SUMMARY REPORT

of the
IEA Programme
on
District Heating and Cooling, including the Integration of Combined Heat and Power

ANNEX VIII

2005-2008

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Introduction

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

At the 2005 Gleneagles G8 an important role was given to the IEA in advising on alternative energy scenarios and strategies aimed at a clean, clever and competitive energy future. Two years later, at the Heiligendamm G8, it was agreed that “instruments and measures will be adopted to significantly increase the share of combined heat and power (CHP) in the generation of electricity”. District Heating and Cooling is an integral part of the successful growth of CHP: heat networks distribute what would otherwise be waste heat to serve local communities.

The IEA is active in promoting and developing knowledge of District Heating and Cooling: while the DHC programme (below) itself is the major global R&D programme, the IEA Secretariat has also initiated the International DHC/CHP Collaborative the kick-off event of which took place in March 2, 2007 with a 2-year Work Plan aiming to raise the profile of DHC/CHP among policymakers and industry. More information on the Collaborative is to be found on IEA’s website www.IEA-org.

The major international R&D programme for DHC/CHP

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

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

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

As one of the IEA's 'Implementing Agreements', the District Heating & Cooling programme is the major international research programme for this technology. Active now for more than 25 years, the full name of this Implementing Agreement is 'District Heating and Cooling including the integration of Combined Heat and Power'. Participant countries undertake co-operative actions in energy research, development and demonstration.

Annex VIII

In May 2005 Annex VIII started, with the participation from Canada, Denmark, Finland, the Netherlands, Norway, South Korea, Sweden, United Kingdom, United States of America.

Below you will find the Annex VIII research projects undertaken by the Implementing Agreement "District Heating & Cooling including the Integration of Combined Heat and Power".

Project title	Company	Number
New Materials and Constructions for Improving the Quality and Lifetime of District Heating Pipes including Joints – Thermal, Mechanical and Environmental Performance	Chalmers University of Technology Project Leader: Ulf Jarfelt	8DHC-08-01
Improved Cogeneration and Heat Utilization in DH Networks	Helsinki University of Technology Project Leader: Carl-Johan Fogelholm	8DHC-08-02
District Heating Distribution in Areas with Low Heat Demand Density	ZW Energiteknik Project leader: Heimo Zinko	8DHC-08-03
Assessing the Actual Energy Efficiency of Building Scale Cooling Systems	International District Energy Association Project leader: Robert P. Thornton	8DHC-08-04
Cost Benefits and Long Term Behaviour of a new all Plastic Piping System	NUON Project leader: Hans Korsman	8DHC-08-05

Benefits of membership

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

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

Membership proves invaluable in enhancing the quality of support given under national programmes. Participant countries benefit through the active participation in the programme of their own consultants and research organisations. Each of the projects is supported by a team of experts, one from each participant country. As well as the final research reports, other benefits include sharing knowledge and ideas and opportunities for further collaboration.

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

Information

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

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The IA DHC/CHP, Annex VIII, also known as the Implementing Agreement District Heating and Cooling, including the Integration of Combined Heat and Power, functions within a framework created by the International Energy Agency (IEA). Views, findings, and publications of the IA DHC/CHP do not necessarily represent the views or policies of all its individual member countries nor of the IEA Secretariat.

NEW MATERIALS AND CONSTRUCTIONS FOR IMPROVING THE QUALITY AND LIFETIME OF DISTRICT HEATING PIPES

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ABSTRACT

Polyethylene terephthalate (PET) foam seems to have the potential to compete successfully with PUR foam as insulating foam for district heating pipes of small dimensions at low temperatures (<100˚C).

INTRODUCTION

New materials and constructions for district heating pipes must be very efficient from different points of view: Mechanical, thermal, environmental and economical. In this project the efficiency of PET foam as an insulating material has been studied and the results will be briefly described below.

MECHANICAL PERFORMANCE

The mechanical performance has been studied using the European standard EN 253:2003 as the reference. This standard is written with respect to polyurethane (PUR) foams for pre-insulated district heating pipes. The standard applies for continuous operation at 120 ˚C for 30 years. However, for pipes of small dimensions, outer diameter ≤120 mm, both temperatures and mechanical loads are lower.

Compressive strength

The short-term compressive strength decreases with increasing temperature with a drastic change at approximately 80ºC. This is due to the material's glass transition temperature. It can be seen that the compressive strength at high temperatures does not fulfil the requirements of 0.3 MPa for the PUR foam according to EN 253. It should be kept in mind, however, that this requirement is likely unnecessarily conservative for small pipes.

The short-term elastic modulus behaves in a similar fashion, with an obvious temperature dependence and a significant drop of stiffness around the glass transition temperature.

Water permeability and vapour resistance

The tested PET foams were impermeable to liquid water and only vapour diffused through the PET foam. The vapour resistance was approximately 10 times greater for the PET foam than for a regular PUR foam.

Water absorption

The water absorption for PET foam was found to be 7 %- vol. The requirement on PUR foam in EN 253 is a maximum of water absorption of 10 %. PUR foam usually absorbs around 5 %.

Glass transition temperature

The results verify that the PET foams turn softer at approximately 80 ºC, as could also be seen from the short-term compressive strength measurements. It is not possible to make a direct comparison with PUR. PUR is a thermoset material which does not undergo this kind of phase transition.

Creep behaviour

The creep properties of PET foam seem to be very good. Extrapolation of the creep curves to 30 years of technical service does not indicate any significant creep deformation, neither at room temperature nor at 80 ºC.

Flexibility – bending properties

Samples of PET taken parallel to the extrusion direction are much stiffer and much more brittle, while samples taken parallel to the cross direction are so flexible that no fracture was seen up to the testing limit of 12 % strain. The material can easily be processed to withstand bending strains to a sufficient degree for flexible district heating pipes.

The PUR foams behave in a little more brittle manner. The "flexible" PUR foam did not exhibit a significantly more flexible behaviour than the rigid PUR foam. A strain limit of approximately 11 % was seen for both materials. It is also interesting to note that the flexible foam is much stiffer than the rigid foam.

INSULATING PERFORMANCE

A newly produced PUR foam has a little lower thermal conductivity than a new PET foam (both foams were blown with cyclopentane and of the same density). The difference depends mainly upon smaller cells and a lower content of air in the cell gas of the PUR foam.

