SUMMARY OF RESEARCH ACTIVITIES
1996-1999

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Preface

Introduction
The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries. As an element of the International Energy Programme, the participating countries undertake co-operative actions in energy research, development and demonstration.

District Heating offers excellent opportunities for achieving the twin goals of saving energy and reducing environmental pollution. Its is an extremely flexible technology which can make use of any fuel including the utilisation of waste energy, renewables and, most significantly, the application of combined heat and power (CHP). It is by means of these integrated solutions that very substantial progress towards environmental targets, such as those emerging from the Kyoto commitment, can be made.

Annex I
IEA's Programme of Research, Development, and Demonstration on District Heating was established in 1983 at a meeting in Stockholm. In the first phase (Annex I) ten countries took part in the programme: Belgium, Canada, Denmark, Federal Republic of Germany, Finland, Italy, the Netherlands, Norway, Sweden and USA.
The National Energy Administration, Sweden, was the Operating Agent for Annex I, in which the following technical areas were assessed:
– Heat Meters
– Cost Efficient Distribution
– Heat Production
– Use of Low Temperature Heat Sources in District Heating
– Conversion of Building Heating Systems to District Heating.

A Summary Report of all research activities carried out under Annex I in the period between November 1983 and December 1987 was published in 1988 by the National Energy Administration Sweden (report Status Energiverk; 1988: R16).

Annex II
In 1987 Annex II started which included the following technical items:
– Consumer installations
– Piping
– Advanced Fluids
– Heat Meters
– Advanced Heat Production Technologies
– Thermal Energy from Refuse.

The Netherlands Agency for Energy and the Environment (NOVEM) acted as the Operating Agent for Annex II. Nine countries participated in this Annex, i.e. all countries of Annex I except Belgium.

The Summary Report of all the research activities carried out in the time period between May 1987 and November 1990 was published in 1990 by NOVEM (Report NOVEM 1990 R-12).

Annex III
In May 1990 it was decided to continue in Annex III. All participants of the second phase participated for another three-year period. The United Kingdom decided to join as well.
Items in Annex III were:
– R&D Project Review
– Promotional Activities
– Piping Technologies
– Consumer Heating System Simulation
– Supervision of District Heating Networks
– Advanced Fluids.

NOVEM once more acted as Operating Agent. In 1993 NOVEM published the Summary Report of the Research Activities carried out between May 1990 and May 1993 (Report NOVEM 1993 P-10).

Annex IV
In May 1993 it was decided to continue the

activities; Annex IV was started up. In Annex IV all countries of the previous Annex participated, except Italy. In 1994 Korea decided to take part in the programme. The Executive Committee decided upon the following items for the programme under Annex IV:

– Integrating District Cooling and Combined Heat and Power
– Advanced Transmission Fluids
– Piping Technology
– Supervision of District Heating Networks
– Efficient Substations and Installations
– Development of long-term co-operation with
– East European Countries
– Low Cycle Fatigue
– Managing Hydraulic Systems in District Heating
– Review of Water Treatment Practices.

Again the Netherlands Agency for Energy and the Environment (NOVEM) was the Operating Agent. All research activities carried out between May 1993 and March 1997 were summarised in the report 1997 N9.

Annex V

In May 1996 Annex V started up. USA decided to step out of this Annex. The following countries co-operated in Annex V: Canada, Denmark, Finland, Germany, Korea, the Netherlands, Norway, United Kingdom and Sweden. The Executive Committee set the following priorities:

– Optimisation of Operating Temperatures
– Balancing the Production and Demand in CHP
– Cost Effective DH&C Networks
– Fatigue Analysis of District Heating Systems
– District Heating and Cooling in Future Buildings
– Handbook about Plastic Pipe Systems for District Heating
– Optimal Operation, Operational Availability and Maintenance in DH Systems

NOVEM also acted as the Operating Agent for Annex V.

Annex VI

In May 1999 Annex VI started. All the countries that participated in Annex V joined Annex VI. USA decided to participate again. The following areas of interest were focussed on:

– Network Installation and Operation
– Consumer Installations
– System Operation
– District Cooling
– Institutional Issues
– Handbook
– Workshops with Euroheat & Power

Available budget

The available budgets per Annex are listed below:

Annex I	US$	525,000
Annex II	US$	675,000
Annex III	US$	1,000,000
Annex IV	US$	1,100,000
Annex V	US$	1,000,000
Annex VI	US$	1,120,000

Information

General information about the IEA District Heating and Cooling Programme can be obtained from:

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Executive summary

Background
One of the major aims of IEA has been, and still is, to reduce the vulnerability of member countries to the interruption of imported energy supplies, particularly their dependence on oil. Recent history has shown that large-scale disturbances of the supply of energy could be created by international political conflicts.

Other goals have assumed increasing importance in recent years, particularly reducing the environmental impacts of energy use and promoting Sustainable Development.[1] Of special importance is the need to reduce emissions of Greenhouse Gases (GHG) that contribute to climate change.

Increasing end-use energy efficiency and expanding use of renewable energy are generally recognised as key requirements for reducing GHG, promoting sustainable development and reducing vulnerability to supply disruptions. Often overlooked is the critical role that District Heating and Cooling (DHC) can play in meeting these goals by reducing fossil fuel consumption by facilitating productive use of waste heat and renewable energy sources.

Of particular importance is the recovery, through Combined Heat and Power (CHP), of the heat that is usually wasted in generation of electricity. Electrical demand continues to grow world-wide and the ability of gas networks to deliver clean burning fuel to the urban centres, where the power is required, will drive local power generation. Because of the enormous and rapidly growing role that electricity plays in meeting world energy needs, CHP is a critical element in an effective effort to reduce GHG emissions.

CHP requires a heat sink for the low-grade thermal energy given off as part of the generating cycle, and large industrial heat sinks for low-grade energy are increasingly hard to find. Urban buildings are the best, most stable long-term partner for CHP plants. Therefore, DHC must be a vital element in the drive to increase CHP power production.

Biomass fuels, used in different types of energy plants, will have to play a major role in any renewable energy future. DHC systems in several countries are already supplying urban centres with heat from waste burning CHP plants. The DHC networks are essential to delivering biomass energy to urban centres.

In general terms, communities concerned about GHG reduction should first adopt policies for the reducing end-use energy requirements. Having done this, the community should be considered as a system and should seek to utilise:
- waste heat from industrial and municipal operation;
- waste renewable materials such as landfill gas, wood or agricultural wastes or municipal wastes;
- new renewable energy such as harvested biomass or cooling from oceans, lakes or rivers;
- combined heat and power (CHP) or cogeneration should always be considered, especially if fossil fuel is to be used;
- if all of the above have been explored, then efficient use of fossil fuel must be considered.

DHC has proven to be a major contributor to GHG reduction in many member countries and recognition of DHC's importance is growing. In fact, many countries where it is established are renewing their commitment to DHC as they find new ways to use the technology to

1. In "Our Common Future", the World Commission on Environment and Development defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

reduce environmental impacts. DHC facilitates linkages between supplies that are environmentally desirable and end users that could not otherwise make use of those energy sources.

Organisation and Participation

Co-operation between the participating countries is governed by an Implementing Agreement. Decisions on the work programme and budget are taken by the Executive Committee, which has representatives from all participating countries. For the meetings of the Executive Committee international organisations in the field of District Heating and Cooling from Europe (Euroheat and Power Unichal) and North America (IDEA) are invited to attend on an observatory basis.

Projects are defined in Annexes to the Agreement. The Operating Agents acts in the interest of all countries and co-ordinates the activities, negotiates contracts etc. within the budget and programme limits decided upon.

In the Annex V, which results are described in this summary report, the following projects have been included:

Project title	Lead Country	Project management
Optimisation of Operating Temperatures and an Appraisal of the Benefits of Low Temperature District Heating	United Kingdom	Merz Irchard Ltd Mr. Paul Woods 4 Roger St. WC1N 2JX Londen UK Tel: +44 171 242 1980 Fax:+44 171 242 1981 Email: paulwoods@t5.co.uk
District Cooling, Balancing the Production and Demand in CHP	Finland	Electrowatt-Ekono Oy. Mr. Matti Kivistö Tekniikantie 4 A, Otaniemi P.O.Box 93, FIN-02151 Espoo, Finland Tel: +358 9 46911 Fax: +358 9 469 1239 matti.kivisto@poyry.fi
Cold Installation of Rigid District Heating Pipes	Germany	MVV Energie AG Mr. Frieder Schmitt Luisenring 49 D-68142 Mannheim Tel:+49 621 2900 Fax: +49 621 290 2089 Email: f.Schmitt@mvv-b6.ma.uunet.de
New Ways of Installing District Heating Pipes	Germany	MVV Energie AG Mr. Frieder Schmitt Luisenring 49 D-68142 Mannheim Tel:+49 621 2900 Fax: +49 621 290 2089 Email: f.Schmitt@mvv-b6.ma.uunet.de

Reuse of Excavated Materials	Germany	MVV Energie AG Mr. Frieder Schmitt Luisenring 49 D-68142 Mannheim Germany Tel:+49 621 2900 Fax: +49 621 290 2089 Email: f.Schmitt@mvv-b6.ma.uunet.de
Fatigue Analysis of District Heating Systems	Denmark	RAMBØLL Mr. Karl Erik Hansen Teknikerbyen 31 D-2830 Virum Denmark Tel: +45 4598 8710 Fax: +45 4598 8535 Keh@ramboll.dk
District Heating and Cooling in future buildings	Norway	SINTEF Mr. Rolf Ulseth Norwegian University of Science and Technology Department of Refrigeration and Air Conditioning N-7491 Trondheim Norway Tel: + 47-73-593862 Fax: + 47-73-593859 E-mail: rolf.ulseth@kkt.ntnu.no
Plastic Pipe Systems for District HeatingHandbook for Safe and Economic Application	Sweden	ZW Energiteknik AB Mr. Heimo Zinko Box 137 S-611 23 Nyköping Sweden Tel: +46 155 203080 Fax: +46155282545 Zinko@algonet.se

For each of the projects an experts group was created, in which experienced representatives of the participating countries contributed to the project-definitions and to the progress of the activities.

