differences in District Heating Systems

**Prepared by**:

ZW Energiteknik AB,
Mr Heimo Zinko

## Summary

The aim of the project is to propose and verify methods to detect the most critical consumers in the net with respect to insufficient cooling of the DH water and to develop an action programme for suitable measures to be taken to increase the temperature difference in district heating networks.

Hence, the main result of this cooperation is a methodology and the demonstration of its practical application for detecting substations that seriously affect the return temperature of the whole net in a negative way. Contributors to the project were Sweden (ZW Energiteknik AB and the Södertörn District Heating Company), USA (Fraunhofer CEE), also based on the experience of their German mother institute UMSICHT in Oberhausen and Korea (KDHC).

The consortium worked according to the following tasks:

Analysis of measurement data according to the Excess Flow - or Target Temperature methods in order to determine the status of the substations in the net and to identify the reasons for potentially high return temperatures.

**Identification and repair of malfunctioning substations.**

Verification of improvements based on repeated analysis of measurement data after renovation of malfunctioning substations.

Substantiation of the importance of this work by illustrating it with examples of the economic benefits derived from improvements.

### Analysis of Excess flows

The work for detecting malfunctioning substations is principally based on the evaluation of the excess flow of substations. Excess flow is defined as the difference between the actual flow of district heating water, which passes a substation in order to transfer the desired load to the customer, and the flow through a substation that works better or ideally. For this evaluation, two methods have been developed and applied: Excess Flow Method and Target Temperature Method, respectively.

### Excess flow Method

This method answers essentially the question of how a substation would perform, if the return temperature were below the actual average value of the return temperature; let's say by 5°C. In this hypothetical case, each substation is assumed to contribute to the same lower average return temperature, i.e. Reference Return Temperature (RRT) according to its own heating capacity. Lower return temperature means lower mass flows. Hence, this hypothetical approach towards a new average temperature will indicate a possible excess flow, telling us, how much each substation affects the actual return temperature of the district heating network.

### Target Temperature Method

There is, however, a practical limit for the achievable return temperature in a substation. Such limiting factors are design return temperatures of the house heating system, the temperature of the incoming cold city water and the requirements of the hot water circulation as well as the physical conditions of the heat exchanger. Therefore, an ideal Target Return Temperature (TRT) can be defined, depending on some operating and climatic conditions.

The Swedish District heating system in Skogas and the Cheongju DH system in Korea were evaluated applying both the excess flow method and the target temperature method, as well as a combination of both. A number of malfunctioning sub-stations could be identified and improved in both systems.

### Economic incentive

Extended improvement work over longer periods means costs. However, it is also shown in this project that the work for decreasing return temperatures has a positive pay-off. For example, it is estimated for Sweden that the decrease of the return temperature by one degree corresponds to an economical value of the order of 100 million US$. In certain cases, payback times for undertaken measures are in the order of months or a couple of years. It is obvious that the consequent improvement of operational temperature differences in district heating systems and resulting low return temperatures has an economic potential which is highly underestimated by many district heating operators.

# How cellular gases influence the insulation properties of district heating pipes and the competitiveness of district energy

**Prepared by**:

Juha-Pekka Lemponen, Lappeenranta University of Technology, Finland,

Micheal Kraaz, Ingenierbüro Kraaz, Germany

Henning D. Smidt, Danish Technology Institute, Denmark (project leader)

## Summary

The report deals with a number of different methods to determine the composition of cellular gas in the foam according to the results of the experiments which have been made over time.

A program for calculating heat loss has been developed and it is able to calculate the value of heat loss in a CFC pre-pipe system produced in 1985. The calculations are based on data from 2005 to 2035.

A questionnaire survey has been conducted in the countries associated with Euroheat & Power and answers received from 25 plants in six countries.

The section on vacuum insulation deals with the basic properties of energy transmission in materials, where the properties of a series of panels in the market are checked. This is followed by a section on technology used in order to acquire the vacuum necessary to obtain the insulating property. The section ends with general experiences from the use of vacuum.

## Conclusions:

Still after 20 years in use, CFC-blown pipes will have app. 5% lower heat loss than pre-insulated pipes with traditional blown PUR-foam. This will be the case also for the coming 30 years period, meaning that the phasing out of CFC has reduced the competitiveness and probably the spread of district heating to new areas. Also the environmental impact has contributed to a reduction in competitiveness of district heating caused by the phasing out of CFC.

