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IEA District Heating and Cooling

Programme of Research, Development and Demonstration on District Heating and Cooling

DISTRICT HEATING AND COOLING IN FUTURE BUILDINGS

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IEA - District Heating and Cooling Project

District Heating and Cooling in Future Buildings

(DH&C-FB)

by

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PREFACE AND ACKNOWLEDGEMENTS

The International Energy Agency (IEA) was established in 1974 within the framework of the OECD to implement an International Energy Program. A basic aim of the IEA is to strengthen the co-operation between the member countries in the energy field. One element of these co-operative activities is to undertake energy research, development and demonstration (RD&D).

District Heating is, by the IEA, seen as a means by which countries may reduce their dependence on oil and improve their energy efficiency. It involves increased use of indigenous or abundant fuels, the utilisation of waste energy and combined heat and power production.

The IEA "Program of Research, Development and Demonstration on District Heating" was established at the end of 1983. Under Annex I, ten countries participated in the program: Belgium, Canada, Denmark, Federal Republic of Germany, Finland, Italy, The Netherlands, Norway, Sweden and USA.

The National Energy Administration, Sweden was Operating Agent for the program under Annex I, in which the following technical areas were assessed:

- Development of heat meters
- Cost efficient distribution and connection systems for areas of low heating density
- Small size coal-fired hot water boiler
- Medium size combined heat and power plants
- Low temperature applications in district heating systems

The results of these topics have been presented in printed reports published by the National Energy Administration, Sweden.

In 1987 it was decided by nine of the original ten participating countries (ex. Belgium) to continue the implementation of co-operative projects under an Annex II.

The Netherlands Agency for Energy and the Environment (NOVEM), was Operating Agent for Annex II, in which the following technical areas were assessed:

- Heat meters
- Consumer installations
- Piping
- Advanced fluids
- Advanced heat production technology
- Information exchange

In 1990 the co-operating countries decided to continue the implementation of new co-operative projects under a new Annex III. During this annex United Kingdom joined the project. NOVEM was Operating Agent also for Annex III, in which the following areas have been assessed:

- District Heating and the Environment
- Supervision of District Heating Networks
- Advanced Fluids
- Piping
- District Energy Promotion Manual
- Consumer Heating System Simulation

In 1993 the co-operating countries (ex. Italy) decided to continue the implementation of new co-operative projects under a new Annex IV. The name of the main co-operating project was now changed to "IEA - District Heating and Cooling Project", which emphasise the increasing awareness of District Cooling as an energy efficient technology.

During this annex The Republic of Korea joined the project. NOVEM has been Operating Agent also for Annex IV, in which the following technical areas have been assessed:

- Combined Heat and Power/Cooling Guidelines
- Advanced Transmission Fluids
- Piping Technology
- Network Supervision
- Efficient Substations and Installations (ESI)
- Manual on DH-piping, Design and Construction
- Development of long term Co-operation with East-European Countries

The results from Annex II, III and IV have been presented in printed reports published by NOVEM.

In 1996 the co-operating countries decided to continue the implementation of new co-operative projects under a new Annex V in which the following technical areas have been assessed:

- Cost effective DH&C networks
- Fatigue analysis of DH networks
- Optimization of low temperature DH-systems
- **District Heating and Cooling in Future Buildings**
- Balancing the production and demand in CHP
- Plastic pipe DH-systems - Handbook

The report at hand describes the project called "District Heating and Cooling in Future Buildings" (DH&C-FB).

The work on the project DH&C-FB- has been monitored by the "IEA-Experts Group on DH&C-FB" (EG-DH&C-FB), with Associate Professor Rolf Ulseth from The Norwegian University of Science and Technology (NTNU) as project leader.

The members of "EG- DH&C-FB" have been:

- Mirja Tiitinen (Finland)
- Zoltán Korényi (Germany)
- Joo Tae Ahn (Korea)
- Gert Boxem (The Netherlands)
- Monica Havskjold/Heidi Juhler (Norway)
- Gunnar Nilsson (Sweden)
- Robin Wiltshire (United Kingdom)

The project leader wants to thank everybody who has contributed and made it possible to carry through this work - especially every individual of the EG for making a good effort and showing a positive will to co-operate. A special thank to, Jacob Stang, Tor I Hoel, Peter Noeres, P. Klose, D. Hölder, W. Althaus, Markku Ahonen and Ki-Dong Koo for their supportive contribution to the joint work and in the effort to make the report.

Thanks should also be given to the "Executive Committee" who gave priority to do work on the DH&C-FB-project.

On behalf of SINTEF Energy Research, I will also take this opportunity to thank "The Research Council of Norway" for the financial support that made possible our participation in "The IEA-District Heating and Cooling Project".

The technical development in all countries, on this and adjacent fields, depend on research co-operation on such international projects. And besides – the benefit from the network of professional colleagues you learn to know by the co-operation is invaluable.

SINTEF Energy Research, April 1999

Rolf Ulseth

Rolf Ulseth
Project leader

District Heating and Cooling in Future Buildings

Summary

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).

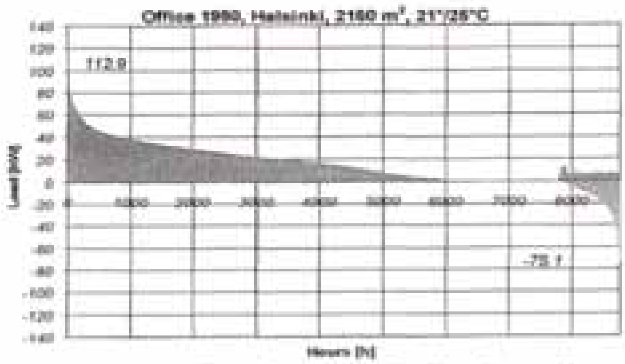


Figure 1 Duration curves for heating and cooling for a "1990 office building" in Helsinki.

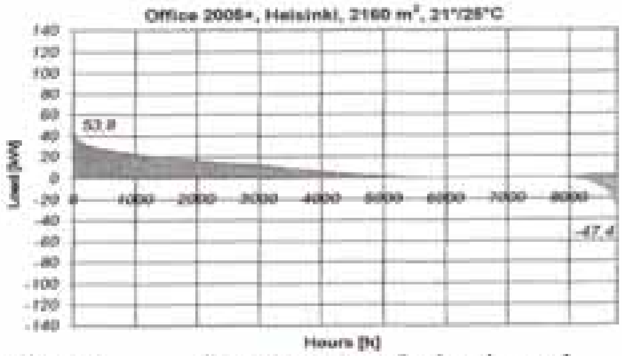


Figure 2 Duration curves for heating and cooling for a "2005+ office building" in Helsinki.

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.

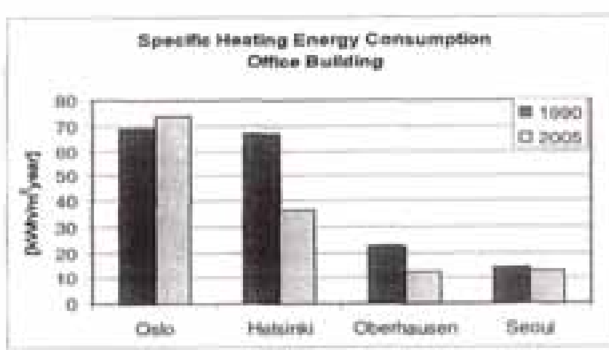


Figure 3 Specific values for the total, yearly heating energy consumption. Simulated values.

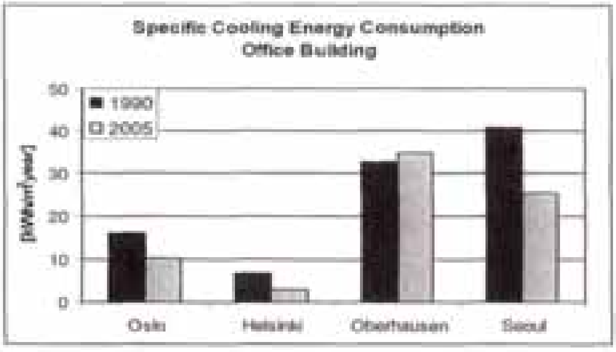


Figure 4 Specific values for the total, yearly cooling energy consumption. Simulated values.