In microcellular PUR foams the cell size is around 0.1-0.2 mm and in the PET-foams studied the cell size varies between 0.6 to 1.0 mm. However, the PUR foam has been developed during more than 50 years but the PET foam during less than 10 years and can thus be expected to be further developed. In the future a new PET foam will probably exhibit the same thermal conductivity as a PUR foam.

The results from the determination of the diffusion properties gave a clear cut indication that the long term thermal performance of a PET foam is better then that of a PUR foam. The effective diffusion coefficients of oxygen, nitrogen and carbon dioxide in a PET foam are about 5-15 times lower than those in a PUR foam.

The long term thermal conductivity has been calculated for three different district heating pipes of the same dimensions (DN 40/125): 1. PUR foam insulation, 3.0 mm thick polyethylene casing, 2. PET foam insulation, 3.0 mm thick PET casing and 3. PET foam insulation without any casing. See Figures 1-3 and Table 1. In these calculations it was assumed that the PET foam had been further developed so that the cell sizes of the PET and PUR foam were the same. Due to the slow diffusion in the PET foam, the decrease of insulating capacity of the PET foam insulated pipe without casing is even less (about 6%) than that of the PUR insulated pipe with 3.0 mm HDPE casing (about 16%). The PET insulated pipe with 3.0 mm PET casing exhibits the slowest decrease (about 3%) of insulating capacity during 30 years among the three alternatives studied.

Table 1. The equivalent thermal conductivity and heat losses for PUR and PET insulated district heating pipes (DN40/125) over an operation period of 30 years.

Type of pipe		Equivalent over 30 years	
Insulation	Casing	Thermal conductivity of the foam $W \cdot m^{-1} \cdot K^{-1}$	Heat Flow $W \cdot m^{-1}$
PUR	HDPE 3mm	0.0294	13.3
PET	PET 3mm	0.0256	11.6
PET	no casing	0.0288	13.1

ENVIRONMENTAL PERFORMANCE

From the present study it can be concluded that PET foam has the potential to compete successfully in terms of environmental performance with cyclopentane blown PUR foam as insulating foam for district heating pipes. The possibility to produce cyclopentane blown PET foam of low density will increase the competitiveness of PET foam. Unfortunately this possibility did not exist at the time of the environmental study. Commercial methods to produce PET foam for the insulation of district heating pipes must be developed. Utilization of recycled PET can reduce the environmental impacts from the production phase of the pipes life cycle and would contribute to the efficient use of resources in society.

There is also a need to find alternatives to PUR foam, due to the toxicity of the isocyanates, one of the main components in PUR foam production. Another aspect is that welding close to PUR foam may give rise to high concentrations of hazardous compounds in the work environment.

ECONOMIC ASPECTS

The prices of PET and PUR foam have been about the same during the last years. The possibility of utilising recycled material in the production of PET foam will decrease material costs.

CONCLUSIONS

According to the present study PET foam seems to have the potential to compete successfully with cyclopentane blown PUR foam as insulating foam for district heating pipes of small dimensions at low temperatures (<100˚C).

ACKNOWLEDGEMENTS

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Dr. Stefan Forseaus Nilsson, Swedish Research Institute, is responsible for all mechanical tests.

Dr. Morgan Fröling, Department of Chemical Environmental Science, Chalmers University of Technology, Sweden. is responsible for the environmental study.

Dr. Camilla Persson, Department of Building Technology, Chalmers University of Technology, Sweden, has performed the calculations necessary for Table 1 and Figures 1-3.

The PET foam was produced by B.C. FOAM s.p.a., Volpiano, Ttaly.

REFERENCES

The full report with all references will be published by IEA.

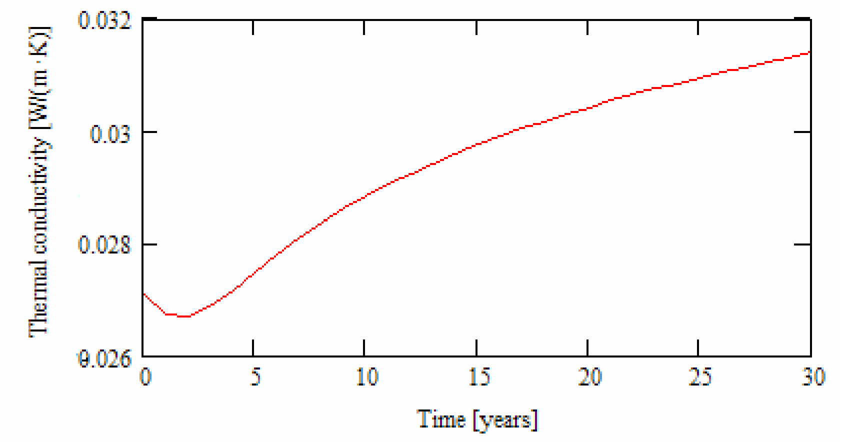

Figure 1. Thermal conductivity over time for a PUR insulated district heating pipe (DN40/125). Service pipe temperature 80 ˚C and casing temperature 15 ˚C. Casing material HDPE, thickness 3.0 mm.

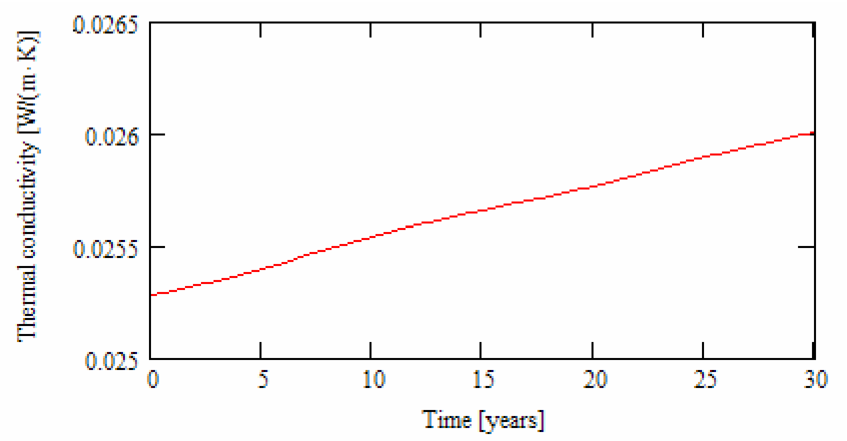

Figure 2. Thermal conductivity over time for a PET insulated district heating pipe (DN40/125). Service pipe temperature 80 ˚C and casing temperature 15 ˚C. Casing material PET, thickness 3.0 mm.