The results of all these projects are published in separate reports and are summarised in the following chapters of this report, NOVEM 2000: T7.

In order to reach a large audience in the district heating and cooling field, an agreement was made with the editor of ‘Fernwaerme International’ (FWI) to use this magazine for publishing periodical information about the ongoing activities, results of studies and other publications.
‘District Energy’, the official newsletter of the International District Energy Association (IDEA) also pays attention to the IEA-activ-

ities. This newsletter can be downloaded from the Internet
http://www.energy.rochester.edu/idea/denow/

At international conferences and symposia on District Heating and Cooling we set up presentations, providing information on the activities and their results.
All country-representatives extend the promotional activities in their home-countries.
Mutual information exchange between IEA and Euroheat and Power Unichal, for the European region, and the IDEA for North America are firmly supported to reach a wide range of interested people.

Most of the Annex V-reports have been printed in 500 copies. Of these, 400 copies were to be distributed in the participating countries by the national representatives. The remaining copies were produced for distribution on request to those who are interested by the Operating Agent.

Optimisation of Operating Temperatures and an Appraisal of the Benefits of Low Temperature District Heating (1999: T1)

One of the most fundamental decisions to be made by a designer of a new district heating system is the selection of design operating temperatures. Lower operating temperatures will reduce the cost of heat production from CHP plant but to achieve lower temperatures requires additional investment in the heating systems within the buildings. The cost of the district heating network is reduced if the temperature difference between flow and return is maximised. There is therefore a need to establish the optimum design temperatures to achieve the most cost-effective scheme.

In order to identify the optimum design temperatures, a series of case studies based on notional groups of buildings were developed and comparative economic analyses produced. The case studies comprised combinations of:

three types of built form: apartment blocks, row houses and commercial buildings;
two sample climates : London and Toronto;
three types of CHP plant: extraction-condensing steam turbine, back pressure combined cycle gas turbine and spark-ignition gas-engine.

The analysis of the heating systems within the buildings was carried out by CANMET who developed simulation models using the Simulink software. This enabled hour by hour heat demands, district heating flow rate and return temperatures to be calculated for each case. These heat demand patterns were then used as the basis for the spreadsheet models developed by Merz Orchard to simulate the operation of a CHP plant over the year and hence calculate the cost of heat production. Designs for the district heating network were produced using System RORNET by Merz Orchard and the capital cost was estimated. Finally, costs were obtained from manufacturers for district heating substations, radiators and air heating coils required within the buildings. All of these cost elements were calculated for a range of design operating temperatures, from 90°C to 70°C flow and from 55°C to 30°C return.

The results are presented in a series of graphs for each case study analysed showing the cost of heat against the design temperature difference for different flow temperatures. It was found that, for all cases, it was not worthwhile to reduce the design flow temperature below 90°C as this leads either to a smaller temperature difference and therefore higher network costs or, if the temperature difference is maintained, additional costs for larger radiators. Both of these cost penalties are more significant than the small reduction in heat production cost obtained with using lower flow temperatures.

For a peak flow temperature of 90°C the optimum temperature difference was found to be about 35°C (55°C return temperature) in all cases, although the cost curves are relatively flat and a variation in return temperature of +/-10°C about the optimum resulted in a cost variation of less than 3%.

There are many other potential benefits from using lower temperatures, in particular the ability of the district heating network to utilise low grade heat sources available from industry, solar heat and heat pumps. The cost penalty from selecting a 70°C temperature instead of 90°C was found to result in an overall increase in the cost of heat of between 4% and 6% of a typical heat selling price. It is possible that, in some circumstances, this relatively small increase is justifiable given the potential environmental benefits in the longer term of maximising the use of waste heat and renewable energy by means of district heating. However, in many cases, the low grade heat sources will contribute only part of the energy supply and will effectively pre-heat the return water. A reduction of return water temperatures will therefore be the more important requirement.

District Cooling, Balancing the Production and Demand in CHP (1999: T2)

Purpose of the Report
The main objectives of the research project were to

- Produce information on integrating heating and cooling with combined heat and power (CHP), focusing on district-heat-driven absorption cooling
- Investigate the possibility of balancing the production and demand with the means of heat-driven cooling in connection to CHP
- Collect systematic information and operating experiences of existing district cooling systems connected to CHP
- Collect information on new promising heat-driven cooling techniques

The report is not a complete guide to district cooling or CHP, but it concentrates on some specific issues which had not been investigated before and which were of special interest. The report continues the work that was published in 1996 with the title “Integrating District Cooling with Combined Heat and Power”which gives a broad picture of the field.

Briefly, the main emphasis in the report is put on cooling technologies, integrating cooling with CHP and cooling with district heating networks. In the following the main topics and findings of the report are summarized.

Cooling Technology
The main objective of the Cooling Technology section was to introduce alternatives to one-stage water/LiBr absorption process, which is the most common heat-driven cooling technique today. Namely, the present absorption chillers are not very well suited to be driven with district heating or other relatively low-temperature heat.

The report introduces the principles of refrigeration and cooling and presents a number of water chilling and cooling technologies. The purpose is to present a comprehensive list of heat-driven cooling technologies available today or in the near future. The described features include the working principle of each technique, temperature ranges, energy efficiency, capacity questions, applicability in different conditions and economy.

Energy Efficiency of CHP Connected Heat-driven Cooling
There has been a lot of debate, which is more energy efficient: to extract steam from a steam turbine to drive heat-driven chillers or to produce electricity as much as possible from the steam and use the electricity to drive electric vapor compression chillers. This question was answered by developing a method suitable for comprehensive comparison of heat- and electric-driven cooling in connection to steam turbine CHP. In the method the efficiency of heat-driven cooling is measured in electricity lost due to heat generation for cooling duty, and COPe,Abs is used to denote the total “electric” efficiency of absorption cooling. In addition, all the auxiliary electricity consumption is taken into account. The method requires simulation of a CHP plant and information on the COPs and internal auxiliary electricity consumptions of heat- and electric-driven cooling plants.

Balancing the Production and Demand
In a warm climate the annual electric power peak occurs in summer partly due to electric air-conditioning and refrigeration. If a part of the air-conditioning cooling demand was covered with heat-driven cooling machines, the power peak would be shaved off. If balancing the production and demand was possible by this means, constructing new power capacity for increasing peak demand could be avoided. An essential question is, whether existing CHP plants could be used more effectively than today for cooling production employing heat-driven cooling processes.

To answer this question a problem of maximum cooling output from a CHP plant was studied for condensing and back-pressure steam turbines. All the electric power output of a CHP plant was imagined to be converted to cooling with electric vapor compression chillers. A possible increase to this reference cooling output by using heat-driven absorption chillers is referred to as a “balancing effect”. The results of simulated cases showed that the capacity balancing effect in the condensing CHP is practically zero, unless the electricity production in the condensing tail is very inefficient.

The balancing potential in back-pressure facilities seems to be substantial (up to 180 MWch with a plant of 45 MWe/90 MWth), which is mainly due to increased power production with the aid of increased heat load required by absorption chillers. Namely, the electric com pression chillers were responsible for more than 70% of the balancing effect in the example cases. The excess power production in summer could be used for any other purpose than cooling as well. For example, using absorption chillers with backpressure CHP could reduce the electric power demand by reducing the number of electrical chillers, and at the same time the CHP plant would provide additional power producing capacity to help cover the electric power peak.

The results are also applicable to gas turbine combined cycle or similar cases with heat recovery from flue gases. In such a case a part of the heat is obtained from “waste heat” and it does not affect the power production in any way. Thus, using waste heat for heat-driven cooling can increase the balancing effect considerably.

If constructing a new power plant becomes necessary to cover the peak power demand caused by cooling need, it cannot be called “balancing the production and demand” anymore. When considering a new CHP plant for maximizing the cooling output, the question is, how much cooling output per fuel input the plant produces. The choice is no longer between cooling techniques but also CHP plant types. This problem is addressed in this report.

Absorption Chillers Driven with District Heating

CHP and district heating is commonly used in countries with a cold winter. In some countries where district heating is used, there is also considerably great cooling demand in summer. Heat-driven cooling techniques make it possible to use the heat portion of the CHP production for cooling duty in summer. A logical idea is to take the advantage of the energy transmission capacity in the existing district heating networks. Today the most common district-heat-driven cooling technique is the single-effect water/lithium bromide absorption chiller. District-heat-driven absorption chillers could be installed in individual buildings instead of electric compression chillers. Using district heating networks for cooling in summer could improve the economy of district heating in warm climates.

The possibility of driving absorption chillers with district heating hot water was investigated. Chiller connections to the district heating network are presented and their characteristics are listed in the report. The supply temperatures in hot water networks are usually below 100°C or even 80°C in summer, which may cause some problems for heat-driven cooling applications.

There are two main problems related to district-heat-driven absorption cooling. The first is choosing the optimal district heat supply temperature for the absorption chiller design point in summer to minimize the total costs of cooling. This design problem can be solved by optimization and an example of this is provided in the report. However, the problem is very case-specific and no generalizations of the results can be made.

The second problem is the hydraulic restriction of maximum water flow in existing district heating transmission pipelines. The existing transmission pipes designed for wintertime heating demand limit the cooling load served by absorption chillers to about 20% of the maximum wintertime heating load. The problem has its basis on the small hot water temperature difference and the low COP of the absorption chiller. The only solutions to this problem are developing better heat-driven cooling machines and possibly laying additional district heating network capacity. Nevertheless, as shown elsewhere in the report, this 20% could be enough to see significant effects on the capacity balancing, economy and energy efficiency of existing backpressure steam turbine CHP. In the existing systems re-building the district heating house connection lines for the water demand of absorption chillers is often necessary, but this is surprisingly small component in the cooling plant total costs. If some of the branch lines have to be re-built, the costs become easily too great.

New district heating networks can be designed to meet the maximum flow rates, which may occur in summer or winter. The allocation of costs between the heating and the cooling then becomes an issue.