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

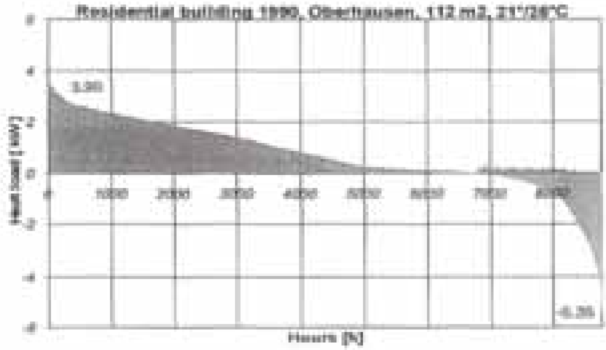


Figure 5 Duration curves for heating and cooling for a "1990 residential building" in Oberhausen

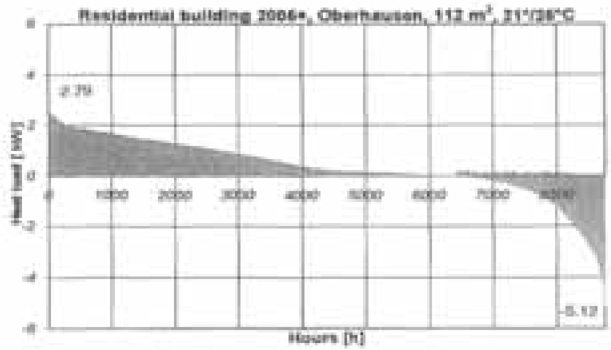


Figure 6 Duration curves for heating and cooling for a "2005+ residential building" in Oberhausen

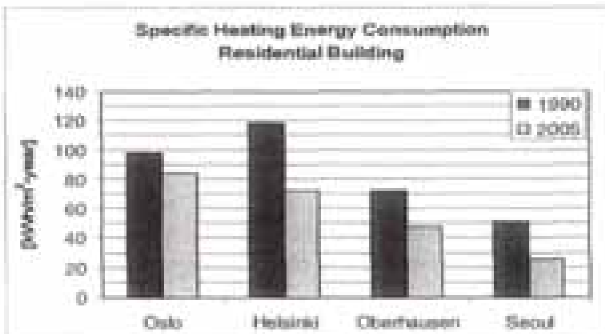


Figure 7 Specific values for the total, yearly heating energy consumption. Simulated values.

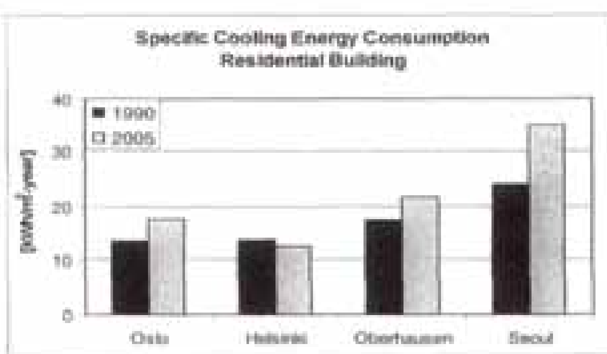


Figure 8 Specific values for the total, yearly cooling energy consumption. Simulated values.

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.

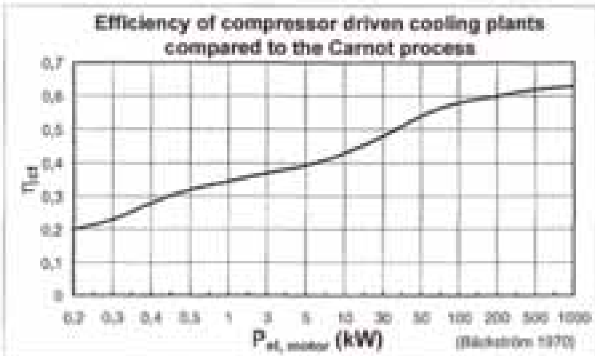


Figure 9 Efficiency curve for an average cooling plant as function of the size of the motor of the electric compressor compared to a Carnot process

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.

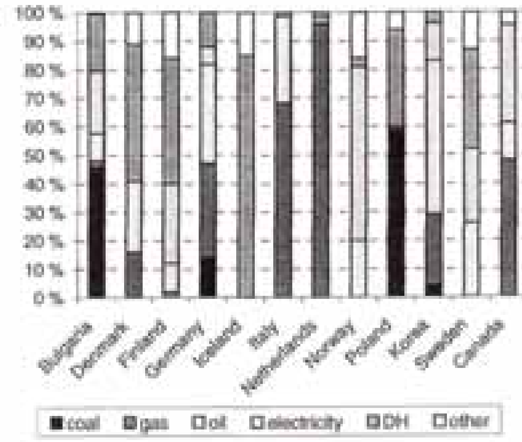


Figure 10 Type of residential heating in some selected countries /Unichal 1995/

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 CO_2, SO_2 and NO_x.

[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).

District Heating and Cooling in Future Buildings

INTRODUCTION TO THE JOINT REPORT

The main objective of the present work has been to sort out the new conditions for the future expansion of DH and DC that will be caused by the changes that can be foreseen in the future building stock. The anticipated development of heating and cooling will be in focus.

It was decided from the start that the DH&C-FB-project should be performed as a joint project between SINTEF Energy Research, Fraunhofer UMSICHT, VTT Building Technology and Korea District Heating Corporation.

On this background, and for technical reasons, it was found appropriate to make the joint report in the following four parts:

Part I:

District Heating and Cooling in Future Buildings

Part II:

Reduction of Electric Energy Consumption and Peek Power by DC Compared to Conventional Local Cooling Plants

Part III:

Primary Energy Savings by District Heating Compared to Local Heating Systems

Part IV:

Environmental Benefits by DH&DC Compared to Local Heating and Cooling Plants

Part I:

District Heating and Cooling in Future Buildings

By

Rolf Ulseth Jacob Stang Tor I. Hoel

1. District Heating and Cooling in Future Buildings (Part I)

1.1 Background

Efficient use of energy and energy saving in buildings are expected to be very focused areas in the future due to resource policy, environmental reasons, and the fact that the cost of energy is expected to increase relatively more than most other products. One of the consequences of this evolution is a constant development of better insulation of buildings.

This evolution has already - to some extent - changed the problem of controlling indoor temperatures in buildings from being mainly a heating problem to be an integrated heating and cooling problem. This evolution may have some effects on the competitiveness of District Heating and District Cooling in the future.

1.2 Objective of the IEA-project

The main objective of the project is to sort out the new conditions for the future expansion of District Heating (DH) and District Cooling (DC) that will be caused by the changes we can foresee in the future building stock. Expected development of the heating and the cooling loads and energy consumption patterns are in focus.

1.3 The project

The project is organised as a co-operation project between SINTEF Energy Research (N), VTT Building Technology (F), Fraunhofer UMSICHT (G) and Korea District Heating Corporation (K), with the project leadership at SINTEF, and with project support concerning input values for simulations (See page 8) from the other partners. The project is monitored by an "Experts Group" consisting of appointed members from seven of the member countries of Annex V of the IEA-District Heating and Cooling Project.

A basic goal of the project is to map the heating and cooling loads and the energy consumption in a "typical" office building and a "typical" residential building from 1990, and make comparisons with the same expected "typical" buildings in 2005+. A simulation tool is used for the study. The simulations for the actual countries are done for the same defined "standard" building configuration.

The defined "standard" office building and the defined "standard" residential building has been discussed and agreed on in the "Experts Group".

The office building has four storeys, with the floor area of 18m • 30m of each storey, and the residential building is a row house building with four flats in each row house with two storeys, with the floor area of 7m • 8m of each storey for one flat. The simulations are performed for a typical climatic situation in the respective four countries; Norway, Finland, Germany and Korea.

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". The construction of the "reference year" for the different countries is based on slightly different methods, but this fact has been considered to have no significant effect on the practical result from the simulations.

In this paper we are presenting results from the following places in the four countries; Oslo, Helsinki, Oberhausen and Seoul.

It has to be mentioned that the climate may vary quite a lot within the different countries. Nevertheless, the results should give a good indication on the average situations in the respective countries.

The simulations are performed with the dynamic simulation programme FRES, (Flexible Room climate and Energy Simulator) which is developed at SINTEF/NTNU.

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

- Determination of primary energy savings by DH compared to local heating systems
- Determination of the reduction of electric energy consumption and peak power by DC compared to conventional local cooling plants
- Determinations of environmental benefits from DH&DC compared to local heating and cooling plants

1.4 Simulation results

It is generally known that the density of the heating and the cooling consumption is one of the most critical factors for the feasibility of DH and DC systems. The density in relation to the maximum load demands is also a very critical factor. The reason why can be seen by the following equation, which basically describes the total cost per unit for the delivered energy:

$$C_s = \frac{I_s \cdot a}{\tau} + e_s \qquad (1)$$

C_s = total specific energy cost	(money/kWh)
I_s = specific investment cost	(money/kW)
e_s = specific cost of energy	(money/kWh)
a = annuity factor	(1/year)
τ = equivalent time of max. load	(hours/year)

This equation shows that the findings from the simulated cases could be very fruitfully compared on basis of the values of the figure τ for the respective cases.

In the simulations in this project, the room temperatures are set to 21°C when calculating the heat loads. The cooling loads will be very much depending on the maximum allowed room temperature during the high load periods. Here we have mainly simulated the cooling load presupposing that it will be acceptable to let the room temperature slide from 21°C to 25°C before cooling of the room is introduced. If cooling is not introduced, a cooling load indicates that the room temperature will slide above 25°C.