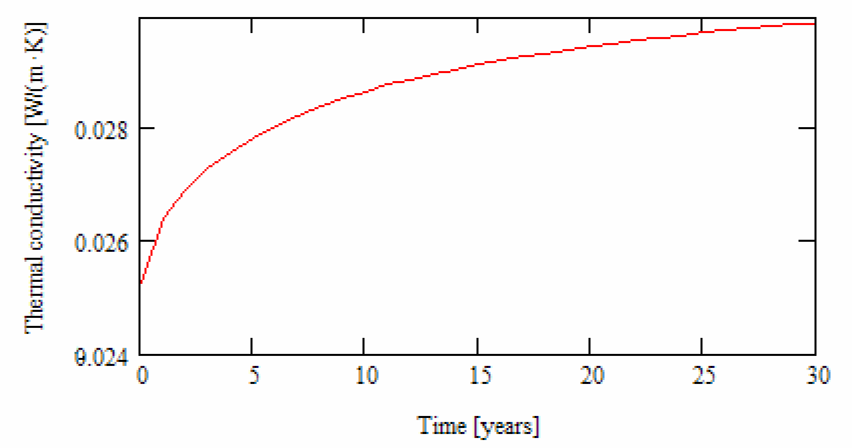

Figure 3. Thermal conductivity over time for a PET insulated district heating pipe (DN40/125). Service pipe temperature 80 ˚C and outer surface temperature 15 ˚C. No casing.

IMPROVED COGENERATION AND HEAT UTILIZATION IN DH NETWORKS

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ABSTRACT

A cogeneration plant supplying a single building or connected to a small DH network is usually heavily dependent on the heat demand. Long-term heat storing can make it possible to produce more electricity in the cogenerationplant, to use biofuels or other renewable fuels instead of fossil fuels and to connect new areas to the network. The investigation of these issues requires knowledge on the heat load profiles of the network and the electricity production of the cogeneration plant. In addition to thermal storage, the cogeneration can be improved by using CHP process configurations which have high power production efficencies at partial heat loads.

OBJECTIVES/GOALS

The objective of this project is to evaluate and develop approaches that will inprove the economic feasiblity and the thermal efficiency of cogeneration through better utilization of the produced heat and higher power generation in the CHP plant. The results can be applied both in cogeneration plants producing electricity, heat and cooling for a single building and in a district heating network system situated in or near areas with low heat densities. The economic feasibility of cogeneration in small DH networks is currently low and should be increased for future expansion of district heating.

In this project, a general load model will be constructed for esimating demand profiles for simultaneous DH and power loads. The model will be needed for both considering the suitability of CHP and long-term thermal storages (storage period longer than a few days) for the total system and for finding the best conditions for thermal storage use in the system. Long-term thermal storages and their usability for supplying heat or cooling in low heat density areas e.g. to new housing or industrial areas situated at longer distances from the existing main network will be investigated. Also possibilities for the combined use of cogeneration plants and long-term storages either connected to a single building or a small DH network will be considered. The power production of the cogeneration plants will be improved by searching the most efficient way to utilise the thermal storages with one or several CHP plants and by selecting those modules to the CHP process which have the economically feasible electrical efficiencies also during part load operation.

The goal of the project is to provide new possibilities to increase economical feasibility and thermal efficiency of cogeneration plants with efficient utilization of the produced heat with long-term thermal storage. This enables more efficient electricity production even in lower heat loads and gives possibilities to expand the district heating production to low heat density areas. Also the possibilities to increase the power porduction in the cogeneration pocesses are investigated. A model for heat and power loads is developed as well as an optimisation method for the most efficient thermal storage integration to the cogeneration plant and to the network.

TARGET AUDIENCE AND BENEFITS

The results are useful for district heating companies looking for possibilities to expand their networks to new and possibly remote residential or industrial areas. Also the manufacturers of smaller cogeneration units benefit from the improved heat utilization possibilities. Manufacturers of steam cycle CHP plants can utilize the results for improved electrical efficiency of the process and for optimal integration of plants with a thermal storage.

The results are assumed to benefit all participating countries, e.g. Sweden, which have a low share of CHP and rural areajs with small DH networks. Countries like Finland with small heating plants, that would need a profitable way to include electricity production in these processes would benefit from the project, as well as countries like Denmark that are actively developing small-scale CHP and DH systems to serve small communities. The more credible heat and electricity demand profiles benefit many countries, e.g. Norway, when the profitability of cogeneration use in a new site is evaluated. Countries, like UK or Canada, which have relatively low shares of DH connected with CHP can use the results when they are looking for new ways to increase the efficiency and the market share of cogeneration. Countries like Netherlands, which are aiming to maximize the environmental benefits of their small-scale CHP plants connected to DH networks, will benefit from the results.

ACKNOWLEDGEMENTS

This work is a research project within Annex VIII of the Implementing Agreement DHC-CHP within a framework created by the International Energy Agency (IEA)[1].

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[1] `http://www.iea-dhc.org/`

District Heating Distribution in Areas with Low Heat Demand Density

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Summary

The following measures leading to improved system economy were analysed, according to the following main sections of the project:

a. Techniques for reduction of piping costs and heat losses from heat distribution networks (DK)

b. Increased use of district heat instead of electricity in households (SE)

c. Load profiles and operational analyses of areas with low heat demand density (FIN)

The project was organised in such a way that each of the partners had the main responsibility for one of the areas of interest indicated above. However, all project partners of the other countries are supporting the responsible lead partner with relevant input from their own countries, thus covering a broad district heating experience.