Economy of District-Heat-Driven Cooling
The economy of district-heat-driven absorption cooling with condensing and backpressure CHP was studied from the viewpoint of the energy producer. Absorption chillers were imagined to be installed in individual buildings instead of electric compression chillers, which they were also compared to. The CHP plant and the district heating network were assumed existing, hence none of their costs were allocated for cooling production, except for the district heating house connection line that was assumed to be re-built. Some factors, including absorption chiller plant design and driving temperature profile over the cooling season, were optimized.

The economy of integrating district-heat-driven absorption cooling with condensing CHP does not look very promising compared to the same size of electric compression chillers. However, the situation is very case-specific and depends mainly on the relative prices of electricity and heat. The makeup water costs are highly important in the total annual costs of cooling. The lower the costs of water, the better are the chances of absorption cooling. In the case of natural heat rejection, e.g. river, lake or sea, absorption cooling can be very competitive with electric compression cooling.

The backpressure steam turbine CHP shows a substantial potential for integrating district-heat-driven absorption cooling with it. The costs in all calculated absorption cases were over 60% less than those in the electric cooling case. This is due to increased production of electricity with the heat load caused by the absorption chillers.

Examples of optimized absorption chiller plant design parameters and heat supply temperature profiles can be found in the report. However, the latter ones are very case-specific and should be treated as examples only.

Summarizing, the following aspects in local conditions improve the competitiveness of heat-driven cooling in relation to electric compression cooling:
- The ratio of electricity price to heat price is high
- Makeup water costs are low (or condenser cooling is achieved by lake/river/sea water or other means without a wet cooling tower)
- Normal summertime heat supply temperature is high

- Number of equivalent full-load hours for cooling is great
- Electric transmission losses are high
- Heat transmission losses are low
- Maintenance costs of heat-driven chillers are lower than those of electric chillers and the lifetime is longer
- Distance between the chiller and the cooling tower is short
- (In the case of district-heat-driven cooling) District heating house connection line is short or it does not have to be re-built for the heat-driven cooling application

In the case of steam turbine CHP, if the heat supply temperature has to be raised above the normal summertime temperature for a long period of time only because of heat-driven cooling, the economic feasibility of heat-driven cooling reduces considerably.

Operating Experiences

Within the project three series of measurements on a district-heat-driven one-stage water/LiBr absorption chiller were performed in Seoul, Korea at the end of summer 1997. The purposes of the measurements were to record normal operation and to experiment the effects of applying relatively low-temperature driving hot water.

Unfortunately, the measured data was highly transient and no far-going conclusions on the chiller steady-state performance could be drawn. However, the results show that trying to force the chiller to work with a lower hot water temperature than normally causes strong transients and oscillation as the chiller tries to find an equilibrium. The physical laws governing the chiller make the cooling water temperatures low and/or chilled water temperatures high to compensate lowering of the hot water temperature.

The report introduces three realized cooling cases in Germany. More extensive operating experiences from Germany were collected with a survey, and some statistics of the survey are presented. There is practical, cooling market and cost information on the German situation of district cooling in the report.

Cooling and the Environment

Most of the air-conditioning cooling demand in the world today is covered by electric vapor compression chillers. The refrigerant fluids employed in vapor compression chillers have been found to contribute to ozone depletion and global warming. The decomposers of ozone, CFCs and HCFCs, are subjected to phase-out by international agreement. This development has already resulted in promising alternatives for the old refrigerants. A major improvement is that the HFCs do not deplete the ozone layer and they really can replace the old refrigerants in a number of applications. Today many new vapor compression chillers employ HFCs, but as the ozone depleting HCFCs are still being used to some degree, heat-driven cooling processes can be supported with the fact that their working fluids do not contribute to the ozone depletion at all.

In the future, when the refrigerants of vapor compression applications become totally harmless to the ozone layer, the only impact to the global environment will be the greenhouse gas emissions. A greater quantity of greenhouse gases is released into the atmosphere from energy consumption for cooling duty than from refrigerant discharge. This fact makes the energy efficiency very important in analyzing the global environmental impacts of cooling, which are mainly caused by CO2 emissions. However, it is important to notice that in respect to the global warming the amount of gas emission does not give the total picture, but the characteristics of the gas in the atmosphere have also to be taken into account.

Summarizing Conclusions

On the basis of the findings in this report the following summarizing conclusions can be drawn:

The energy efficiencies of large-scale electric compression chillers and single-effect water/LiBr absorption chillers driven with steam turbine CHP are roughly in the same order of magnitude. They both depend on the conditions to a great extent. Often a case-specific analysis must be provided to find the most fuel saving cooling concept between heat- and electric-driven ones, and the whole energy conversion chain must be included in the analysis. Using “waste” heat (the production of which does not reduce the electric output of CHP) for driving heat-driven cooling processes can save considerable amounts of primary energy.

Existing CHP:
If the electric power demand peak occurs in summer due to electric cooling, it is possible to achieve substantial peak shaving by using heat-driven cooling units with existing backpressure steam turbine CHP. In this case also, heat-driven cooling would be very profitable business for the energy producer, if the excess backpressure electricity was sold at a good price. Power peak shaving is also possible by exploiting suitable heat sources for heat-driven cooling, e.g. “waste” heat recovery from gas turbines or CHP engines, process waste heat, etc. Steam turbine CHP equipped with a condensing tail cannot provide any substantial power peak shaving by using the heat-driven cooling processes available today, unless the condensing tail is very inefficient or the condensing pressure high.

If there is an existing district heating network, its energy transmission capacity can be exploited for heat-driven cooling if it is economically feasible. With today’s single-effect water/LiBr absorption chillers district-heat-driven cooling can be feasible depending on the local conditions. Especially in the cases of existing backpressure steam turbine CHP or “waste” heat recovery the economy seems viable. The existing transmission pipes designed for wintertime heating demand limit the cooling load served by absorption chillers to about 20% of the maximum wintertime heating load. Re-building the district heating house connection pipes is often necessary for the water demand of the absorption chillers, but if the re-built pipe length is short, this does not reduce the feasibility considerably.

New CHP:
If a new CHP plant is designed in the conditions in which the electric power peak takes place in summer due to increasing electric cooling demand, it is wise to choose such a CHP concept which provides the maximum cooling output per fuel input. This problem has been addressed in “Integrating District Cooling with Combined Heat and Power” by Spurr and Larsson and the CHP technologies rank as follows, from highest to lowest cooling output per unit fuel input:

- Gas turbine combined cycle
- Engine CHP
- Gas turbine
- Steam turbine

This ranking holds true regardless of the chiller technologies employed. For the steam turbine options the condensing turbine results in higher cooling output than the backpressure turbine (with the present commercial cooling techniques available).

Although not considered in detail in this report, the engine CHP has proven to be feasible for combined power, heating and cooling production. It is very energy efficient and has potential for smaller district energy systems. Absorption chillers have been successfully integrated with the engine CHP, because the heat recovery does not affect the power production and the temperatures of produced heat are suitable for the driving heat.

A great question mark remains, to what extent, if at all, heat-driven cooling could improve the chances of CHP and district heating in relatively warm climates. There are well-known advantages related to CHP: energy efficiency, effective pollution control in centralized production and benefits in load diversification. Heat-driven cooling does balance the heat demand over the year, but if separate pipe networks have to be constructed for cooling (chilled water) and heating (hot water), the first costs of the system obviously become high. Furthermore, this does not necessarily improve the economy of district heating. A great drawback in this respect is the fact that the cooling load that can be served by district-heat-driven applications is rather small, if the district heating transmission pipes are dimensioned according to wintertime heating demand. Extensive district-heat-driven absorption cooling requires larger pipe diameters than wintertime heating, and thus the costs increase and the allocation of costs between the heating and the cooling becomes an issue.

The nature of all the different products of cogeneration must be understood. District heating and cooling must have a local demand, whereas electricity is a global product on the deregulated market. With heat-driven chillers cooling can be transformed from electricity demand into heat demand, from global market into local market. Local district energy demands must be fulfilled by local suppliers. Producing district thermal energy may or may not affect the power production, depending on the CHP technology used.

The local conditions will have the deciding impact on the feasibility of any design. In some cases, it could be preferable to have both condensing and backpressure CHP plant types, or maybe other such as engine CHP plants, connected to the same district energy system. The cooling plants, for their part, could consist of combinations of heat- and electric-driven units.

The delivery of district cooling could be provided with a district heating network to the degree it is possible and feasible. Chilled water network gives a possibility to use electric chillers for district cooling. Despite the cooling technique (electric or CHP-integrated heat-driven) or the distribution technique, cooling production in units of sufficient size guarantees higher energy efficiency than production in small-scale individual units. It must be emphasized that district heating and cooling systems also provide reliability and comfort to customers, the value of which is difficult to estimate.

Cost Effective District Heating & Cooling Networks[1]
Cold Installation of Rigid District Heating Pipes (1999: T3.1)

Today, thermal pre-stressing of the pipes is generally avoided when they are laid by the cold installation method.
With today's practice of cold pipe installation the design stress parameters are no longer limited by the material's 0,2% yield strain.

Of all possible options cold pipe installation is the simplest kind of laying technology, which opens new and effective possibilities of construction-site organization. With appropriate preparation the activities can be performed in a single-day-construction manner.
The static stresses caused by cold pipe installation exceed the stresses resulting from the 0.2% yield strain. The design is governed by a fatigue analysis based on the appropriate number of load cycles for district heating. Hence, the material's mechanical stress resistance is used to an extensively high degree.
With cold pipe installation resulting stresses can reach the stresses of the actual yield strain. As a consequence, the pipe endings, which are generally located in the expansion zone, undergo considerable displacements. Solutions have been worked out to control the high stresses and strains. These are described in this report. In general, operating the system at moderate temperatures, cuts back some of the disadvantages and restrictions of the cold pipe installation method.

The method of cold pipe installation is definitely applicable today. The decisive questions concerning material stresses are solved both theoretically and experimentally. An increasing number of companies do apply cold pipe installation using several years of experience particularly those made in Denmark, Sweden and Germany. Further investigations will be likely to bring along simplifications in the design of service connections.

1. This project consists of three reports Cold Installation of Rigid District Heating Pipes (T3.1), New Ways of Installing District Heating Pipes (T.3.2) and Reuse of Excavated Materials (T3.3)

The predominant advantage of cold pipe installation is the reduction of construction time and costs. Extensive investigations of the time span of construction have shown that construction time decreases to 67% and costs to 81% when compared to pipe laying by ways of thermal pre-stressing.