Figure 1.1 – 1.8 show results from the simulations for the "standard" office building for the stage of 1990 and 2005+. The figures show to the left the so-called **duration curve of the *hourly mean values* of the heating load** as long as we have no cooling load. To the right in the figures the **duration curve of the cooling loads is shown.** Above the zero line to the right we see the corresponding values of the heating loads when we have heating and cooling loads at the same time.

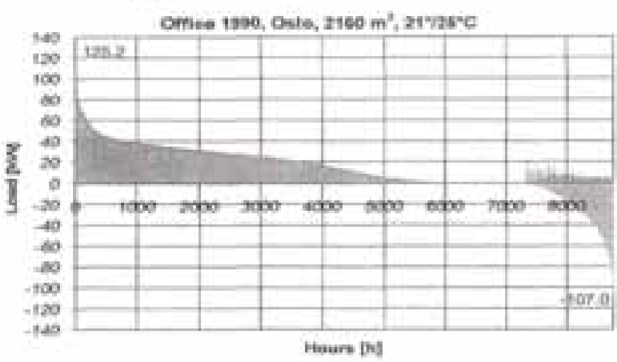


Figure 1.1

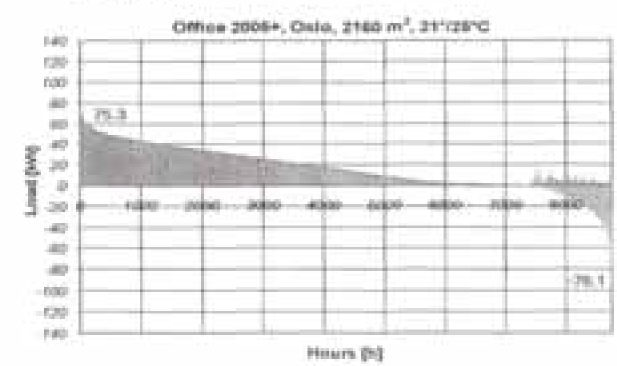


Figure 1.2

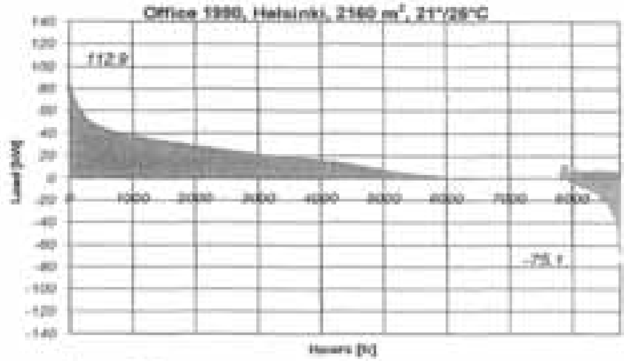


Figure 1.3

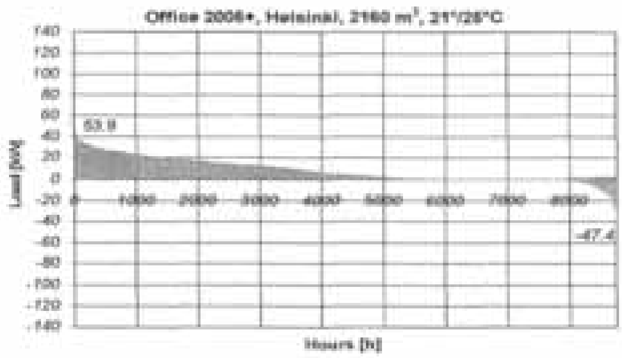


Figure 1.4

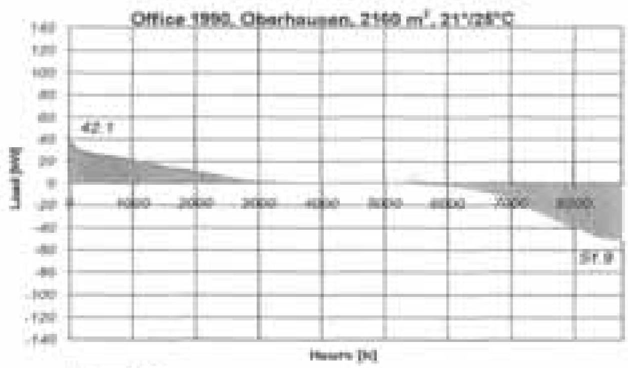


Figure 1.5

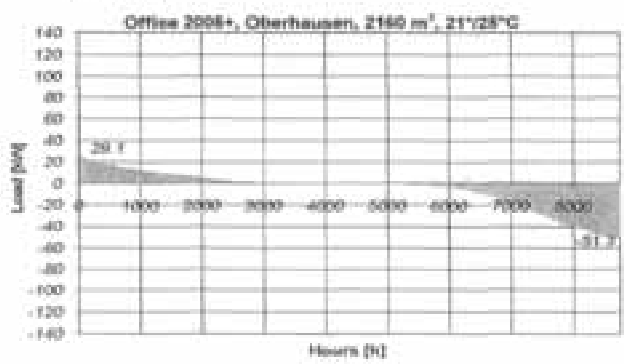


Figure 1.6

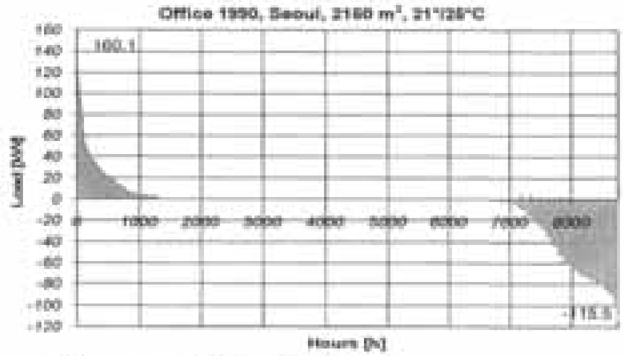


Figure 1.7 (Night setback of the room temperature)

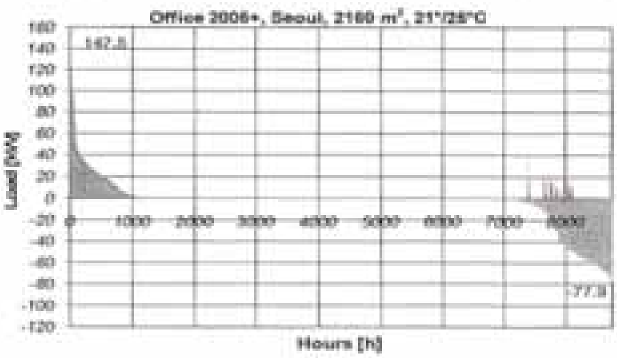


Figure 1.8 (Night setback of the room temperature)

Figure 1.9 shows the **total, yearly heating energy consumption** for the office building in the respective countries, and figure 1.10 shows the **total, yearly cooling energy consumption.**

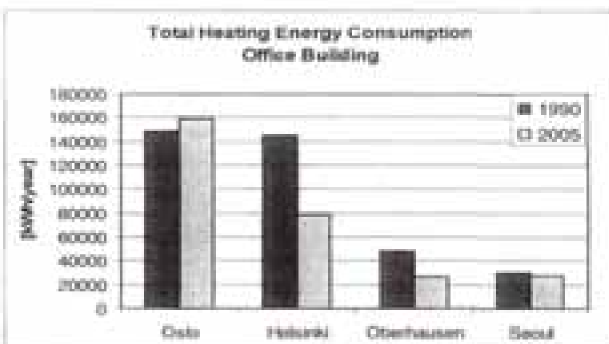


Figure 1.9

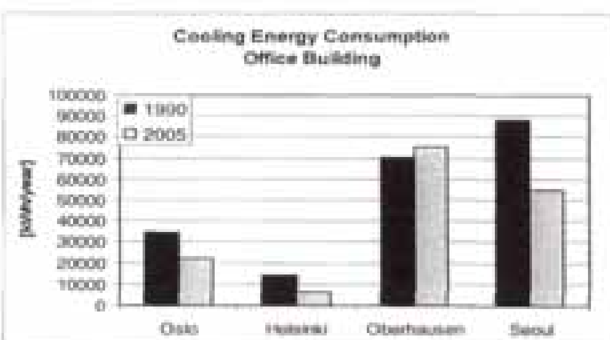


Figure 1.10

Figure 1.11 and 1.12 show the **specific values for the total yearly heating and cooling energy consumption** for the office buildings in the respective countries.