Background

In many countries with long district heating tradition, such as is the case in Scandinavia, district heating is well developed and the market development has been slowed by increased use of energy efficiency measures in buildings. When available at all, district heating reaches often about 80 -90 % of the central city area. In the areas with lower heat demand density surrounding the city centre, often only 10-15 % of the buildings are connected to the district heating system. One way to allocate an increased market share to district heating is to apply new measures/techniques for supplying heat into areas with lower heat demand density that to date have not been considered economically suitable for district heating. Among the investigated alternatives are measures for making heat distribution more efficient as well as new heating applications. As a result, heat distribution in areas with low heat demand density could be done more effectively and at lower cost.

The objective of this project is to propose and to analyse measures for improving the economy of heat distribution in areas with low heat demand density. The consequent application of these measures will not only reduce distribution costs but also the environmental impact of energy use in these areas.

Systems with low heat density are struggling with relatively high investment costs and high heat losses. One way to reduces these costs would be to make components smaller and lower the amount of groundwork in the distribution net. Another way is to distribute more energy in the same piping structure, hence decreasing the relative amount of fixed costs of the delivered energy. Therefore, in this report we are first presenting new technologies that are on the frontier for application in district heating systems. This holds as well for the heat distribution system as for systems using heat. We describe technologies that have been used in demonstrations projects or in real projects such as new types of pipes (i. e. triple pipes) or only just in the laboratory (egg-shaped pipes). For the same purpose, we present new distribution methods, such as small service pipes with booster pumps or small pipes in combination with heat storage units. In addition, we describe components and measures, which can gain worldwide interest for their capability of replacing electricity by heat, in our case district heat.

Cost analyses are critical for the outcome of this report. By analysing real systems, we were able to calibrate other programs used for cost calculations. Because project costs can be very site-specific and costs of different systems on different places are usually very difficult to compare, we concentrated in this project on the cost comparison of systems constructed with comparable cost structures. These system comparisons were applied on the systems analysed from Finland and Denmark, leading to some general conclusions about the systems to be used in areas with low heat density.

Concerning the use of energy, we are presenting measures for increasing district heating loads without wasting energy. We give example of systems in which the use of district heat is increased at the expense of electricity use. Households can be provided with equipment such as heat driven washing machine, dishwasher and tumble-drier. In the future, people may want to increase their comfort by using air-conditioning, pools and spa-tubs and possibly other equipment such as car heaters and greenhouses, all of those supplied with district heat instead of electricity. This saves not only electricity for other and exergetically more favourable applications, it will also help to compensate for decreasing heat loads and to maintain heat distribution efficiency.

Content of the report

The report contains the following main chapters dealing with the questions of heat demand, distribution systems and new loads suitable for areas with low heat demand density.
Chapter 1 - “Introduction” presents the background and introduces the problem area.
Chapter 2 - “Heat demands for district heating” - discusses after the Introduction the basic load conditions for practical district heating networks and describes the relation of heat density and line heat demand. It also shows examples for the lower limits of heat density in district heating and elucidates how measures for energy saving on the one hand and new district heating loads on the other hand can shift these limits.
Chapter 3 - ”Examples of applications with low heat demand” describes examples from sparse district heating applications realised in Sweden, Finland and Denmark. The intention of this chapter is to show how district heating is used in areas with low heat demand density, and which losses and other typical system conditions are prevailing for such systems.

Chapter 4 - "Evaluation of loads in district heating systems with low heat demand density" describes the evaluation of two systems with low heat demand density: Neidonkallio near Espoo, Finland and Peter Freuchenvej in Nykøbing/Falster, Denmark. In Neidonkallio, the energy for space heating is delivered via substations with two heat exchangers in parallel, one for space heating and one for hot water preparation. In the Peter Freuchenvej-system, this solution is used in a couple of buildings, whereas the majority of the buildings have direct-connected radiators and a hot water storage tanks fed by district heating.

Chapter 5 - "Techniques for reduction of piping costs and heat losses from heat distribution networks" discusses methods and techniques that in recent years have been developed especially for areas with low heat demand density. A great deal of the development has been achieved in development projects in Denmark, Sweden and Finland. Compared to standard technology, these achievements concern new material for pipes and insulation, new design of pipes, methods for routing district heating pipes, and in addition how to reduce heat losses by other measures, i. e. reduction of pipe diameter in combination with advanced flow control.

Chapter 6 - "Cost model for heat distribution systems in areas with low heat demand density" presents a simple cost model for local district heating systems to be used for applications with low heat density. The model itself is based on spreadsheets created in Excel that are constructed so that they show system costs for alternative construction layouts applied on the same system. This cost model is applied on the two system analysed in detail for this report, i.e. and Neidonkallio and Nykøbing.

Chapter 7 - "Increased use of district heat instead of electricity in households" shows how the load of detached houses can be increased, partially by shifting the energy use from electricity to district heating. The chapter describes methods for increased utilisation of district heating that were demonstrated in a project in Gothenburg, Sweden. It also describes how the total load would change if some of these loads were to be used in row houses in Neidonkallio.

Chapter 8 - "Improved system solutions" describes results of system analyses performed to illustrate eventual cost saving that can be received by careful system design. Essentially, the main changes are use of twin pipes instead of single pipe systems, use of smaller pipe dimensions, eventually with booster pump, varying insulation thickness, new routing (house-to-house) and the use of hot water tanks instead of directly connected hot water preparation. Two systems, one in Finland (Neidonkallio) and one in Denmark (Nykøbing/Falster) are investigated.

Chapter 9 - "Connection of future areas with low heat demand density". This chapter summarises the most important items for achieving cost-effective connection of buildings in areas with low heat demand density, for example small customer loads such as detached houses. The chapter presents a checklist of items that are important for cost reduction when planning a district heating distribution net, either for an area with existing detached houses or for new development. Minimizing pipe dimensions and groundwork is important in any case. In addition, different ways to connect substations are discussed. Finally, the importance of reaching a high degree of connection for local district heating net is underlined.

Chapter 10 - "Conclusions" summarises the quintessence of the work and gives recommendations for future applications.

Chapter 11 collects all *"References".*

Additional information about how to calculate heat losses and further costs comparisons for alternative system solutions are collected in the *Appendices*.

Final conclusions

A main conclusion of this report is that a number of techniques and measures are available to help reduce costs for heat distribution in areas with low heat demand density. Expressed in terms of heat densities, we believe that areas with a heat density of 10 kWh/m^2,yr or with line heat demand of 0.3 MWh/m,yr can be economically served by district heating.