The supply with district heating, which is regarded as less-polluting and resource conserving, can be expanded as much further as pipelines can be installed more cost-efficient. Therefore, many initiatives aim at the reduction of pipeline construction costs. One of the possible solutions is the cold installation of pipes. In contrast to the commonly applied laying technology it takes advantages of an increased utilization of the pipe-system's mechanical strength. However, cold installation techniques require a more detailed stress analysis as a basis for design.

Nowadays, bonded pre-insulated pipes are used almost exclusively when buried district heating pipeline systems are installed. These systems are international state-of-the-art. As they use rigid steel pipes as medium pipes only these systems are being dealt with in this report. A series of European Standards already exists on technical specifications of the raw material, another standard is currently being prepared for the design, layout and laying of this pipe system. Besides this, flexible pre-insulated pipes are coming up on the market and will become more important in future.

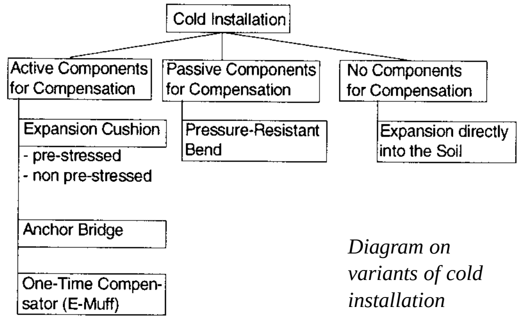
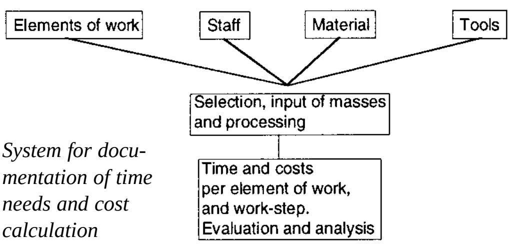


Diagram on variants of cold installation

Advantages	Disadvantages
• no costs for preheating • reduced excavation costs for trench braces • fewer provisional bridges for residents • early backfilling of the trench possible • reduced traffic obstruction • lower expense for traffic guiding • cold installation makes the single-day-construction possible • simplified repair technique in the zone of restrained pipe when preheated	• reinforcement of weak components, like tees, reducers, etc. calls for high material strength in the fully restrained and transition zones • require strengthened valves • limited angular misalignment permissible • not applicable for large nominal diameters from • DN 400 (stability) • Increased planning and safety efforts at subsequent parallel excavation • problems if infrared joint-inspection is desired

Table 2-2: Advantages and disadvantages of cold installation, cost effects

Construction-Times, Construction Costs
Cold installation reduces construction costs. A detailed calculation of the savings is difficult to do since construction costs are always a result of a specific construction site and each site has it's unique cost relations. It gets even more complicated when costs are compared between different companies and especially involved for international comparisons. There are certain similarities between countries, e.g. Sweden, Germany et. al., according to which the ratio of excavation/backfilling to pipe installation as civil engineering costs for BPP-systems are in the order of 60 to 40; for further details please refer to the report. On the other hand this ratio is almost inverted in Finland to 40 over 60, where details are also provided. In Finland the lower civil engineering costs are probably caused by a high share of construction under unpaved surfaces.



System for documentation of time needs and cost calculation

In Germany (Mannheim) very detailed investigations of actual construction times were performed by means of which one is able to rank the different construction techniques from a more universal point of view. The labor for workers as well as for machines were divided into elements and simulated with computer. The calculation model was tuned by comparison with actual construction projects. Cost comparisons are started with the creation of a specific construction case. The calculation solves for the most cost-efficient construction-technique.

In a number of simulation runs the experience was verified that reduced construction times lead to lower construction costs. Obviously, shorter construction time means a better utilization of resources.

Also the cold installation was analyzed for single-costs and the results compared to those of the common thermal pre-heating laying technology. The results are presented in this report.

The cost analysis was performed using a model construction site, which was rated typical by several district heating utilities. Nominal diameters of DN 65 up to DN 100 were prevailing whereas the length of pipe route totaled 500 m.

The cross sections of the trench for the analyzed laying technologies

• Variant 1: thermally pre-stressed
• Variant 2: cold-installed

are presented in this report. Figures will show that variant 2 could be done by proceeding day-by-day, so-called single-day-construction, where no trench side support was required. Day-by-day proceeding means, that the route was divided into short length segments for each of which excavation, pipe laying and back-filling could be done during a single day. Day-by-day proceeding becomes feasible, if the construction site is well prepared (asphalt layer is cut, pipes are welded and checked for leak-tightness) and also finishing work-steps are permitted (reinstallation of the street's wear layer). Here, the single-day-construction lengths were about 40 m; also, a single-day progress of 100 m for DN 80 has already been accomplished.

The single-day-construction technique responds to the time-limited stability of the trench walls by reducing time and thereby saving the braces to support the trench. The soil remains stable for almost always a minimum duration of one day in which the pipe is buried and the trench back-filled.

Cost Effective District Heating & Cooling Networks
New Ways of Installing District Heating Pipes (1999: T3.2)

The investments into new district heating networks in Central and Northern Europe is estimated to be about half a Billion US$ per year. With new laying technologies it seems to be possible to reduce the overall costs by 10 to 15%. The savings expected to be 50 to 75 Mill. US$ explain the utilities' interest in these developments.
The installation of pre-insulated plastic jacket pipes is widely standardized, see CEN standards as well as the manufactures' guidelines for design. The pipelines are built from prefabricated material and laid Side-by-Side inside the trench according to well approved techniques. Common practice is to divide the building costs into three blocks:
- civil costs,
- material costs,
- installation costs.

The material costs can only be influenced a small degree by further rationalization of the production. For increased cost-effectiveness the civil-work block seems to be worthwhile to consider, since civil costs make about 50% of the overall costs and they still account for about 30% in Northern Europe where these costs are traditionally known to be low.

Two ways of construction have been established which primarily reduce the volume of earthworks for the pipelines and also influence their installation. One of these techniques arranges the pipes not horizontally (Side-by-Side) but vertically on top of each other (Piggy-Back laying), whereas the other combines two medium pipes in one jacket pipe (Twin-Pipe). Piggy-Back Laying has been practiced for 7 years while Twin-Pipes are in use for 15 years. Both techniques allow smaller trenches and thus lower the required efforts for civil-work.

Thus the highest potential for cost-reductions of district heating networks lies in the earthworks. By using advanced pipe-laying technologies the trench's cross-sectional area may be shrunk considerably. In contrast to the conventional Side-by-Side laying of pipes the earth masses and costs can be lowered significantly by putting the two pipes on top of each other or using only one plastic jacket for the supply and return pipes as is the case with the Twin-Pipe system.

The Piggy-Back laying requires a narrower trench which has to be excavated a little deeper than with conventional Side-by-Side laying. The pipeline is designed using standard equipment specified by EN 253.

The Twin-Pipe system is used up to a medium pipe diameter of DN 150. It also requires a narrower trench. In addition, the Twin-Pipe features improved thermal insulation and requires only half the number of pipe-runs when compared to conventional DH-pipe systems.
The new laying technologies show some cost advantages versus the standard methods within the considered diameter range of less than DN 150. The cost benefit is about 10 to 20 %. The Piggy-Back laying is cheaper even with pipe diameters of DN 200 and larger.

The cost-advantages of the new laying alternatives have been calculated for conditions that apply in Germany and Finland. This means, high resp. low, civil costs on the one hand and construction with vertical, resp. sloped, trench-walls on the other hand.

The German conditions roughly result in equal costs for Piggy-Back or Twin-Pipe systems. Here, the overall costs for both techniques are about 85 % of those of standard laying. When combined with the well-established cold installation technique the costs can be further reduced to about 70-75%.

In Finland, the situation is more in favor of the Twin-Pipe system (81%) over the Piggy-Back laying with its 92% of the reference costs.

Taking the benefits of the improved insulation into consideration costs for the Twin-system would reduce to 71% of the reference.

In this report the technical specialties of the two techniques are described and possible savings are demonstrated.

Cost Effective District Heating & Cooling Networks
Reuse of Excavated Materials (1999: T3.3)

On grounds of environmentally friendly construction the utilities are trying to use recycled material or industrial leftover instead of raw material as trench backfill. Environmental protection has been proven to not always increase construction costs, but also lower costs in certain cases. Priorities in the case of trench-backfilling are with the use of excavated materials because they are the least-cost alternative available.

Today's standard practice is the use of the before mentioned materials for the pipe and filling layers in the trench in combination with mechanical compaction. In the past serious quality standards were defined for materials and their manual installation to be applied in the pipe layer for reasons of pipe-protection. With the background of the current investigation these requirements may be loosened towards the approval of recycled material which seems to fulfill the demand for pipe protection just like the Swedish recommendation of 0/16 mm grain sizes instead of formerly required 0/4 mm. Further release of those rules seems possible in the future.

A very promising technology is the installation of the backfill material by hydraulic compaction. The material is mixed with water and a binding ingredient to form a fluid which then is poured in the pipe-trench. The fluid encloses the pipe entirely which takes away the need for costly manual compaction. However, the main economic advantage of this method is its reduction of required trench-width by about 30 cm when compared to manually compacted trenches. Thereby, the masses of excavated soil, backfill and reinstalled surface layer are reduced significantly. The application of this technique becomes interesting if the savings exceed the costs of the stabilized mixture. The prices for the mixture will possibly decrease in future due to higher volumes of production and a developed competition between suppliers.

Dependent on recipe, excavated soil may be almost exclusively used as the basis for the mixture (frequently referred to as SSM), if standard soil properties prevail. The casting of the pipes with fluid mixture seems to favor the use of coarse materials. By means of the fluidization coarser grains are encapsulated and their location fixed by fine ones. – The trench may be filled up to the street's level interface, above which the road will be reinstalled in a conventional fashion.

The above method of construction offers potential for further development in case that SSM will be granted the approval as frost-resisting road construction material. The trench could then be filled up to the interface on which the bituminous layer is installed instead of stopping the fluid refill underneath the support layer.