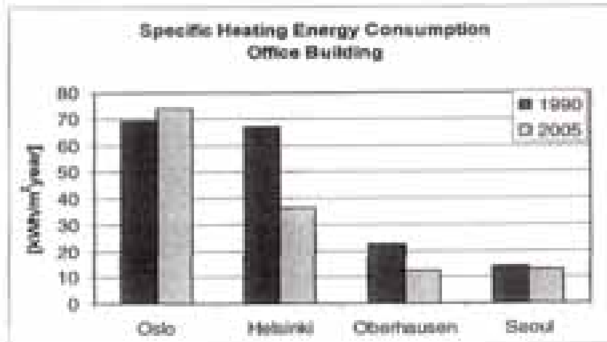


Figure 1.11

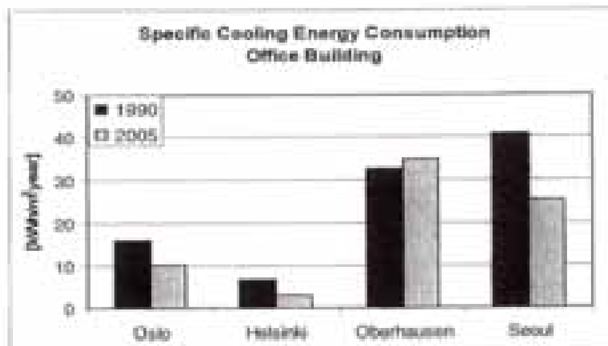


Figure 1.12

Figure 1.13 and 1.14 show the **specific maximum heating and cooling loads** for the office buildings.

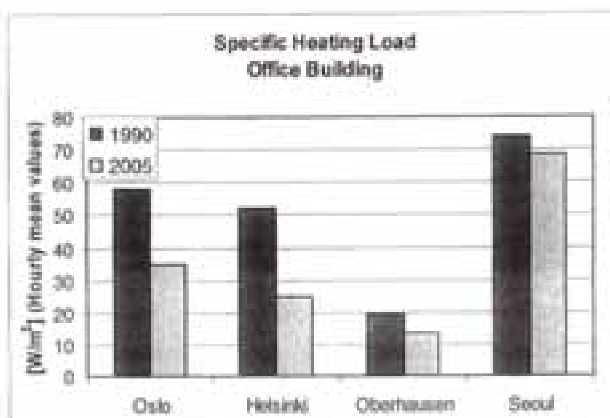


Figure 1.13

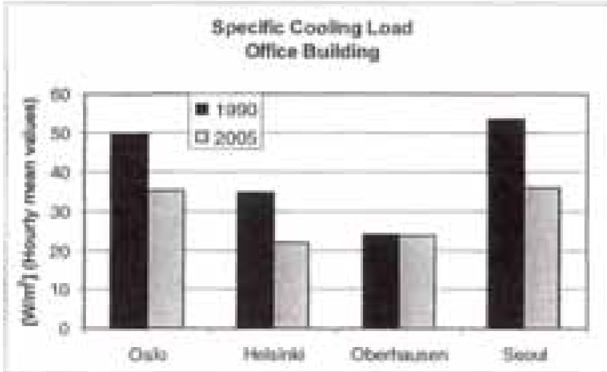


Figure 1.14

The reasons behind 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 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 situation from 1990 to 2005+ is caused by the fact that the effect of an anticipated better insulation is counteracted by in increased ventilation rate.

The figures 1.15 – 1.22 show the results from the simulations for the "standard" residential building for the stage of 1990 and 2005+. The figures show so called **duration curves of the *hourly mean values* of the heating load** as long as we have no cooling load to the left.

To the right in the figures the **duration curve of the cooling loads is shown.** Above the zero line to the right we see the **corresponding values** of the heating loads when we have heating and cooling loads at the same time. The values for the residential buildings are average values per flat for the four flats in the simulated row house.

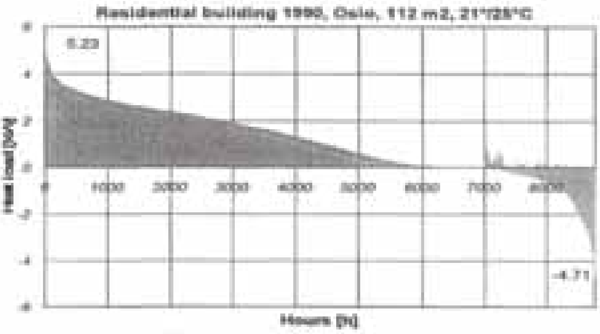


Figure 1.15

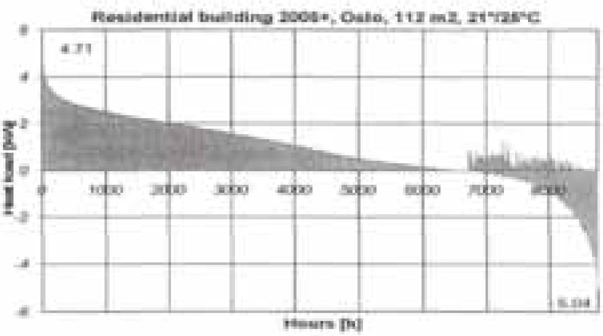


Figure 1.16

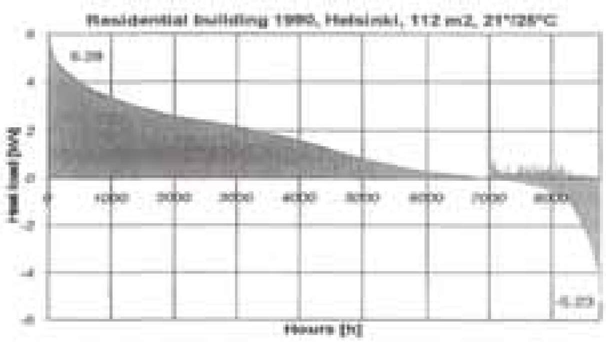


Figure 1.17

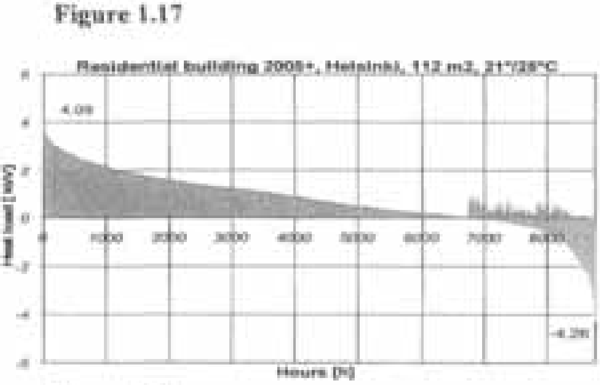


Figure 1.18

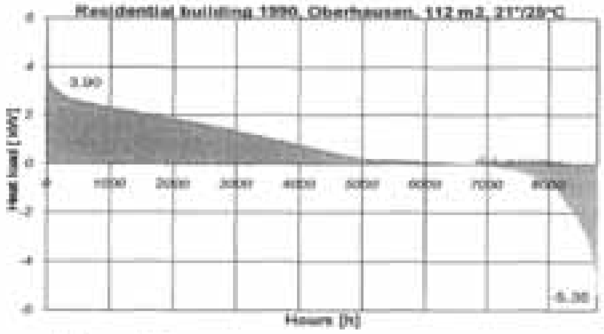


Figure 1.19

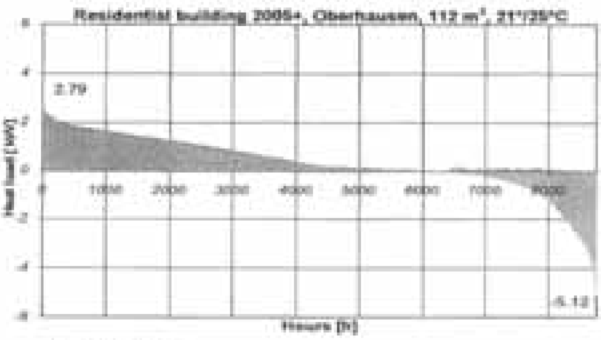


Figure 1.20

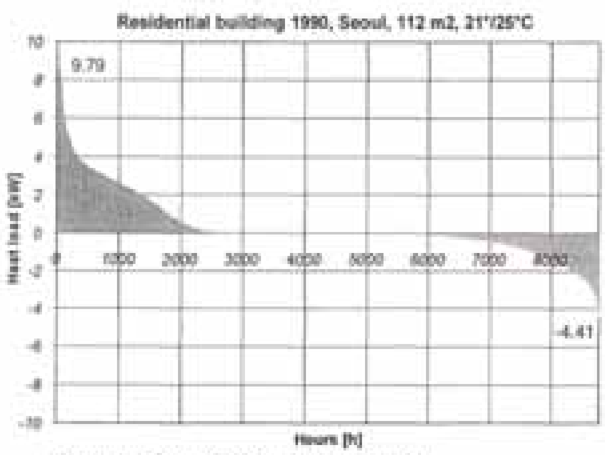


Figure 1.21a (With night setback)