Based on a number of projects, it has be determined that district heating, in order to achieve good economy for low heat demand density, requires more careful planning than traditional district heating. In many cases, alternative solutions that do not follow the traditional district heating manuals can be successfully applied and will give lower costs. Some of these alternative solutions may in the future find their way into handbooks for sparse district heating design, while others for now must be considered as unusual measures and analysed carefully before being applied.

The first preinsulated networks were in use in the late 1960'ties and thus many old systems are in need for renovation. The recommendations given here for better design and reduced heat losses in new DH systems are of course also valid for the renovation of old systems.

The following provisions have been found to affect the total costs of connection to district heating:

System design

- Examples from Denmark have shown that *low pressure and low temperature systems* with direct connection of the radiator system can reduce costs. Such systems can either be used in small local networks or as secondary systems connected to main district heating systems.
- System design that *reduces pipe dimensions* is important in design of systems for detached houses. Such systems can be systems with *hot water accumulators* instead of directly connected heat exchangers, or service pipes with reduced diameter and ultimately even a *booster pump* for adequate heat supply.
- House-to-house connection is already a classical way to connect detached houses. However, it is difficult to get the customer interested due to larger impact on their premises. On the other hand, in connection with lower system costs and rewards for own work, it is possible to implement this method of reducing connection costs.
- The *degree of connection* is an import issue for both the utility and the customer, because the fixed costs decrease with the number of customers. This accentuates the importance of investment in marketing and dissemination of information to the potential customers from the very beginning of a project dealing with new connections to an area.

District heating pipes

Pipes have a twofold impact on the system costs: *Investment and heat losses*. All measures that can reduce one of these are of interest, such as good *insulation performance* and *advanced pipe design.*

- The thermal conductivity of polyurethane insulation depends on the temperature as well as on the time elapsed since the foam was produced (ageing). Heat losses and heat loss coefficients can be accurately calculated for single, twin and triple buried heating pipes.
- New types of pipe systems are compared in respect to their possible installation costs and heat losses. *For an 80 mm (nominal) distribution pipe,* we compared a pair of single pipes with a *circular twin pipe* and with an *egg-shaped twin pipe*. We found that the egg-shaped pipe reduces the heat loss by 37 % and the investment index by 12 % compared with the pair of single pipes.
- For *service pipes* a pair of single pipes ø 25/77 mm is the reference case. We found that the *triple pipe* (a system with two smaller supply pipes and one return pipe, one of them used in the case of high hot water consumption) reduces the heat loss by 45 % compared with the reference case and by 24 % compared with a *circular twin pipe*. The reduction in investment index can be up to 20 %. New alternative designs of service pipes, involving a combination of co-insulation, asymmetric insulation, and dissimilar dimensions of two or three media pipes, have the potential to achieve saving of roughly 50 % compared with traditional pair of pipes.
- *Service pipes* should be as small as possible and no reserve capacity should be calculated for. Similar holds also for the distribution pipes. Taken future energy saving measures into account, reserve capacity should only be taken into consideration if it is obvious that additional loads will be connected in the future.

Civil works

The classical trench design is for double pipes with drainage bed. In accordance with local conditions, the trench can be made smaller with corresponding reduction of excavation work and handling of soil volumes. The following measures are possible:

- The use of twin pipes is mandatory in systems with low heat demand density. The reduction of excavation work is a clear cost advantage.
- Reduction of pipe dimension may in many applications result in a smaller trench, which should be taken advantage of if possible.
- Reduced ground cover can be applied in piping without traffic loads. Hence, the routing should take advantage of such possibilities (parks, gardens, sidewalks).
- Drainage bed pipes can often be omitted, especially in trenches for service pies.

New loads

District heating systems should be marketed to new customers with an additional benefit: District heating can deliver part of the energy, which to date has been supplied by electricity. Eventually, this could cover a broad spectrum of applications. In the beginning, new applications could be the white goods *washing machine*, *disk washer* and *tumble dryer*. Small absorption cooling for air conditioning systems and heating of pools and spa-tubs are other potential applications.

An example is a demonstration of new loads in Gothenburg (Sweden): There it was shown that 7500 kWh of district heating could replace 5500 kWh of electricity. This application resulted in 35 % reduction of primary energy (based on power generated from a coal condensing power plant).

Evaluation and system analysis

System analyses have been verified with system simulations for Neidonkallio and Nykøbing/Falster. The analyses compare the total cost for different pipe systems and district heating solutions, such as: single pipes, twin pipes, triple pipes, reduced pipe dimensions, systems with booster pumps in service pipes and systems with hot water accumulator instead of direct hot water heat exchanger.

The results of these analyses conclude that costs could be reduced by about 25 % in smaller systems (Nykøbing/Falster) and by 40 % in larger systems (Neidonkallio).

Reference

Heimo Zinko et al: District Heating Distribution in Areas with Low Heat Demand Density. IEA-Report. IEA-DHC Annex VIII, 2008:8DHC – 08-03.

Assessing the Actual Energy Efficiency of Building Scale Cooling Systems

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Summary

When comparing the economics and efficiency of district cooling service to in-building air conditioning systems, it is important to consider the full operating costs of in-building equipment over a range of load conditions; with chillers operating at part loads; auxiliaries designed for peak conditions; and in-building systems often over-sized for safety factors and impacted by various performance degradation and depreciation.

This project sought to collect data on actual operating costs and performance of in-building chiller plants in order to better understand cooling requirements, costs and efficiencies in comparison to district cooling service. The project team found very limited data of relevance on actual building system performance that included operating costs for full systems related to cooling requirements. Data tended to focus on chiller electricity performance but did not consider the full systems involved in cooling output and did not measure actual cooling delivered for comfort or process to the building space. Industry data on buildings that had converted to district cooling provided a before/after scenario to analyze the building chiller system performance.