As a consequence, the cut-backs of the bituminous layer could be avoided which normally are required in the area of highly frequented roads to assure the quality of the bituminous joint between existing and restored surface. The construction-time has already been reduced significantly, the so called Single-Day-Construction became possible.

Even the simplest way of hydraulic compaction – the washing-in of backfill with water – has its justification in the construction of buried pipe systems. Soil and backfill need to be permeable to water. Admittedly, the compression is a little lower than with mechanical compaction but it is sufficient for pipe laying underneath paved areas with small loads like sidewalks or bicycle lanes. Also, it may be useful to add a step of final mechanical compaction to a pipe which has been washed-in in the first step.

This report is no construction guideline for the real case. It rather informs about the ongoing efforts aiming to ease the way for the use of recycled materials for the backfilling of pipe trenches in general. In the meantime, it is meant to catalyze the participation and discussion on the unsolved questions of this technique.

Obviously, it is possible to achieve a decent quality of district heating pipes without utilizing high-quality materials for the bedding resp. the backfilling of the pipe. Moreover, costs may be saved while, at the same time, resources are conserved, transportation and landfill-volumes are reduced and obstructions by construction works are minimized.

These findings yield first suggestions for the reuse of former construction material in district heating pipe installation. More systematic investigations are necessary before further optimization of construction works becomes possible which would bring about even higher cut-backs in costs.

The owner of a pipe system is always aiming at low cost solutions thus installing the most cost-efficient materials as trench backfill. The least-cost alternative that is readily available is the excavated material. If it is not possible to store the overburden next to the trench it has to be removed leaving the backfill options with virgin sands – as commonly used in the past – recycled or landfilled material. The price will be decisive amongst these choices.

In the past, usually natural sands were required for installation in the pipe zone. If this requirement is lifted crushed, thus sharp-edged, material may be used assuming that it is less expensive. In Sweden, crushed material of corresponding fine grading is permitted equivalent to natural material. In other countries, for instance Germany / Austria, natural sands are still required. The results presented in this report do not justify these requirements anymore.

The specifications of the materials used for pipe bedding are primarily governed by pipe-safety concerns. Thereby, it is necessary to distinguish whether the pipe is in the fully restrained zone – remaining fixed in the soil – or in the friction zone thus moving in axial direction. In addition to that, the pipe may shift radially at the tails of the friction zones or close to branches.

Besides the requirements for a long service-lifetime and low costs in the pipeline construction business aspects of environmental protection have become increasingly significant. It is urgently wanted that natural resources within and outside the construction site are conserved as much as possible. In this context fall the demands to restrict the transport of excavated material and backfill to a minimum and to avoid any unnecessary inconvenience for neighbors caused by the construction activities. For use in the construction site the before excavated material should be taken if possible and new material should be avoided for the backfill of the trench wherever possible. Conserving the resources can further be done by using recycled materials, industrial leftover or waste-material.

The calls for cost-efficiency and ecology don’t necessarily exclude but may rather complement eachother in the case of pipeline construction. The elevated prices for new material and the frequently rising prices for the deposit of overburden both point in the same direction as does the call to protect the environment, i.e. to reuse existing material. Despite the fact that the cost relations and boundary conditions are varying within regions and even more on a national level since the access to resources underlies strong regional differences, the protection-constraints apply in general. Facing these constraints the utilities are trying to use advanced technologies since they are exposed to specifically high attention by the public as compared to private companies.

For the reuse of material for pipeline construction several interesting solutions exist at different places. In this report only construction methods will be described that may be transposed onto other places and their construction sites. The report will cover construction techniques which use mainly recyclable materials or recycled industrial waste.

Fatigue Analysis of District Heating Systems (1999: T4)

Introduction
This project is divided in two parts:

1. A practical part with temperature measurements
2. A theoretical part dealing with design model and calculations.

Practical part
The practical part was a continuation of a project under IEA District Heating and Cooling, Annex IV, named: Temperature Variations in Preinsulated DH Pipes, Low Cycle Fatigue. In that temperature variations were measured at 17 district heating sites in Denmark, Germany, Korea, The Netherlands and Sweden.

For the present Annex V the measurements were made by the Korean District Heating Corporation with the equipment used in the Annex IV project (4 units) at locations chosen by the Korean District Heating Corporation. The measurements at the four new locations lasted for one full year.

The data was sorted by the rain-flow method and matrixes of temperature variation and graphs are produced in accordance with the data processing done in the Annex IV project.

The data processing was done by Lund's Institute of Technology, Sweden.

Theoretical part
The discussion in the theoretical part is mainly based on the design model in a draft European standard prepared by joint working group JWG1 under CEN/TC107/TC267. This standard uses the hot-spot method for low cycle fatique analysis.

Based on this method a limited number of details of preinsulated bonded pipe systems are analysed. The details include:

- Some 90° bends
- Consumer connections, where the tee piece is the critical part
- Bevel welds (small changes of direction up to e.g. 5°)

Background
The development of preinsulated pipe systems for district heating has for quite some time been characterised by simplification of laying methods, thus employing cold-laying or prestressed systems instead of using expansion facilities like compensators and U-bends, giving more robust and cost-effective systems.

The simplified laying methods on the other hand give rise to higher stress and strain in the system, and therefore suitable calculation methods have been developed in order that the full potential of the systems can be utilised. This development has, e.g., taken place in an technical committee, TC 107 under the European Standardisation Organisation, CEN. The result, a Draft Standard for the Design and Installation of Preinsulated Bonded Pipes for District Heating, is presently being prepared for enquiry.

When the stress range is larger than twice the yield stress, the system is said to be in the low cycle fatigue range. When designing according to the draft standard, it is clear that the most important limit state for pre-insulated bounded pipes is low cycle fatigue. In this limit state, the temperature variations are the most decisive action.

On this background, the measuring project in Annex IV was implemented with the purpose to register the number of temperature variations (at 17 sites). In this project the measuring program was extended with 4 new sites in Korea. Furthermore, this project deals with the whole concept for calculation in the low cycle fatigue range to give a general view of the method and to give examples for fatique analysis.

Results
Temperature measurements

In this project temperature measurements were made on 4 points numbered 18 to 21 in continuation of the 17 points in Annex IV. Point 19 is a commercial building with district cooling, the other sites are blocks with apartments as follows:

- Number 18: 208 apartments
- Number 20: 408 apartments
- Number 21: 690 apartments

All measuring points are placed in substations on the primary side, which means on the district heating side of the installation and on top and underside of the pipes.

The temperature variations are transformed to full equivalent temperature cycles with a full temperature variation at ΔT_{ref} =110°C. The results for the 4 sites are shown in this report.

The results for point 19 and 21 are in the same range as the results in Annex IV while the results for point 18 and 20 for the return pipe gives much higher values than we have seen in Annex IV. The maximum value in Annex IV. The maximum value in Annex VI was about 400 cycles for b=4 (b is the slope of the SN-curve) for the return pipes by the consumer. For point 18 and 20 the corresponding values are about 730 cycles.

A new table for all the results in Annexes IV and V have been worked out. See table 1.1. There are no changes for production (main pipes), while all the new points are found at consumers (service pipe).

Supply			
Production	Min.	Average	Max.
b=3	17	136	365
b=4	4	42	102
b=5	1	18	37

Return			
Production	Min.	Average	Max.
b=3	2	7	14
b=4	0	1	1
b=5	0	0	1

Supply			
Consumer	Min.	Average	Max.
b=3	7	130	578
b=4	2	51	308
b=5	1	28	197

Return			
Consumer	Min.	Average	Max.
b=3	35	667	3262
b=4	4	174	819
b=5	1	55	245

Table 1
Numbers of full temperature cycles for ΔT_{ref}=110°C and b=3, 4 and 5 based on results in this project and in the project in Annex IV, ref. [2].

By analysing the results from measuring on top and bottom of the pipes, it can be concluded, that there are only small differences on the supply pipe. On the return pipe there are differences, which go up to 25°C and with some single values of 40°C. Especially one consumer has big differences in the summertime. The differences mean very little for the fatigue analyses, but the differences may have effect on temperature measuring in connection with operation and energy measuring systems.

The commercial building with district cooling has an average number of temperature cycles, but the level for the return temperature is in the range from 60°C to 100°C with an average of about 80°C. This level is 10-20°C higher than the other consumers.

Results theoratical part

In this project a proposal for 'design lines' has been developed for temperature historic. The lines are shown in this report. The formulas for the curves are as follows:

- For all Supply pipes and return pipes production :
  $n_i = 2x10^6 \left(\frac{1}{\Delta T_i}\right)^{2,6}$
- Return pipes:
  $n_i = 2x10^6 \left(\frac{1}{\Delta T_i}\right)^{2,2}$

n_i is number of cycles during 30 years for $\Delta T = 1, 2, 3 .... °C$.

where

n_1 ($\Delta T = 1$) means all cycles for $0 < \Delta T \leq$ 1°C
n_2 ($\Delta T = 2$) means all cycles for $1°C < \Delta T \leq$ 2°C
etc.

Example:

If we set in 50 in the formula for return pipes, we get n = 347, this means that over 30 years we can expect 347 temperature variations in the range from 50-51°C. If we use the formula for supply pipes, instead we get 77 expected temperature variations.

Conclusions, Design model
A conservative conclusion based on the result of the present project would be:

1. The present design method as suggested by the draft European standard is maintained:
   - The Palmgren-Miner rule applies
   - The number of full temperature cycles, N_0, is calculated from temperature history presuming a SN curve and a reference temperature, ΔT_{ref}
   - The stress variations are proportional to the temperature variations, $\Delta\sigma = c\ \Delta T$
   - Von Mises or Tresca for multi-axial stress/strain state
   - SN-curve is used for lifetime estimation
2. Further improvement of design methods must be based on fracture mechanics and stress history.
3. Fatigue life must be characterised by temperature history, not by full temperature cycles.
4. Small temperature cycles e.g. $\Delta T < 20°C$ can be ignored.
5. Modelling of pipe-soil interaction must be improved, specially p-y diagrams in areas with road surface.
6. Stress intensification factors should be based on "hot-spot" stresses. It should be investigated if the difference between "hot-spot" stresses and the "experimental" method (Mark) applies to other components than bends.
7. The calculation examples might suggest that a higher SN-curve could be applied for un-welded material. However, insufficient modelling of soil reactions, the transformation from multi-axial stress state to the reference stress and the lack of reduction factor for electro chemical environmental actions indicate that the designer should be cautious applying a higher limit.
8. Concerning multi –axial stress-strain state: A "flat" SN-curve ($b \geq 4$) is more likely to represent the true conditions rather than a "steep" SN-curve ($b \leq 3$)

Alternative conclusion
The uncertainties in the present design methods are large concerning:

1. Actions (temperature history and p-y diagrams)
2. Modelling
3. Stress concentration factors
4. Choice of SN-curves including the effect of electro-chemical environment.