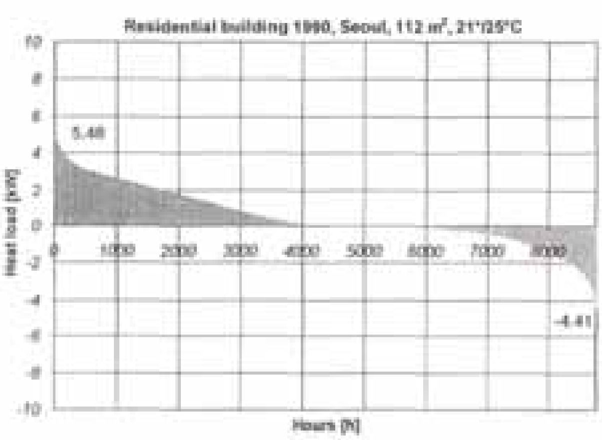


Figure 1.21b (Without night setback)

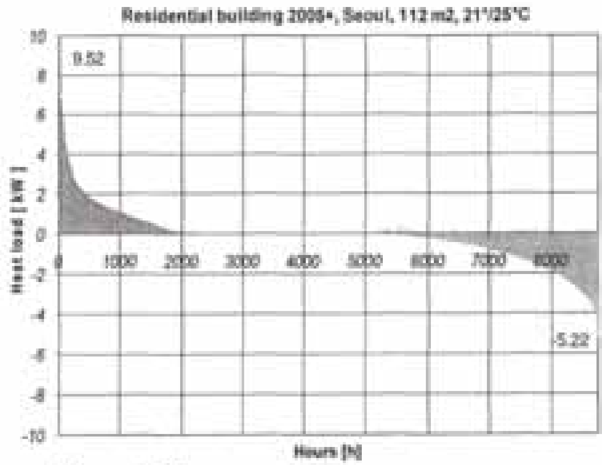


Figure 1.22

The high values of the heating loads in the Seoul cases in figure 1.21a and 1.22 are caused by the fact that night setback of the room temperatures are applied. In these simulations it is assumed that one has heating capacity available to reheat the rooms to the desired value of 21°C during one hour.

The disadvantage of this strategy of running the heat plant is the need of a very high capacity on the heating system to increase the room temperature in the mornings.

To reduce the heating capacity and choose a longer period to reheat the room might be a better solution for the overall economy, even if this strategy will increase the yearly heating consumption.

Figure 1.21b shows the picture with no night setback of the room temperature. The simulations show that the yearly energy consumption will be lowered about 20 % by night setback compared to the consumption with no night setback.

Figure 1.23 shows the **total, yearly heating energy consumption** for the residential building in the respective countries and the figure 1.24 shows the **total yearly cooling energy consumption.**

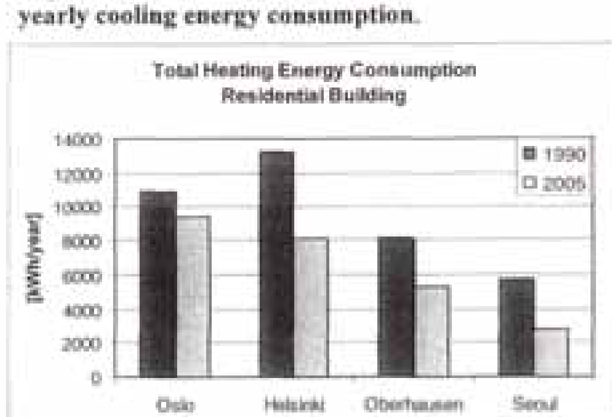


Figure 1.23

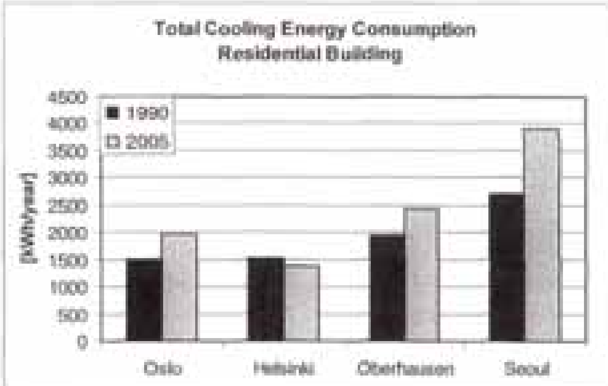


Figure 1.24

Figure 1.25 and 1.26 show the **specific values for the total yearly energy consumption for heating and cooling** for the residential buildings in the respective countries, and the figures 1.27 and 1.28 show the **specific maximum heating and cooling loads.**

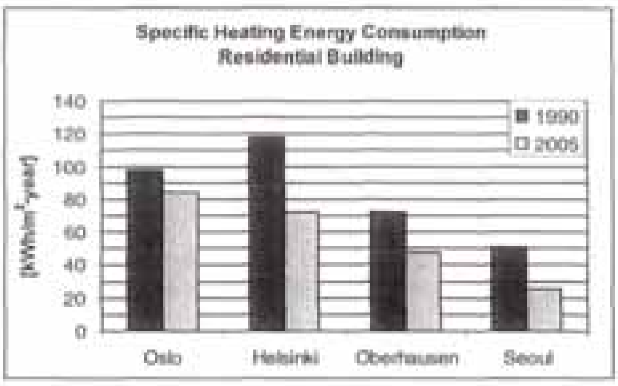


Figure 1.25

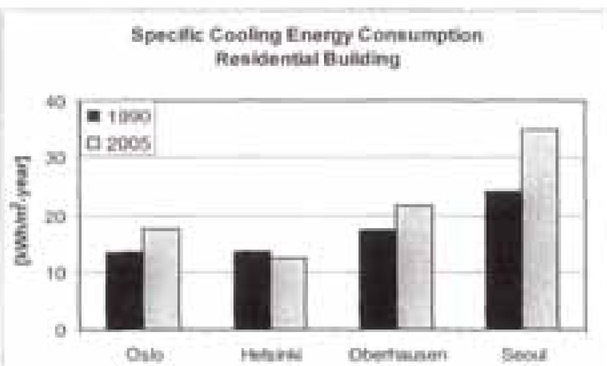


Figure 1.26

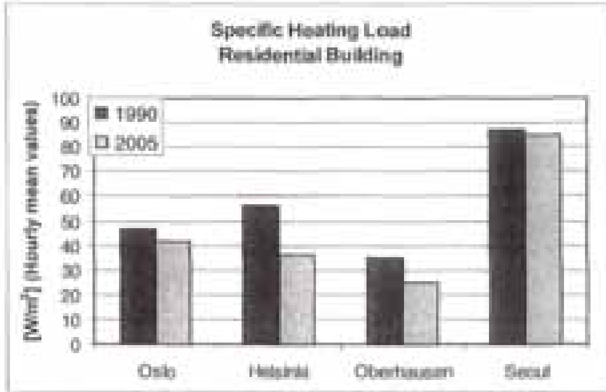


Figure 1.27

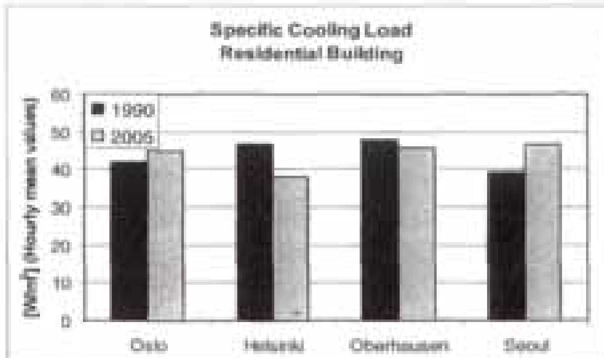


Figure 1.28

1.5 Equivalent time of maximum load

Table 1.1 shows the calculated values of the **equivalent time of maximum load** (**τ**) for the total heating for the office building.

Office 2160 m²	Oslo	Helsinki	Oberhausen	Seoul
90-21°/25°	1190	1280	960	190
05-21°/25°	2120	1460	1030	190

Table 1.1 Equivalent time of maximum load for the total heating (hours/year)

Table 1.2 shows the calculated values of the **equivalent time of maximum load** (**τ**) for the total cooling for the office building.

Office 2160 m²	Oslo	Helsinki	Oberhausen	Seoul
90-21°/25°	320	190	1330	760
05-21°/25°	290	140	1490	710

Table 1.2 Equivalent time of maximum load for the total cooling (hours/year)

Table 1.3 shows the calculated values of the **equivalent time of maximum load** (**τ**) for the total heating for the residential building.

Resident. 112 m²	Oslo	Helsinki	Oberhausen	Seoul
90-21°/25°	2090	2100	2070	590
05-21°/25°	2000	1980	1890	300

Table 1.3 Equivalent time of maximum load for the total heating (hours/year)

Table 1.4 shows the calculated values of the **equivalent time of maximum load (τ)** for the total cooling for the residential building.