Background

The costs, energy efficiency and environmental impacts of District Cooling (DC) are often compared to those of building-scale cooling systems. In such comparisons, the assumptions regarding the efficiency of building-scale systems have a significant impact on the comparative economic conclusions as well as the analysis of efficiency and the related environmental impacts. Generally, the assumptions for building systems are based on theoretical values or chiller equipment ratings based on static laboratory conditions rather than "real world" data reflecting part load operations, weather variations, operator inputs, full system operation (including auxiliaries); actual cooling loads and system depreciation. This may result in underestimation of the economic, efficiency and environmental benefits of district cooling service.

Intent of the Report

This project set out to develop more realistic data on building-scale air conditioning system efficiencies, by investigating the actual annual efficiency of building cooling systems and determining how this differs from the theoretical annual efficiency using values based on test conditions. Particularly when considering all auxiliaries (e.g. cooling tower fans, pumps) and the relative frequency of part load vs. full load operating conditions, the annual operating efficiency could differ dramatically from the stated efficiency at design conditions.

The objective of this project was to 1) conduct a literature search to find documentation of real world air conditioning system operations; 2) to collect data from multiple sources and variety of building types; and 3) to evaluate "before/after" conditions in buildings converted to district cooling service. The report was intended to be useful for realistic comparisons of DC to building-scale systems in a number of contexts, including:

- marketing of DC service to prospective customers by DC utility companies;
- municipal planning for a development area;
- private sector planning for multi-building developments; and
- local, national or EU energy/environmental policy analysis.

The fundamental question this project attempted to answer is "What is the total real-world annual electrical efficiency of building-scale chiller systems?" The investigation was focused on larger buildings (peak cooling load >200 tons or 700 kW), although some data on smaller systems was obtained and is presented.

Content of the Report

The report contains the following main sections:

Introduction - provides an overview of the project hypothesis and the background for the project.

Key Technical Variables and Measures - discusses basic efficiency measures such as Coefficient of Performance (COP) and KW/Ton efficiency. Coefficient of Performance (COP) is the ratio of the rate of heat removal to the rate of energy input at a specific set of load and condensing conditions. More efficient systems have a higher COP. Since this parameter is a ratio, consistent application of any unit of energy can be used, e.g., COP = kilowatts (kW) cooling output / kW power input. kW/ton Efficiency is another measure of cooling system efficiency and is often used in the USA. One ton of cooling is equal to the removal of 3.516 kW (12,000 Btu per hour) of heat.

This section of the report reviews the key variables affecting system efficiency, in order to provide a context for the later discussion of data. These variables include but are not limited to:

- Type of chiller equipment
- Sizing of chiller(s) and cooling tower(s) relative to seasonal loads
- Condenser temperature
- Chilled water supply temperature
- Use of variable frequency drives (VFDs)
- Age of equipment and maintenance history

The report looks at annual efficiency comparison measures used for chiller selections including ARI 550 (IPLV and NPLV) and other technical guidance including ESEER; ASHRAE Guideline GPC 22 and ASHRAE Standards 90.1 and the Energy Performance of Buildings Directive (EPBD).

Modelling has the advantage that it is known that the comparison is between exactly similar situations, except for those aspects that have been deliberately changed. It also allows comparable results to be produced for different climates and systems. The disadvantage is that the results are only as good as the models used, and the models do not capture the negative impacts of performance degradation due to suboptimal operation and maintenance practices.

Prior Studies - looks at search results for similar studies performed in North America and Europe and finds limited relevant data that properly tracks building cooling loads relative to equipment energy consumption. While a great deal of attention is given to the efficiency of the chiller itself, we have found very few studies or data relating to the total plant efficiency including the auxiliaries (cooling tower fans, condenser water pumps). Auxiliaries can have a significant negative impact on annual efficiency, particularly if fans and pumps are driven by fixed speed motors rather than variable frequency drives. The chiller plant equipment of interest is that required to produce cooling, i.e. chillers, cooling towers, condenser pumps, and in some cases chilled water pumps* along with special equipment such as cooling tower sump heaters and water conditioning equipment. Chilled water pumps are asterisked because they are not part of the equipment that produces the cooling in these chiller plants. They move the chilled water from the plant to the terminal equipment in the building HVAC system. The primary pumps in primary/secondary pumping may be an exception, since they are there to pump constant flow through each chiller.

Data Obtained in this Study - explores challenges involved in collecting relevant data and the complexity and costs associated with data gathering; storage and analysis. Indirect measurement has the advantage of reflecting actual rather than theoretical conditions, but it is difficult to ensure that conditions are truly the same for the pre-connection and post-connection measurements (or to reliably compensate for any differences). Such differences may arise, for example, because of weather or changing occupancy. Direct measurement is best, but it is expensive and time-consuming to implement. The scope of this study did not provide adequate budget for installation and monitoring of metering equipment in test settings.

Findings

There are three basic approaches to assessing chiller system efficiency:

- Modelling, typically using detailed building and system simulation;
- Indirect measurement (monitor changes in total building electricity consumption after a building is connected to district cooling, and compare the reduction to the measured chilled water consumption following connection); and
- Direct measurement (submetering) of chiller system components and chilled water production.

This project set out to develop more realistic data on building-scale system efficiencies, by investigating the actual annual efficiency of building cooling systems and determining how this differs from the theoretical annual efficiency using values based on test conditions.

Many variables affect the efficiency of building chiller systems, including type of chiller equipment, size of chillers and cooling towers relative to seasonal loads, condenser temperatures, chilled water supply temperatures, use of variable frequency drives (VFDs) and the age and maintenance history of the equipment.

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Very few data are available that directly quantify the actual annual efficiency of building-scale chiller systems through sub-metering, and some of the data obtained had gaps or flaws that constrain their usefulness. Limited case study data on submetered building chiller systems are reported in the literature.

Sizing of Chillers and Cooling Towers Relative to Load

The experience of the international district cooling industry over the past 30 years is clear: conventional load estimation methodologies and software tend to overstate peak loads. This is understandable, given the consequences of underestimating loads for the purposes for which these methods are used. The last thing a consulting engineer wants is to be blamed for inadequate capacity. Consequently, typical load estimation methodologies tend to result in unrealistically high load estimates. Design practices that contribute to high load estimates include:

- Using inappropriately high design temperatures for wet bulb and dry bulb;
- Assuming the peak dry bulb and wet bulb temperatures are coincident;
- Compounding multiple safety factors; and
- Inadequate recognition of load diversity within the building.