Alternative design approaches could be:

Temperature variations must be monitored (specially at the consumers) and controlled at a low level (N_0 < ??). If N0 is chosen sufficiently low, low cycle fatigue design will be unnecessary. This approach will be possible in systems equipped with "intelligent" heat meters presently under development.

Or

For T_{design} < e.g. 90°C design is done according to company standards and low cycle fatigue design is unnecessary.
For T_{design} > e.g. 90°C cavities are established at all expansions and all tees are chosen according to DIN 2615 Reihe 4. With this approach it might also be possible to develop standardised solutions in order that low cycle fatigue design becomes unnecessary.

Or

For T_{design} < e.g. 120°C and preheating design is done according to company standards. Stress reducing measures must be taken for bends and tees.
It is presupposed that the above mentioned company standards are developed in accordance with the European standard or other generally recognised methodology for piping systems taking the large axial forces in pre-insulated pipes into account.

Calculation examples
In the report calculations are made on bends, tees and bevel welds. The calculations are based on the draft European standard.

The calculations in this report show that modelling with beam-element programmes with bi-linear soil springs is very sensitive to the placing of springs.

A number of stress reducing measures have been examined. It is well known that increasing the bend radius reduces the stresses and thus increases the fatigue life. Increasing the wall thickness of the bend gives a moderate increase of the fatigue life in some cases. The most consistent way to increase the fatigue life for bends is to increase the flexibility locally by creating cavities. Foam cushions can also be used, but they have their own limitations.
The results for bends are demonstrated in this report. It also presents calculations that concerns tee at branch connection to consumers.. Again it is shown that minor changes in the modelling give large variations in the results.

The calculations on tees show that choosing the right type of a tee can give a considerable increase in fatigue life. For example an extruded T-piece DN 200/DN 80 with standard pipe wall thickness and axial stress 150 N/mm2 in the main pipe can only allow 58 load cycles without safety factor. If instead a DIN2605 Teil 1, Reihe 4 weld in tee is chosen, the cycles will be added to 7469 cycle
(ΔT_{ref} = 110°C, b = 4).

The calculations in this report confirm that problems with the fatigue life of tees always can be handled by increasing the wall thickness.
The calculations on bevel welds show that there are no problems with respect to the calculations in the report. But bevel welds can give problems with buckling by cold laid systems where the second order effects (local buckling) can be a decisive action.

Further studies
1. At measuring sites R12, R18 and R20 fatigue failures have been recorded. However, none of these sites have had a life time of 30 years in spite of the fact that the number of full temperature cycles have been calculated to be in range normally assumed by design. For these sites it might be interes-

ting to establish the actual stress history. Alternatively it could be considered if the rather large number of temperature cycles can have caused micro cracking, which due to the electro-chemical environment (the pH-value of the water) causes stress crack corrosion (SCC) earlier than expected by the usual design approach.

2. Calculating the reference stress at a multi-axial stress state by using von Mises or Tresca. The possible error thus introduced might explain the difference in the SN-curves used and the lower experimental curve established by Markl.
3. Improved modelling of the pipe-soil interaction under road surfaces.
4. The present study deals mainly with the lifetime of steel pipes. However increased stress levels in the steel will also give increased stresses in the PUR-foam. The limit state for compression and shear stresses in the PUR-foam are insufficiently well known and should be elaborated further.
5. There are still some uncertainties concerning stress concentration factors mainly due to the difference between stress concentration factors based “hot-spot stresses” and factors based experiments. However the way the stress concentration factors are applied when modelling the pipe-systems can give large differences. For example the two methods for calculating stresses in the draft European Standard give much different results.
6 The calculations in this report have confirmed what often has been observed when making comparative studies with different edp-programmes: Beam-element programmes with elastic-plastic soil springs are very sensitive to even small changes in the model. Minor changes in the modelling can give large differences in the calculated lifetime. It would therefor be suitable if minimum requirements for modelling were set up.
7. Further assessment of the influence of the electro-chemical environment on the fatigue life of pre-insulated district heating pipes. In principle this could be done by making fatigue tests on relevant steel qualities embedded in hot district heating water. Especially it should be examined what influence the pH-value has. Only very limited research has been done in this field because the effect of corrosion of low cycle fatigue cracking cannot be accelerated.

District Heating and Cooling in Future Buildings (1999: T5)

For the future development of District Heating (DH) and District Cooling (DC) the development of the heating and cooling consumption is assumed to be an important factor for the economic feasibility of these technologies.

On this background the IEA-District Heating and Cooling Project has given priority to a research project called District Heating and Cooling in Future Buildings. The main goal of the project has been to get a picture of the expected development of the heating and the cooling consumption in the future building stock compared to the building stock of today.

A simulation tool has been used to calculate the heating and cooling loads and the energy consumption in a "typical" office building and a "typical" residential building from 1990, and comparisons are made with the same expected "typical" buildings in 2005+.

The simulations are performed for a typical climatic situation in the respective four countries; Norway (N), Finland (F), Germany (G) and Korea (K).

The input data for the building structure are based on the national building codes in the respective countries. The input data for the local climate are based on a standardised "reference year". A slide in the room temperature from 21°C to 25°C is accepted before cooling is introduced.

The results of the simulations are presented by so-called duration curves and figures with comparative results for the heating and cooling loads and the heating and cooling consumption. Equivalent time of maximum load is also calculated, and the effect of an allowed sliding in the room temperatures before cooling is introduced is shown.

Based on the results from the simulations, the project has also focused on some subsidiary goals:

- Reduction of electric energy consumption and peak power by DC compared to conventional local cooling plants
- Primary energy savings by DH compared to local heating systems
- Environmental benefits from DH&DC compared to local heating and cooling plants

Some examples of the results are shown in figure 1-8.
The simulated load figures are mean hourly values.
The project has been performed at SINTEF Energy Research (N) with project support from VTT Building Technology (F), Fraunhofer UMSICHT (G) and Korea District Heating Corporation (K).

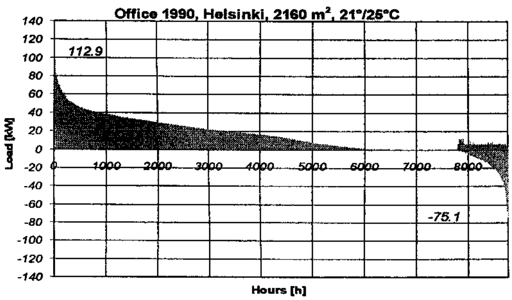


Figure 1 Duration curves for heating and cooling for a "1990 office building" in Helsinki.

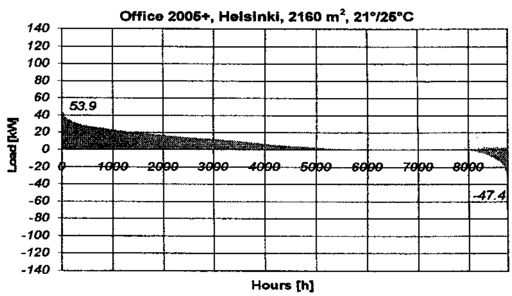


Figure 2 Duration curves for heating and cooling for a "2005+ office building" in Helsinki.

From figure 1 and 2, we can see that the heating and the cooling loads are expected to decrease by 2005+ compared to 1990. The main reasons for this is in this case a better insulated building envelope and a reduced amount of ventilation air.

Figure 3 and 4 show the specific values for the total, yearly heating and cooling energy consumption for the office buildings in the respective four countries.

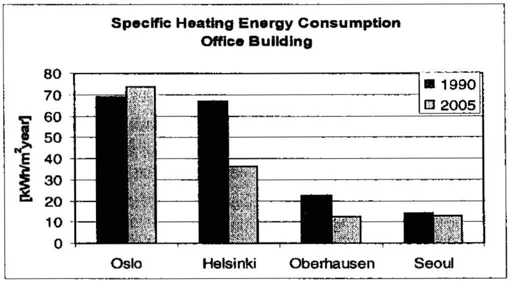


Figure 3 Specific values for the total, yearly heating energy consumption. Simulated values.

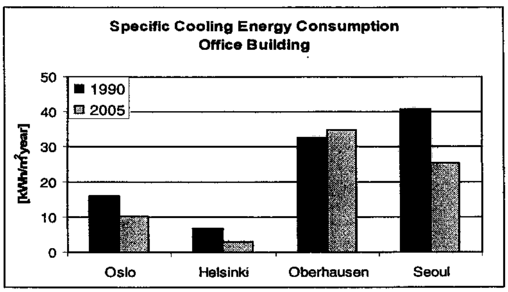


Figure 4 Specific values for the total, yearly cooling energy consumption. Simulated values.

The reasons for the variations in the simulation results from case to case are of cause a combination of a lot of different factors.

The slight increase in the total heating consumption for the 2005+ building in Oslo is caused by a new building code, which demands a certain amount of ventilation even at night due to the contaminants from the building materials. The reduced cooling load for the Oslo building is mainly cased by reduced ventilation rates.

The reduction of the total heating consumption for the 2005+ building in Helsinki is mainly caused by an expected better insulation of the building envelope, especially for the windows. The ventilation rates are also reduced.

The low values of the total heating consumption for the office building in Oberhausen is caused by the fact that no mechanical ventilation are anticipated. For the 2005+ building the building envelope is better insulated. The high values for the cooling consumption in Oberhausen are mainly due to the comparatively warm summer climate.