Resident. 112 m²	Oslo	Helsinki	Oberhausen	Seoul
90-21°/25°	320	290	360	610
05-21°/25°	390	320	470	750

Table 1.4 Equivalent time of maximum load for the total cooling (hours/year)

1.6 The effect of sliding room temperature on heating and cooling load and yearly energy consumption

It is quite easy to imagine that the cooling energy consumption will be reduced when we allow the room temperature to slide from 21° C to 25° C before cooling of the room is introduced. For the office building in Oslo we see in the figures 1.29, 1.30 and 1.31 how the picture is changed when decreasing the allowed slide in the room temperature from 21°C to 25°C and down to no slide at all, 21°/21°C.

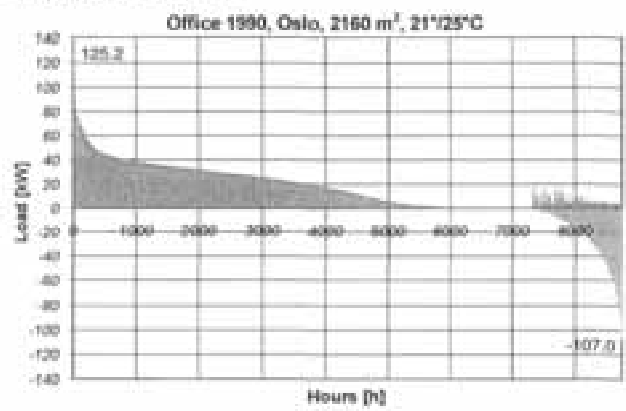


Figure 1.29

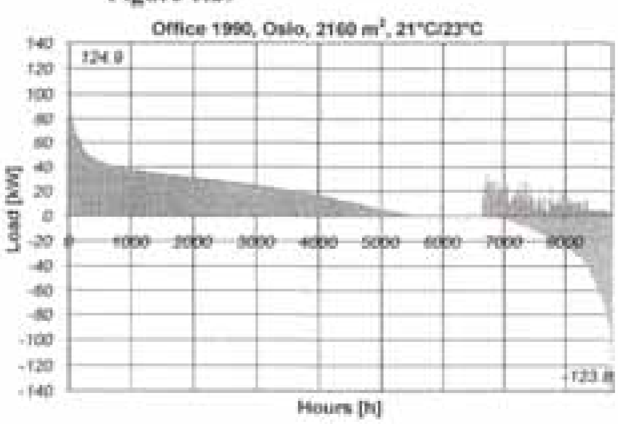


Figure 1.30

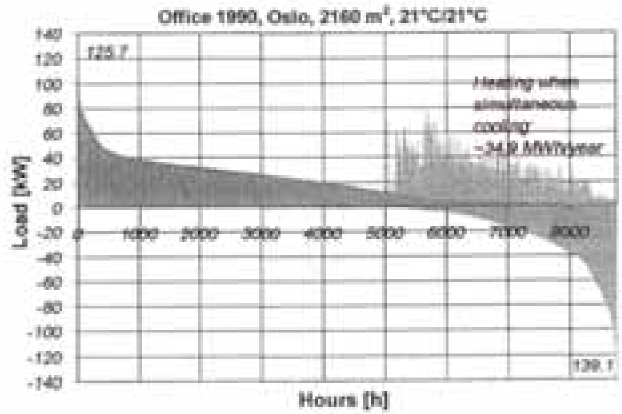


Figure 1.31

The cooling load and the cooling energy consumption increases considerably when we decrease the allowed slide in the room temperature. When no slide in the room temperature is allowed the heating energy consumption will also increase significantly.

Figure 1.32 shows the changes in the **total yearly heating and cooling energy consumption** with different slide of the room temperature and figure 1.33 shows the **specific values for the total yearly heating and energy consumption** for the different conditions.

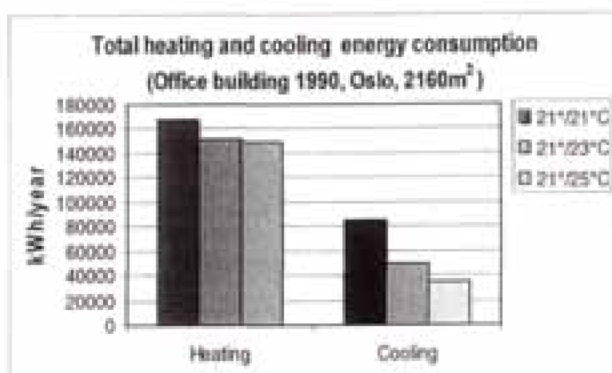


Figure 1.32

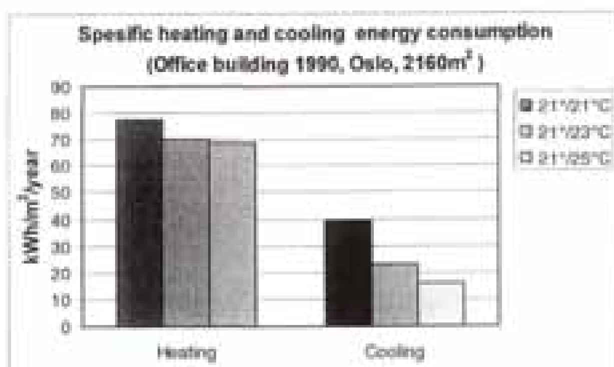


Figure 1.33

1.7. Conclusions

• We have to be aware of the fact that the simulations give only theoretical values. Due to non-optimal construction and operation of the Heating, Ventilating and Air Conditioning systems (HVAC-systems), we will normally observe other values in practice.

Normally the heating and cooling consumption might be considerably higher than the theoretical values. Nevertheless, the theoretical results should give a good picture on the relative values. Figure 29-33 should give an idea of what may happen when the temperature control system is wrongly adjusted or do not work properly according to the planed intentions. In practice this situation quite often seems to be the case.

• The simulation results will, to some extent, be influenced by choices made by opinion by a small group of individuals based on their best judgement. These choices may of cause in some cases be debated.

• The results show very clearly the typical effects of the different climatic conditions in the different countries. We also see the effects of different strategies of running the heating systems.

• The consequence of changes in the building codes is very clearly demonstrated in the office case from Oslo. The new, Norwegian building code from 1997 demands that the ventilation plant in an office building has to be run throughout day and night due to the contaminants from the building materials.

It is hard to believe that the building codes for example in Finland and Norway will stay as differently in the future as we see in the office case.

• The results from all countries very clearly show the effect of the improved insulation of the walls and the windows from 1990 to 2005+.

• The equivalent time of maximum load seems to stay more or less at the same level in the future except for the office building in Oslo due to the new demands in the new Norwegian building code from 1997.

1.8. Input values for the simulations

A survey of the input values used in the simulations is presented in table 5 and 6 on the following pages where the following terms are used:

n = data from Norway – Oslo
g = data from Germany – Oberhausen
f = data from Finland – Helsinki
k = data from Korea – Seoul

o = data for office buildings
r = data for residential buildings

90 = typical data for the year 1990
05 = expected data from the year 2005+

1.6 References

SINTEF Flexible Room climate and Energy Simulator (FRES), 1993

Table 1.5 Input values for the simulations – Office building

	U-values				Ventilation plant					Ventilation air flow rate			Shading			
Simu-lation	Outer wall	Roof	Ground floor	Win	VAV	Cool coil	Heat rec eff	Inlet air temp	Duration	Offices	Meet room	Com space	N	E	S	W
o90-n	0.28 W/m^2K	0.19 W/m^2K	0.28 W/m^2K	2.4 W/m^2K	No	Yes	0.7	5/20°C - 16/15°C	11 h wd	10 $m^3/h\ m^2$	15 $m^3/h\ m^2$	5 $m^3/h\ m^2$	Cu	VB	VB	VB
o90-f	0.28 W/m^2K	0.21 W/m^2K	0.22 W/m^2K	1.8 W/m^2K	No	Yes	0.6	5/20°C-16/15°C	11 h wd	4.5 $m^3/h\ m^2$	14.3 $m^3/h\ m^2$	1.4 $m^3/h\ m^2$	Cu	VB	VB	VB
o90-g	0.29 W/m^2K	0.23 W/m^2K	0.38 W/m^2K	2.4 W/m^2K	No	No	-	-	-	-	-	-	No	VB	VB	VB
o90-k	0.41 W/m^2K	0.42 W/m^2K	0.68 W/m^2K	3.4 W/m^2K	No	Yes	Rec air 0.2/0.2	5/20°C-16/15°C	10 h wd 4 h sat	15.8 $m^3/h\ m^2$	9.5 $m^3/h\ m^2$	6 $m^3/h\ m^2$	Cu	Cu	Cu	Cu
o05-n	0.21 W/m^2K	0.14 W/m^2K	0.28 W/m^2K	1.6 W/m^2K	Yes	Yes 07-18	0.7	5/20°C - 16/15°C	All year	7/4.5 $m^3/h\ m^2$	7.4/4.5 $m^3/h\ m^2$	4.5 $m^3/h\ m^2$	VB	VB	VB	VB
o05-f	0.22 W/m^2K	0.16 W/m^2K	0.16 W/m^2K	1.2 W/m^2K	Yes	Yes	0.7	5/20°C - 16/15°C	11 h wd	4.5/1.7 $m^3/h\ m^2$	14.3/1.7 $m^3/h\ m^2$	1.4 $m^3/h\ m^2$	VB	VB	VB	VB
o05-g	0.21 W/m^2K	0.17 W/m^2K	0.38 W/m^2K	1.6 W/m^2K	No	No	-	-	-	-	-	-	VB	VB	VB	VB
o05-k	0.34 W/m^2K	0.34 W/m^2K	0.50 W/m^2K	1.6 W/m^2K	No	Yes	Rec air 0.2/0.2	5/20°C - 16/15°C	9 h wd	21.2/9.1 $m^3/h\ m^2$	10.4/2.6 $m^3/h\ m^2$	7.6/2.6 $m^3/h\ m^2$	VB	VB	VB	VB