The new microcellular PUR-foam that is foreseen to penetrate the market within a few years will change this situation and bring the competitiveness and environmental impact of district heating back to the level before CFC was phased out. This is very positive, especially if carbon dioxide quota, increasing energy prices, new duties and increasing VAT will bring new burdens on the district heating area.

The answers in the questionnaire show that the users prioritise cyclopentane and that the long-term insulation properties are important, but comparison results between heat loss from CFC-blown pipes and cyclopentane pipes are seldom.

The use of vacuum insulation technology based on PUR-foam is useful for shells or rings with a thickness up to 4 cm. Due to the high temperature in the district heating systems, the diffusion rate thru the barrier material is accelerated and the lifetime as to the low thermal conductivity of the product is reduced.

# Biofouling and Microbiologically Influenced Corrosion in District Heating Networks

**Prepared by**:

Danish Technological Institute

Mr Bo Højris Olesen

## Summary

A preliminary survey on biofouling, corrosion, and corrosion mechanisms has been performed throughout selected DH plants within Hungary, Czech Republic, Sweden, Finland, Denmark, Germany, Austria, and Great Britain. Performing this survey had two purposes.: 1) to find out if MIC currently experienced in Danish DH systems may be threatening the integrity of other DH plants and 2) to establish a connection between MIC and system parameters generally available in order to asses the risk of MIC in general.

In summary, general corrosion rates ranged from 1 to 40 micrometer/year, biofouling from 103 to 107 cells/cm2, and local corrosion rates from 0 to 400 micrometer/year.

The corrosion within two out of the ten plants were categorised as MIC. Four plants experienced corrosion that were categorised as either "possibly MIC" (clearly other factors influencing the corrosion though all prerequisites for MIC were present) or ”initiating MIC” (weak indications for MIC). In the remaining four plants either no corrosion was observed or the corrosion was clearly not influenced by microbiological activity.

Comparing the observations of MIC and non-MIC with plant parameters obtained during the survey, gave some indications of what could lead to MIC and what should not. Particularly the use of chemical additives seemed to play a major role in MIC. The following was observed as indications:

- Addition of sulphite as oxygen scavenger increases the risk of MIC
- Addition of hydrazine lowers the risk of MIC but other corrosion problems may occur.
- Keeping a relative low temperature results in higher risk of MIC
- Not maintaining a sufficiently high pH increases the risk of MIC
- Addition of phosphate buffers the pH and lowers the risk of MIC

- Addition of ammonium has similar effects and lowers the risk of MIC

## Conclusions

MIC is not only a Danish problem, but potentially a problem to all DH installations. We recommend that micro organisms and the problems they obviously create in many plants are taken seriously.

On identification and monitoring of MIC we recommend that corrosion coupons are used either directly within the system or within a side stream exposure unit like the pipe flow unit used in this study. For corrosion measurements we recommend that measurements of general corrosion rates are accompanied by topographical analysis of local corrosion since the local rates are often much higher than the general ones. Growth based methods for monitoring biofouling have not proven to be useful. It is instead recommended to use total counts for determining the level of biofouling. The by-product of the corrosive SRB bacteria, sulphide, may be identified through a simple spot test for sulphide rich minerals. It is also recommended to use x-ray fluorescence in the case detailed investigations of possible MIC attacks are needed.

# Strategies to Manage heat losses – Technique and Economy

**Prepared by**:

MVV Energie AG
F. Schmitt, Dr.-Ing.
H.-W. Hoffmann, Dipl.-Ing.
T. Göhler, Dipl.-Ing.

## Summary

Heating utilities should review their concepts for insulating their district-heating lines at regular intervals. Not only should the volume of investment costs be taken into consideration, but also the expected operating expenditures need to be included when conducting required cost-efficiency analyses. After all, heat losses and thus the selected insulation concept substantially influence accruing operating costs. When calculating operating expenditures, heating utilities should regularly review whether the general technical and/or economic setting has/have changed compared to the last computation process. Redetermining them on a five-year basis should be deemed sufficient.