The values of the total heating consumption for the office building in Seoul are partly caused by the climatic conditions. The fact that a night setback of the room temperature is anticipated for the Seoul case will also reduce the heating consumption. The more or less steady value for the heat consumption from 1990 to 2005+ is caused by the fact that the effect of an anticipated better insulation is counteracted by in increased ventilation rate.

Figure 5 and 6 show the duration curves for the residential building in Oberhausen. In both cases just natural ventilation is anticipated. The main reasons for the decrease of the heat consumption for the future building are better insulated building envelope and an anticipated lower infiltration rate.

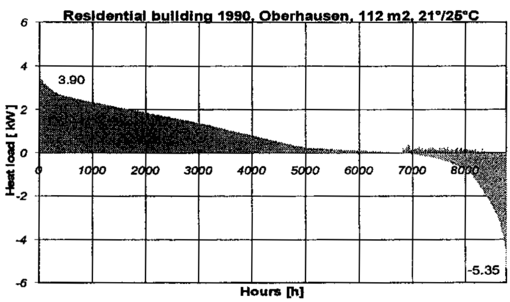


Figure 5   Duration curves for heating and cooling for a "1990 residential building" in Oberhausen

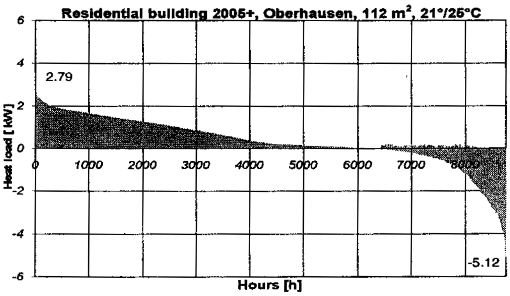


Figure 6 Duration curves for heating and cooling for a "2005+ residential building" in Oberhausen

Figure 7 and 8 show the specific values for the total, yearly heating and cooling energy consumption for the residential buildings in the respective countries.

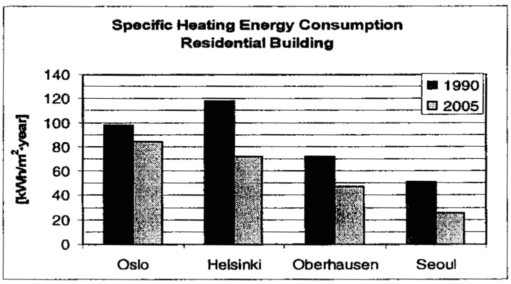


Figure 7 Specific values for the total, yearly heating energy consumption. Simulated values.

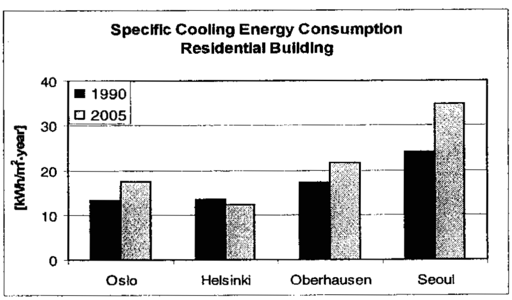


Figure 8 Specific values for the total, yearly cooling energy consumption. Simulated values.

It is commonly known that the peek power on the electricity grid in modern cities in warmer climate normally occurs in the summer time when small, electric driven, cooling equipment and smaller local cooling plants are running for air conditioning of residential and commercial buildings.

One of the reasons for this is that smaller cooling equipment has a low ratio between the cooling output and the electricity input to the cooling compressor as shown in figure 9.

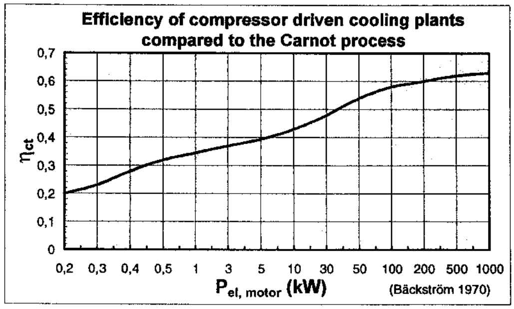


Figure 9 Efficiency curve for an average cooling plant as function of the size of the motor of the electric compressor compared to a Carnot process

From the results from the simulation a calculation of the reduction of electric energy consumption and peak power by DC compared to conventional local cooling plants could be done.

The calculations, which were done for the office buildings, did show that the yearly electric energy consumption and the peek power could be reduced in the range of 30 % or higher by DC compared to conventional local cooling plants.

The calculations for the residential buildings did show that the yearly electric energy consumption and peek power could be reduced in the range of 45 % or higher by DC compared to local, conventional wall or window mounted cooling equipment in the flat.

One of the subsidiary goals of the work was also to look upon the possibility for primary energy savings by DH compared to local heating systems in order to give the different system a "quality ranking".

This is a rather complicated task, since DH may be produced in many different ways. Reduced use of fossil fuels was focused in the ranking judgements.

The situation on the heating market is also very different from one country to another. Figure 10 shows the heating systems for space heat in some selected countries. The missing amount in each country is provided by other sources.

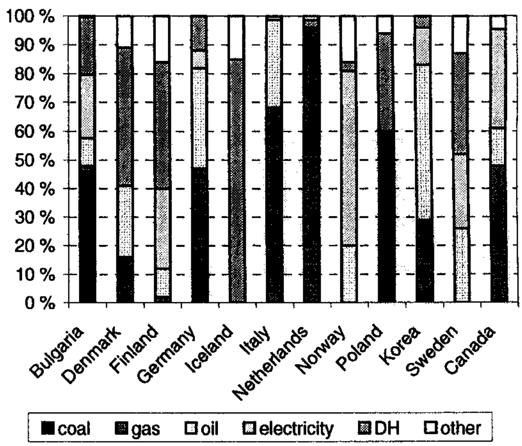


Figure 10 Type of residential heating in some selected countries /Unichal 1995/

As a conclusion a principal ranking of the different processes for the heat supply is given as follows (in order of an increasing use of fossil primary energy):

1. Use of industrial waste heat and waste incineration, CHP and DH driven with biomass, heat pump driven by biomass.
2. Electrical heat pumps, electrical heating systems, electricity from regenerative energy sources, provided that electricity cannot be used sensibly at other locations to substitute fossil energy sources 1
3. CHP + DH by fossil fuels
4. Heat pump processes (local or in combination with DH)
5. Condensing boiler
6. Gas boiler, oil boiler
7. Electrical heating (electricity from fossil energy sources)

By the ranking of no 4, it is presupposed that the Coefficient Of Performance (COP) of the heat pump is sufficiently high to degrade the next on the list.

Depending on the composition of the generated electricity (ratio between renewable and fossil electricity generation) a detailed assessment with exact prevailing circumstances is necessary. An energetic assessment of heat supply systems is only possible and correct if the electricity supply is taken into account too.

Since the ranking the processes is based on reduced use of fossil fuels, this ranking will also gives a strategy for achieving environmental benefits from DH&C. Calculated examples with Finland as reference country shows that further development of CHP has the greatest potential for reduction of the emission of CO2, SO2 and NOx.

1 The emphasis lays on the phrase "electricity from regenerative energy sources". Only in this case the use of electricity is desirable. In reality we should expect better possibilities to use electricity for heating applications (for example by electricity export to other countries).

Plastic Pipe Systems for District Heating, Handbook for Safe and Economic Application (1999: T6)

Introduction

Plastic medium pipes have in some countries, especially in Scandinavia, been used for many years in floor heating applications and in smaller local networks. In Denmark these pipes are also quite common for smaller district heating pipelines. In spite of years of experience, there still exist doubts about the possibilities of using plastic pipes in district heating applications, mostly because of the limitations in pressure and temperatures which must be observed when using plastic medium pipes. The use of plastic medium pipes is also limited to relatively small dimensions, i.e. below 100 mm diameter, which makes it necessary to mix steel pipes and plastic medium pipes in many applications, a combination for which experience so far was not systematically documented.

The aim of the project is to compile know-how and installation experience from various countries and to present the results about plastic medium pipe techniques in the shape of a handbook. The handbook describes the basic properties of plastic materials involved and the conditions for its applications, as well as recommended laying and installation techniques to be used for receiving both technically and economically favourable results

The handbook is divided into two main parts: An engineering part A describing the main aspects of using and applying plastic medium pipes, including also economical system aspects, and a material part B, giving more detailed background information about the specific material properties as an Appendix. Some field projects are documented in the Appendix part C.

A - Engineering aspects

The plastic medium pipe systems are described for all makes commercially available on the European market (i. e. in more than one country) for the last years. This implies that products under development or just pilot products are not included. This limits the make description to the following systems:

Bonded pipe systems with PEX:
ABB-PEX flex (ABB Isolrohr). Brugg-Calpex.
Isoplus-Isopex. Lögstör LR-Pex.
Tarco PEX/FLEX.

Non bonded pipe systems with PEX:
Uponor Ecoflex.

Pipe systems with other material than PEX
Flexalen.

A complete list of properties of these systems mentioned above is included in Table 2.1. It gets evident from this list, that the PEX medium pipe is the prevailing pipe material and that practically all PEX-pipes to be used for district heating have a diffusion barrier of EVOH (ethylenvinylalcohol) which reduces the risk of oxygen diffusion to a great extent. Polybuthylene (PB) - with or without a diffusion barrier - is only offered by one manufacturer. PEX pipes are available in dimensions up to DN 100 mm whereas the PB pipes are offered also up to DN 125 mm. For pipe joints, a variety of joint systems are available, most of them are of type press or screw fittings. An exception is the PB pipe, which can be welded.

The advantage of plastic medium pipe systems is their flexibility. This holds not only for the plastic pipe but also for the total pipe system including insulation and jacket. Even for the largest diameter the minimum radius of curvature is given to 1.5 m. In all pipe systems, except the Uponor-Ecoflex and Tarco, the insulation is made by PU-foam, covered with an outer jacket of PE. The Ecoflex system uses PEX foam insulation with a PE jacket, and Tarco uses a PU-foam with a jacket of an elastomere ethylenic butylacrylate.