The result of overestimation of load is oversizing of chillers and cooling towers, which contributes to operation of systems at suboptimal levels during much of the year. Poor operations, particularly lack of attention to chiller staging, can exacerbate this problem.

Part Load Performance

During the last 15 years, great improvements have been made in part-load efficiency of commercially available chillers. “Part-load performance” of chillers is usually presented based on corresponding decreases in entering condenser water temperature (ECWT) as the load decreases. At a fixed ECWT, the efficiency of older chiller compressors dropped significantly at lower loads. With today’s state-of-the-art chillers, constant-speed chiller efficiency degrades very little until load drops below about 40%. With variable-speed chillers, efficiency is actually maximized at about 50% loading, with kW/ton increasing as load goes up or down from that level. Below 40% loading the efficiency of even variable-speed compressors degrades significantly.

Other Performance Factors

Other variables affecting system performance include condenser temperatures; chilled water supply temperatures; application of variable speed drives on pumps and motors; and the age and maintenance of systems. Isolating these variables to determine relative impact on cost and efficiency is a challenging endeavour.

Although it is possible to obtain very high seasonal efficiencies (less than 0.65 kW/ton) with well-designed, well-operated all-VFD plants operating in favorable climate conditions, during the course of this study we were unable to obtain primary data documenting such performance.

There were also very few data available for the indirect analytical approach to quantifying building chiller efficiency – by comparing building electricity consumption before and after connection to district cooling, and using post-connection cooling consumption data to estimate the efficiency of the building chiller system operations thus eliminated.

Conclusions

Many variables affect the efficiency of building chiller systems, including type of chiller equipment, size of chillers and cooling towers relative to seasonal loads, condenser temperature, chilled water supply temperature, use of variable frequency drives (VFDs) and the age and maintenance history of the equipment.

Very few data are available that directly quantify the actual annual efficiency of building-scale chiller systems through sub-metering, and some of the data obtained had gaps or flaws that constrain their usefulness. Limited case study data on submetered building chiller systems showed the following annual average kW/ton: air cooled 1.50, variable speed screw 1.20, ultra-efficient all variable speed with oil-less compressors 0.55, and district cooling plant 0.85 kW/ton.

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Limited case study data on electricity consumption before and after connection to district cooling yielded calculated annual efficiencies as summarized below.

Building Name	Location	Chiller type	Calculation method	Average annual kW/ton
Gross Chemistry	Duke University, NC	Water-cooled	1	1.33
(Confidential)	Phoenix, AZ	Water-cooled	1	1.25
ITS Franklin	UNC Chapel Hill, NC	Air-cooled	2	1.21
Cheek Clark	UNC Chapel Hill, NC	Air-cooled	1	0.92

Calculation Methods

1. Based on electricity consumption before and after connection to district cooling, and cooling consumption following connection.
2. Submetering of chiller system.

Reference

Robert Thornton, et al: Assessing the Actual Energy Efficiency of Building Scale Cooling Systems, IEA-Report. IEA-DHC Annex VIII, 2008:8 DHC- 08-04.

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COST BENEFITS AND LONG TERM BEHAVIOUR OF A NEW ALL PLASTIC PIPING SYSTEM

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INTRODUCTION

The predominant piping system in the District Heating (DH) industry over the last century consists of a steel medium pipe, polyurethane (PU) insulation and a polyethylene (PE) outer casing (abbreviated to St/PU/PE). This system performs very well. However, steel may rust and the insulation properties of PU may suffer under the influence of water. Therefore, joints have to be made with care and require a certain level of workmanship.

From this perspective, an all plastic piping system might have some distinctive advantages. Plastics do not corrode (that is, a lot slower than steel). Some plastics are extremely flexible and allow for transportation on reels for rather large diameters, thus reducing the number of joints (figure 1). Some plastics may even be welded.

Fig.1. plastic piping in long lengths on reels

This paper describes the summary of the report on “Cost benefits and long term behaviour of a new all plastic piping system” [1], subject of the IEA Implemental Agreement on DH&C Annex VIII. This report focuses on an all plastic piping system, with polybutylene medium pipe, PE foam insulation and an outer casing made of PE (abbreviated to PB/PE/PE systems). Because this is a new piping system, different aspects of the application of this system compared to conventional piping systems are investigated.

LIFE CYCLE ASSESSMENT

Life cycle assessment of the different piping systems shows the impact of several life cycle stages on the environment. One clear conclusion is the dominance of heat loss on the environmental impact [2]. The contribution of heat loss can be subtracted from the long utilisation period of district heating systems. The life time of a pre-insulated pipe, which is about fifty years, is very long. Increasing the utilisation period of the district heating system only enlarges the contribution of heat loss on the environmental impact.

Enhancing the products performance (e.g. increasing insulation thickness) leads to a lower environmental impact. Increasing insulation thickness can not be done endlessly because there is an optimum between insulation thickness extension (decreasing heat loss) and surface extension (increasing heat loss). For economic reasons the optimum for increasing insulation thickness may be around ten percent of the actual insulation thickness. The production phase will consequently rise in impact contribution, but since the effect of production on the total impact is less than one percent, this increase is acceptable from an energetically point of view.

COST BENEFIT ANALYSIS

For both high and low density district networks, costs for materials and installation of the PB/PE/PE system are comparable to conventional St/PU/PE networks [2]. The use of twin pipes only decreases the investment costs due to smaller trenches and lower network lengths. Also, twin pipes (in theory) have lower heat loss which leads to lower costs over its lifetime.

Costs for piping length is the most determining factor in total costs for plastic pipe networks.

Installation costs for the plastic pipe system are uncertain, because experience with the system is still very limited. Costs for installation of the PB/PE/PE system therefore can be seen as a maximum, that will decrease as contractors become more experienced with the system.

Fig.2. Installation of plastic pipes still requires some experience

LONG TERM BEHAVIOUR

Three studies have been conducted on the long term behaviour of the new all plastic piping system. The first study concerns an assessment of the thermal insulation by polyethylene foam. The second study presents the quantification of the change in the thermal insulation of the PE foam as a function of the exchange of gas or vapour between foam cells and the environment. The third study describes the risks for corrosion due to oxygen diffusion through plastic piping systems for the total system, heat exchangers, radiators and couplings.