Detailed cost-efficiency calculations should be made in consideration of the deteriorating insulation quality of the pipelines as a result of the ageing PUR foam. If such ageing process is not taken into account, the actual heat losses may be underestimated by up to 20%. Excellent insulation qualities stand for the distinguishing feature of twin pipes being a special range of preinsulated plastic jacket pipelines. By contrast, the method of laying preinsulated plastic jacket pipelines on top of one another does not have a substantial impact on the occurrence of heat losses.

Most heat losses occur on pipes of small nominal diameters. Even though Insulation Series 1 is today still considered the standard series – in particular in Germany –, there are very well application cases in which insulation of a higher quality proves to be more cost-efficient. Higher-quality insulation is recommended for projects marked by low-cost pipeline construction, in case of high heating costs, and a high temperature difference between the medium and its surroundings.

The related marginal costs were calculated for typical application cases to determine when a higher or lower insulation series will lead to cost benefits. As a minor deviation from the calculated optimal insulation costs only results in relatively low additional costs, it is recommended to change over to the next higher insulation series prior to reaching the relevant level of marginal costs, since it is expected that heating costs will rise in the future due to an ever-increasing shortage of resources. For instance, changing over to the next higher insulation series may be implemented when the relevant marginal costs are underrun by approx. 10% to 20%.

Apart from upgrading the insulation series, the application of enhanced insulation materials marked by lower heat conductivity may help improve insulation efficiency. However, when opting for this approach, it is indispensable that the saved heat loss costs exceed the higher material expenditures.

The closing discussion focuses on how heat suppliers normally deal with heat losses. For the purpose of assessing the state of their own grids, heating utilities are recommended to regularly compare themselves with other district-heating networks on the basis of benchmarks. To provide for – to the extent possible – realistic comparisons of district-heating grids on the basis of statistical data or benchmarks from other enterprises, further ratios, i.e. not just the usual loss factor should be taken into account, as well. The last part revolves around outlining and evaluating measures aiming at reducing heat losses occurring within installed district-heating networks.

# Dynamic Heat Storage Optimisation and Demand Side Management

**Prepared by**:

Fraunhofer Institut Umsicht, Germany

Mr Michael Wigbels

**Summary**

In a partnership of the Department of Mechanical Engineering, Technical University of Denmark, the Finnish Research Institute VTT Processes and the German Fraunhofer Institute for Environmental, Safety und Energy Engineering UMSICHT within this project heat storage possibilities in the respective partner countries have been evaluated. For this purpose three different district heating systems in the participating IEA member countries have been regarded. On basis of different strategies to determine the possible impact of heat storage applications in district heating systems the economic and ecological effects for energy supply companies supplying heat and electricity can be estimated. Within this context especially heat storage applications with respect to the storage capacity of the pipeline system of the district heating network were regarded. Additionally, demand side management strategies based on a partial reduced supply of several customer substations in order to apply the building's volume and mass as a heat storage were in the centre of interest. These Dynamic Heat Storage (DHS) and Demand Side Management (DSM) strategies can be used as a supplement to steel tanks or other ways of heat accumulation.

After a comprehensive data collection phase the project group applied available strategies in order to determine the operational improvement by DHS and DSM strategies. The dynamic heat storage evaluations were based on simulation and optimisation models using simplified network models of the participating energy supply systems.

In the Danish Næstved system it has been shown how DHS could be used to store heat in the network if a failure in the CHP/waste incineration plant occurs. For the Parkvej subsystem in Næstved and the Finnish Jyväskylä DH-system it has been shown how DHS can be used to avoid the use of expensive fuel during the morning peaks. Within the German EVO system it has been evaluated whether the uncoupling of heat and power production in a CHP system could lead to financial and economic advantages. Model

based optimisations on the Jyväskylä DH showed that DSM can further help not to use the expensive fuel at peak loads.

The project results can be summarised as follows:

For DH systems with electricity production (CHP), DHS can increase the possibility for electricity production, resulting in economic savings of up to 5 % per day determined in the Jyväskyla and EVO cases. For the entirely Finnish DH market savings can be estimated of about 3 billion US$ a year.

For DH systems without electricity production, the savings will be smaller, but DHS can be used to store heat made from the cheapest fuel source, for instance if a failure in the supply occurs as it has been simulated for the Næstved system.

DSM should be used to cut peak loads in order to shift from expensive to cheaper fuel. Possible savings of approximately 1-5% in Jyväskyla and Næstved have been determined. For the Finnish DH market due to DSM savings of about 6.5 billion US$ a year are possible.