	Offices				Meeting room				Common area						Room temperatures	
Simu-lation	Pers	Light	Equip	Dura-tion	Pers	Light	Equip	Dura-tion	Pers	Dur pers	Light	Dur light	Equipt	Dur equip	Temp heating	Temp cooling
o90-n	18/16 pers	15 W/m^2	15 W/m^2	wd 4/4 h	7 pers	12.5 W/m^2	2.5 W/m^2	wd 4 h	4/3 pers	wd 4/4 h	9.4/1.3 W/m^2	8/16 h	2.5/0.6 W/m^2	wd/we	21°C	25/23/21 °C
o90-f	18/16 pers	15 W/m^2	15 W/m^2	wd 4/4 h	7 pers	12.5 W/m^2	2.5 W/m^2	wd 4 h	4/3 pers	wd 4/4 h	9.4/1.3 W/m^2	8/16 h	2.5/0.6 W/m^2	wd/we	21°C	25/23/21 °C
o90-g	18/16 pers	20 W/m^2	15 W/m^2	wd 4/4 h	7 pers	12.5 W/m^2	2.5 W/m^2	wd 4 h	4/3 pers	wd 4/4 h	9.4/1.3 W/m^2	8/16 h	2.5/0.6 W/m^2	wd/we	21°C	25°C
o90-k	27/24 pers	20 W/m^2	15 W/m^2	wd 6/4 h	8 pers	15 W/m^2	2.3 W/m^2	wd 4 h	1/0 pers	wd 6/4 h	10/1.2 W/m^2	10/14 h	0 W/m^2	All year	21/10 °C	25°C
o05-n	18/16 pers	8 W/m^2	8.5 W/m^2	wd 4/4 h	7 pers	8 W/m^2	2 W/m^2	wd 4 h	4/3 pers	wd 4/4 h	6/0.6 W/m^2	8/16 h	1.9/0.3 W/m^2	wd/we	21°C	25/23/21°C
o05-f	18/16 pers	8 W/m^2	8.5 W/m^2	wd 4/4 h	7 pers	8 W/m^2	2 W/m^2	wd 4 h	4/3 pers	wd 4/4 h	6/0.6 W/m^2	8/16 h	1.9/0.3 W/m^2	wd/we	21°C	25/23/21°C
o05-g	18/16 pers	10 W/m^2	10 W/m^2	wd 4/4 h	7 pers	8.3 W/m^2	1.7 W/m^2	wd 4 h	4/3 pers	wd 4/4 h	6.3/0.6 W/m^2	8/16 h	1.9/0.3 W/m^2	wd/we	20°C	-
o05-k	27/24 pers	15 w/m^2	9 W/m^2	5/4 h	8 pers	10 W/m^2	1.8 W/m^2	wd 4 h	1/0 pers	wd 4/4 h	7/0.82 W/m^2	9/15 h	0 W/m^2	wd/we	20/10 °C	26

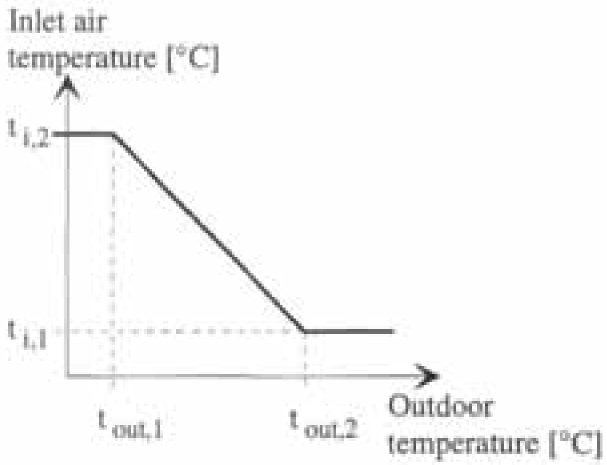
Table 1.6 Input values for the simulations – Residential building

	U-values				Ventilation plant					Air flow rate		Infiltration		Win
Simu-lation	Outer wall	Roof	Ground floor	Win.	H coil	C coil	H rec eff.	In air temp	Op time	Livingr	Bedr	Livingr	Other	Trans-mition
r90-n	0.264 W/m^2K	0.198 W/m^2K	0.283 W/m^2K	2.4 W/m^2K	-	-	-	-	-	[1]100 m^3/h	52 m^3/h	0.6 h^{-1}	0.5 h^{-1}	0.51
r90-f	0.24 W/m^2K	0.209 W/m^2K	0.338 W/m^2K	1.8 W/m^2K	-	-	-	-	-	74/[1]108 m^3/h	38/[2]76 m^3/h	0.15 h^{-1}	0.15 h^{-1}	0.50
r90-g	0.189 W/m^2K	0.331 W/m^2K	0.359 W/m^2K	2.4 W/m^2K	-	-	-	-	-	-	-	0.75 h^{-1}	0.75 h^{-1}	0.75
r90-k	0.401 W/m^2K	0.574 W/m^2K	0.58 W/m^2K	3.37 W/m^2K	-	-	-	-	-	[1]360 m^3/h	[2]131 m^3/h	0.23 h^{-1}	0.3/[3]0.6 h^{-1}	0.78
r05-n	0.201 W/m^2K	0.143 W/m^2K	0.143 W/m^2K	1.6 W/m^2K	4 kW	2 kW	0.5	21°C	All day	145/[1]245 m^3/h	145 m^3/h	0.18 h^{-1}	0.15 h^{-1}	0.51
r05-f	0.215 W/m^2K	0.152 W/m^2K	0.232 W/m^2K	1.2 W/m^2K	2.5 kW	-	0.5	20°C	All day	74/[1]108 m^3/h	38/[2]76 m^3/h	0.15 h^{-1}	0.15 h^{-1}	0.39
r05-g	0.156 W/m^2K	0.331 W/m^2K	0.359 W/m^2K	1.6 W/m^2K	-	-	-	-	-	-	-	0.5 h^{-1}	0.5 h^{-1}	0.75
r05-k	0.331 W/m^2K	0.333 W/m^2K	0.335 W/m^2K	1.75 W/m^2K	-	-	-	-	-	[1]360 m^3/h	[2]131 m^3/h	0.23 h^{-1}	0.3/[3]0.6 h^{-1}	0.78

	Livingroom						Bedroom				Bathroom				
Simu-lation	Pers	Light	Equip	Dura-tion	Temp heat	Temp cool	Pers	Duration	Temp heat	Temp cool	Pers	Light	Equipt	Duration	Temp
r90-n	4 pers	200 W	500/50 W	1/6 h wd 2/6 h we	21°C	25°C	4 pers	8 h wd 10 h we	21°C	25°C	1 pers	75 W	100 W	1 h wd 1 h we	22°C
r90-f	4 pers	200 W	500/50	1/7 wd 2/7 we	21°C	25°C	4 pers	7 h wd 9 h we	21°C	25°C	1 pers	75 W	100 W	1 h wd 1 h we	22°C
r90-g	4 pers	200 W	500/50 W	1/7 wd 2/7 we	21°C	25°C	4 pers	7 h wd 9 h we	21°C	25°C	1 pers	75 W	100 W	1 h wd 1 h we	24°C
r90-k	4 pers	204 W	660/50 W	1/4 we 1/5 sat 2/5 sun	[4]21°C 15°C	25°C	4 pers	8 h wd+sat 10 h sun	[4]21°C1 15°C	25°C	1 pers	120 W	100 W	1 h wd 1 h we	[4]21°C 15°C
r05-n	4 pers	150 W	350/50 W	1/6 wd 2/6 we	21°C	25°C	4 pers	8 H wd 10 h we	21°C	25C	1 pers	75 W	80 W	1 h wd 1 h we	22°C
r05-f	4 pers	150 W	350/50 W	1/7 wd 2/7 we	21°C	25°C	4 pers	7 h wd 9 h we	21°C	25°C	1 pers	75 W	80 W	1 h wd 1 h we	22°C
r05-g	4 pers	150 W	350/50 W	1/7 wd 2/7 we	21°C	25°C	4 pers	7 h wd 9 h we	21°C	25°C	1 pers	75 W	80 W	1 h wd 1 h we	24°C
r05-k	4 pers	156 W	460/50 W	1/6 we 2/4 we	[4]21°C 15°C	[5]25°C 35°C	4 pers	8 h wd+sat 10 h sun	[4]21°C1 5°C	[5]25°C 35°C	1	120 W	80 W	1 h	[4]21°C 15°C