The fraction of open cells was determined experimentally. The final result of these experiments is that the fraction of open cells is not exceeding 6 ± 3 %. The temperature gradient, heat loss and the water flux were calculated for several situations.

The main conclusion of this study by TNO Science and Industry is that insulation properties of PE foam deteriorate significantly when wet, even though the material itself seems to remains intact, whereas PU may degrade. So in order to reach optimum performance, the system needs to be dry. Because water vapour can diffuse through the PB pipe and PE foam, water condensation can occur in the foam cells. This, however, is a very slow process that takes 30 years in the worst case before all foam cells are filled with water.

Fig.3. Example of welding the PB pipes

Calculations to quantify the ageing of foam insulated pipes for district heating are also performed by TNO Science and Industry. The foams studied are PE (polyethylene) foam in the PB/PE/PE system and rigid PU (polyurethane) foam in the steel pipe system.

The initial value for the heat conductivity of the PU foam in the St/PU/PE system is similar to the PE foam of the PB/PE/PE system. The characteristic ageing time is longer for the steel pipe system as a result of the larger medium pipe and casing thickness, which forms a larger barrier for oxygen and nitrogen.

It is expected that the ageing rate of PE and PU foam will be almost identical if both foams are insulated by the same plastic casing. The permeation behaviour of the casing and medium pipe for blowing agent, oxygen and nitrogen is decisive for the ageing rate.

A major threat to heating systems is the diffusion of oxygen through plastic materials. As a consequence there is a risk for corrosion in the steel and copper components of the total system, e.g. heat exchangers, radiators and couplings. To overcome the diffusion of oxygen through the PB medium pipe, the PB/PE/PE system is supplied with an EVOH coating. This is a diffusion barrier that reduces the ingress of oxygen. Nevertheless there is still a certain amount of diffusion of oxygen, even with the EVOH barrier.

The wall thickness decrease over time of steel components is acceptable in case of an equally distributed corrosion attack, but oxygen may initiate localised corrosion, for instance pitting corrosion. At the joints of the PB tubes with the carbon steel tubes the oxygen levels are at the max and this oxygen will react instantaneously with the carbon steel. The corrosion also takes place at locations with a thin protective layer and with conditions that foster corrosion. The risk of severe localised corrosion (pitting) in the carbon steel parts under the mentioned conditions is not quantitatively predictable. But if pitting occurs, it is an out of control process and corrosion rates of mm/year are possible.

A key issue is to maintain an optimal water quality and prevent ingress of air and salts because the occurrence of pitting corrosion is strongly promoted by the presence of salts, especially chlorine.

HEAT LOSS ANALYSIS

With the study on ageing of the insulation foams and heat loss formulae, the heat loss of both plastic and steel systems are determined and compared. Also measurements are performed to provide an experimental foundation [3].

The current PB/PE/PE system contains an air gap between the medium pipe and insulation foam, causing higher heat loss results than theoretically predicted (figure 4). An effective insulation thickness is therefore calculated, resulting in an effectiveness of the insulation foam of 84% with regard to the expected insulation performance.

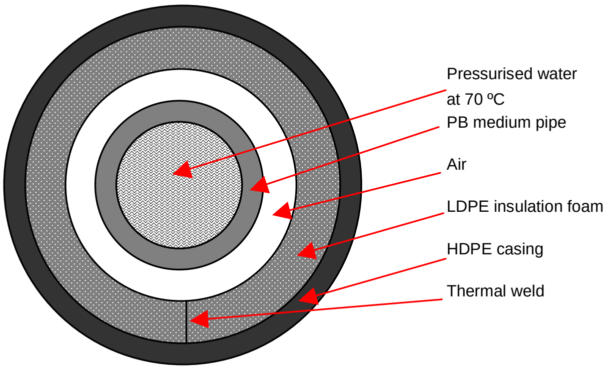

Fig.4. The PB/PE/PE system is not bonded and contains an air gap between medium pipe and insulation

The geometry of the plastic PB/PE/PE piping system could be optimised by closing the gap between service pipe and insulation foam. Further, heat loss could be decreased by increasing insulation of the piping system. A larger outer casing for each diameter for PB/PE/PE would result in lower lifetime heat loss than St/PU/PE systems series 1 and comparable heat loss to series 2.

SYSTEM OPTIMISATION

The new flexible PB/PE/PE piping system in its standard configuration is not insulated as effectively as conventional rigid St/PU/PE (Series I) piping. This is mainly due to less insulation thickness and relatively fast degassing of the PE foam. The obvious method to reduce heat loss is to increase insulation thickness. This would lead to comparable heat loss values.

Calculated heat losses for the distribution system are in the range of 240 to 290 W per house, or 20 – 25% of the yearly consumption [4].

An alternative to reduce heat loss is to install a separate pipe for domestic hot water distribution, thus creating a three pipe system (figure 5). This allows for lower average temperatures in supply and return.

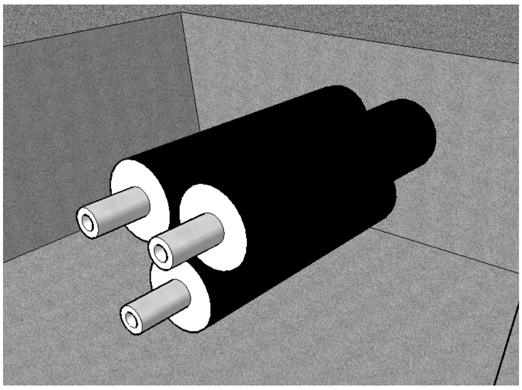

Fig.5. Example of optimising the laying practice of plastic pipes

During warm periods, two of the tree pipes can be shut down completely, as no space heating is required. In our calculation, this was done for 730 h/year.

If the network is designed to heat up quickly, this shut down period may be extended significantly, thus further reducing heat loss.

NOMENCLATURE

DH	District heating
PB	Polybutylene
PE	Polyethylene
St	Steel (St37)
PU	Polyurethane
PB/PE/PE	Polybutylene pre-insulated DH system
St/PU/PE	Steel pre-insulated DH system

LITERATURE

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