The most important difference between plastic pipe systems and preinsulated steel pipes is their simple and quick assembly. Whereas a typical time for the construction of a section of preinsulated pipes might be counted in weeks, plastic medium pipe systems can be installed within a few days.

In assembly, only simple tasks have to be carried out which can be completed quickly. For this reason it has been shown that the same contractor can manage all installation work. The pipe ditch is kept quite narrow with a minimum of excavated material since no welding work has to be made down in the ditch (except some large holes for joints or service Tees). The sand bed can be immediately filled up, the plastic pipe laid down in its full length and the ditch can be refilled within hours except may-be the excavation of larger holes made for joints or branches. By that way, roads are usually only blocked for some hours, bridges are not required and traffic interruption and other impact to the public is kept at a minimum.

Connections of PEX-pipes are best carried out as press connections. They can be mounted using a special tool far more quickly than a welded connection on a steel pipe. Visual control of the joints is sufficient. However, PB pipes are commonly connected by welding.

Whereas the pipe laying effort for the main pipe system is considerably lower for plastic pipe systems compared to preinsulated pipes, branches require about the same effort for both systems. In plastic medium pipe systems, branches are produced very often with prefabricated Tees and the joints have to be carefully insulated and tightened.

Comparing plastic medium pipe systems with preinsulated steel pipes it can be stated that - all work considered - the effort spent for laying plastic medium pipe systems is very much less than for preinsulated steel pipes. This results also in lower total pipe system costs in comparison with the preinsulated pipes. In studies made in Sweden, Germany and Denmark it was shown that the total system costs are well below those for preinsulated pipes up to DN 65, the difference being larger the smaller the dimensions are. That means that the main advantage of plastic medium pipe systems can be found in applications where the transported energy is below 500 kW.

B - Material aspects

The most dominant questions concerning the plastic medium pipes are the limitations in temperature and pressure at one hand and the oxygen diffusion at the other hand.

These questions have been investigated in different laboratories in Europe as well in the USA. Plastic pipe properties have been improved during the years and early measurements should be taken with caution. Reliable measurements for the lifetime expectancy of PEX and PB are nowadays available. These measurements are based on both real time laboratory measurements for more than 10 years and accelerated measurements at elevated temperatures and show that the time to failure is depending on both pressure and temperature. By taking mean values of the time to failure over different measurement series, lifetime diagrams as function of temperature and pressure can be constructed. Such diagrams are now proposed to be included in the new standard for plastic pipes.

For a district heating application with a temperature dependent supply temperature (i.e. 90 °C winter and 70°C summer) and an operating pressure of 5-6 bars, the expected life time can be calculated to be >100 years for PEX and > 60 years for PB pipes.

An important question is that of oxygen permeation through the plastic pipes. Untreated

PEX and PB material exhibit such a high rate of oxygen permeation that such pipes only can be used in special applications where all metallic materials in contact with the water must fulfil fresh water quality standards.

Therefore plastic pipes are covered with permeation barriers in order to reduce the oxygen permeation. For PEX as well as nowadays also for PB, all commercial makes for district heating use ethylenvenylalcohol, EVOH, as such a barrier.

Measurements of oxygen permeation through plastic pipes are very difficult to carry out and can easily be based by systematic errors. In recent times, such measurements have been performed on PEX pipes by laboratories in Sweden, Denmark and Germany. Usually such measurements are related to a given pipe dimension. Depending on the temperature and the test site, the permeation difference between systems with and without barriers is in the orders of 10 - 2000.

The most important question is which impact the remaining oxygen permeation has on the possibility of connecting plastic pipes to steel systems. Investigations have been performed at Fernwärmeverbund Saar in Germany. The expected corrosion impact from oxygen due to plastic pipes in two combined systems with twice as much plastic pipe volume as steel pipe volume, was calculated to be less than 0.03 - 0.1 mm loss of steel pipe thickness during 35 years. A study in Denmark resulted in still lower values. Hence from these and other measurements the conclusion can be drawn that the equilibrium contribution of plastic pipes to the oxygen leakage is negligible and plastic pipe systems can be mixed with steel pipe systems.

The influence of the diffusion of water vapour through the wall of PEX medium pipes on the pipe system is under investigation in Germany. In pipe systems consisting of media pipe, insulation and jacket, accumulation of moisture in the insulation of the pipe-system or also on the inner wall of the jacket can be expected, if the permeability of the jacket is less than that of the medium pipe. Moisture which accumulates in the insulation is expected to reduce the thermal resistance of the insulation. This on the other hand will increase the temperature of the jacket and hence increase its permeability until an equilibrium will be reached. Hence each pipe system is expected to have its own balance of humidity depending on operation temperature and materials involved in jacket and insulation. It is expected that the industry will use results of these measurements for further optimising the water diffusion properties of their plastic medium pipe systems.

C - Field demonstrations

Three examples from Sweden, Finland and Germany are presented in Appendix C of the report. In these projects, care was taken of using the advantages of plastic pipes as system size. Pipe dimensions and operating conditions were concerned. In two of these projects, the advantages of constructing the smallest pipe lines by means of Twin or even Quadruple pipe systems has been used. Although it is difficult to compare the costs of built systems and non-built calculated systems, the general conclusion was that a total cost advantage for small pipe systems (< DN 65) exists compared to conventional steel pipe techniques.
However, it has been found in parallel projects in the same countries (Sweden, Germany, Finland), that new installation techniques such as cold-laying and refill techniques for steel pipe systems and also the use of flexible steel and copper pipes, especially at operating conditions comparable to those of plastic pipe systems, also lead to reduced system costs.

Appendix I: List of Publications

Publications Annex I

1986: R9	IEA District Heating Small-Scale Combined Heat and Power Plants
1986: R10	IEA District Heating Cost Analysis of District Heating Networks
1987: R4	IEA District Heating Temperature Levels in District and Local Heating Systems in Sweden
1987: R6	IEA District Heating Technical and Economic Assessment of New Distribution Technology
1988: R12	IEA District Heating Small Heat Meters
1988: R13	IEA District Heating State-of-the-art Review of Coal Combustors for Small District Heating Plants
1988: R16	IEA District Heating Summary of Research Activities 1983 - 1987

Publications Annex II

Number	**Title**	**ISBN**
1989: R1	District Heating & Cooling R&D Project Review	90-72130-07-3
1989: R2	Advanced District Heating Production Technologies	90-9002876-5
1989: R3	Static problems in the laying of plastic jacket pipes	90-7213-09-X
1989: R4	Fittings in plastic jacket pipelines	90-72130-08-1
1990: R5	Welded Sleeves Technique for Plastic Jacket Pipes	90-72130-17-0
1990: R6	New Methods in Underground Engineering and Installing of District Heating Pipelines	90-72130-16-2
1990: R7	A technology assessment of potential telemetry technologies for district heating	90-72130-10-3
1990: R8	Guidelines for converting building heating systems for hot water district heating	90-72130-12-X

1990: R9	Advanced Energy Transmission Fluids Final report of research	90-72130-11-1
1990: R10	Heat Meters - Report of research Activities - Annex II	90-72130-15-5
1990: R11	Thermal Energy from Refuse Analysis Computer Program	90-72130-18-9
1990: R12	Summary of research activities 1987 - 1990	90-72130-19-7

Publications Annex III

Reports Title		**ISBN**
1992: P1	The environmental benefits of District Heating and Cooling	90-72130-36-7
1992: P1.1	DETECT Consequence model for Assessing the environmental benefits of District Heating and Cooling in a well defined area	
1992: P2	CFC-Free Plastic Jacked Pipes	90-72130-28-6
1992: P3	District Heating Piping with plastic medium pipes, status of the development and laying costs	90-72130-29-4
1992: P4	Bends for Plastic Jacket Pipe Systems, able to withstand high transverse loadings	90-72130-30-8
1992: P5	Consumer Heating System Simulation	90-72130-32-4
1992: P6	R&D Project Review	90-72130-33-2
1993: P7	Advanced Energy Transmission Fluids Final Report of Research, annex III	90-72130-34-0
1993:P7.1	The design and Operation of Ice-Slurry Based District Cooling Systems	90-72130-50-2
1993: P8	Quantitative Heat Loss Analysis of Heat and Coolant Distribution Pipes by Means of Thermography	90-72130-35-9
1993: P9	Promotion Manual for District Energy Systems	90-72130-39-1
	Brochure: ‘A Clean Solution? It is also your responsibility	

Publications Annex IV

Reports	Title	ISBN
1996: N1	Integrating District Cooling with Combined Heat and Power	90-72130-87-1
1996:N2	Advanced Energy Transmission Fluids for District Heating and Cooling	90-72130-94-4
1996: N3.1	Guideline to Planning and Building of District Heating Networks	90-72130-84-7
1996: N3.2	Bend Pipes	90-72130-83-9
1996: N3.3	Execution of Connections to Pipelines in Operation	90-72130-82-0
1996: N4	Quantitative Heat Loss Determination by Means of Infrared Thermography -the TX Model	90-72130-95-2
1996: N5	Efficient Substations and Installations	90-72130-88-X
1996: N6	Temperature Variations in Preinsulated DH Pipes Low Cycle Fatigue	90-72130-97-9
1996: N7	Managing a Hydraulic System in District Heating	90-72130-86-3
1996: N8	A review of European and North American Water treatment practices	
1997: N9	Summary of Research Activities 1993-1996	90-5748-001-8

Publications Annex V

Reports	Title	ISBN
1999: T1	Optimisation of Operating Temperatures and an Appraisal of the benefits of Low Temperature District Heating	90-5748-010-7
1999: T2	District Cooling, Balancing the Production and Demand in CHP	90-5748-009-3
1999: T3.1	Cold Installation of Rigid District Heating Pipes	90-5748-008-5
1999: T3.2	New Ways of Installing District Heating Pipes	90-5748-012-3

1999: T3.3	Reuse of Excavated Materials	90-5748-013-1
1999: T4	Fatigue Analysis of District Heating Systems	90-5748-007-7
1998: T5	District Heating and Cooling in Future Buildings	90-5748-006-9
1999: T6	Plastic Pipe Systems for DH, Handbook for Safe and Economic Application	90-5748-005-0
	Brochure: Information about the Use of Drag Reducing Additives in District Heating Systems	

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Notes