Remarks to Table 1.5:

- The inlet air temperature is given as $t_{out,1}/t_{inlet,1}$ - $t_{out,2}/t_{inlet,2}$, where the different temperatures are illustrated in



- The equipment gain is based on used offices, i.e. if 18 persons in the offices and the equipment gain is 150 W/office, the total equipment gain per floor is
  18*150W=2700 W
- The lighting gain is based on used offices, i.e. if 18 persons in the offices and the lighting gain is 150 W/office, the total lighting gain per floor is 18*150W=2700 W
- Varying persons in the offices during the working hours are moved to the meeting room. If the number of persons in the office is 18/16 pers., there are 16 persons in the offices during the meeting, while there are 18 persons in the offices if there is no meeting. The same yields for persons in the common area.
- In the column for duration of the ventilation plant, wd stands for week days, we stands for week ends, while sat stands for Saturday.
- In the column for shading, *Cu* stands for curtains, *VB* stands for venetian blinds
- Korea has re-circulation of air (Rec.air) with a minimum fresh air part of 20% in the heating modus and minimum 20% fresh air in the cooling modus (0.2/0.2).
- VAV-systems in these simulations are ventilation systems where the air flow varies with the number of persons in the room. In buildings with VAV-systems, the air flow is given for occupied rooms and empty rooms.

Remarks to Table 1.6:

- In the columns for *Duration*, "wd" stands for week days, "we"stands for week ends, while "sat" stands for Saturday. All duration's are per 24 hours.
- The air flow rate might be separated in two, which means that the air flow rate is separated in two different flows during the day, see [1].
- If an air flow rate is indicated without a ventilation unit, the room is ventilated directly with outside air, for instance through a flapper valve
- All buildings have curtains as shading in the windows.
- The equipment gain is separated in two, the left part yields for the hours shown in the column *Duration*, the other part for the remaining hours.
- The duration for the occupation, lighting gain and equipment gain is separated in two, one in the morning and one in the evening. The total duration during the day is the sum of the two numbers.

1 The kitchen ventilator air flow. It is only used one hour while making dinner. The ventilation air flow to the kitchen ventilator is added on the ventilation air flow that is supplied to the livingroom/kitchen.
2 The ventilation air flow ventilate the bathroom while it is occupied.
3 The bathroom has an infiltration rate of 0.6 h^{-1}.
4 The heating set point temperature is set low during the summer time to avoid heating in the summer time.
5 The cooling set point temperature is set high during the wintertime to avoid cooling in the wintertime.

Part II:

Reduction of Electric Energy Consumption and Peek Power by DC compared to Conventional Local Cooling Plants

By

Rolf Ulseth

2. Electric Energy Consumption and Peek Power by District Cooling compared to conventional local Cooling Plants (Part II)

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.

We may use some of the simulation results from Part 1 to exemplify in broad terms how district cooling plants will reduce electric energy consumption and peek power by District Cooling (DC) compared to conventional local cooling plants.

2.1 Efficiency of cooling plants

Figure 2.1 shows, compared to a Carnot process, how the efficiency increases with increased size of the compressor (i.e. increased cooling plants) for an average cooling system.

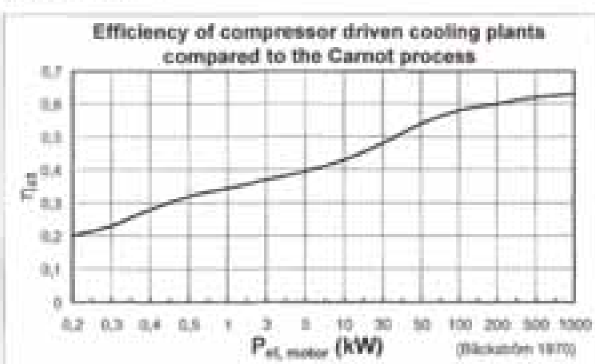


Figure 2.1

Some systems might be more efficient and some might be poorer than shown in fig. 2.1.

2.2 The effect of DC in office buildings

We choose here to use the results from Oberhausen shown in the figures 1.5 and 1.10 for office buildings.
For a cooling plant in an office building with a total maximum cooling load of ~50 kW, a chilled water system with two compressors, each with a cooling capacity of 25 kW, would be a fairly common choice.

Using a sprayed coil cooling tower, with outside air as the cooling source for the condenser, it is assumed that the cooling process should be working in the range of 5 °C in the evaporator and in the range of 35 °C in the condenser as the typical situation.

These conditions will, according to figure 2.1, give an efficiency factor, η_{ct}, in the range of 0,42.

Then we will have the following Coefficient Of Performance (COP) for the cooling process:

$$COP_c = \eta_{ct} \cdot \frac{273+5}{35-5} = 0{,}42 \cdot 9{,}3 = \underline{3{,}9}$$

With this conditions the peek power of the two electric motors for the two compressors will be:

$$P_{el,peek} = 2 \cdot \frac{25}{3{,}9} \sim \underline{13kW}$$

This will be the peek electric power for the cooling production for the single "standard" office building.

Assuming that the office building would be connected to a DC-system, and assuming that the working conditions for the compressors would be similar, the efficiency factor, η_{ct}, will be in the range of 0,6 or higher already with ten "standard" buildings connected to the district cooling system.

The COP_c will then at least be in the range of 5,6 or higher and the peek power for one building will be:

$$P_{el,peek} = \frac{50}{5{,}6} \sim \underline{9kW}$$

The seasonal electric energy efficiency will be somewhat different from the figures of η_{ct} used here, but for relative comparison of the yearly energy efficiency of different plant sizes this will be of minor importance. We should also bear in mind here that the seasonal electric energy efficiency tends to be relatively higher when the size of the plant increases.

2.3 The effect of DC in residential buildings

We choose also here to use the results from Oberhausen shown in the figures 1.19 and 1.24 for residential buildings.

For the residential building 2-4 wall or window mounted split units, with air cooling of the evaporator and the condenser, would be a common choice of equipment for the indoor air cooling.

We may assume here that the typical temperatures in the evaporator and the condenser would be in the range of 15 °C and 40 °C respectively. With these conditions, and assuming tree units in each flat, we will have an efficiency factor, η_{el} in the range of 0,33.

Then we will have the following Coefficient Of Performance (COP) for the cooling process:

$$COP_c = \eta_{el} \cdot \frac{273+10}{40-10} \sim 0{,}33 \cdot 9{,}5 = \underline{3{,}2}$$

With this conditions the peek power of the electric motors for the tree compressors will be:

$$P_{el,peek} = 3 \cdot \frac{1{,}7}{3{,}2} \sim \underline{1{,}6kW}$$

If the flat was connected to the same DC-system as in the example under point 2.2, the COP_c will be in the range of at least 5,6 and the peek power for one building will be:

$$P_{el,peek} = \frac{5{,}2}{5{,}6} \sim \underline{0{,}9kW}$$

The seasonal electric energy efficiency will also in this case be somewhat different than the figures of η_{el}, but for relative comparison of the yearly energy efficiency of different plant sizes this will be of minor importance.

We also here have to bear in mind that the seasonal electric energy efficiency tends to be relatively higher when the size of the plant increases.

2.3 Some conclusions to Part II

• When drawing conclusions from these examples, we have to notice that a lot of different factors will have some influence on the results from case to case.

In spite of that, the effect of the plant size on the efficiency is so significant, that we are here talking about an effect of different magnitude compared to other effects that might have some influence in this context when the other conditions are kept equal.

• The calculations done here for the office buildings 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 done for the residential buildings 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.

• When presenting these comparisons, we have to mention that a DC-system will need some electric power for the pumping of the water in the DC pipelines. This need of electricity will however be comparatively small and in another magnitude than the figures we are comparing here.

• The fan power for the cooling equipment in the rooms should also be mentioned. This power need should normally be the same or less by DC-systems than for the systems we have compared in this context.

• We also have to mention that the potential cooling loss from the pipelines throughout the year is neglected in this comparison. This potential loss will be very much depending of the lying of the piping system.

When the pipelines is laid directly in the soil the water temperature in the pipelines normally will be in the same range as the soil temperature or even below the soil temperature on the average.

Part III:

Primary Energy Savings by District Heating Compared to Local Heating Systems

By

Peter Noeres P. Klose D. Hölder W. Althaus

Table of Contents

Abbreviations:

AHP	Absorption Heat Pump
BHPP	Block Heat and Power Plant
CHP	Combined Heat and Power
COP	Coefficient of Performance
DC	District Cooling
DH	District Heating
DIN	Deutsche Institut für Normung (DIN Standards)
EFLH	Equivalent Full Load Hours
elHP	Electrical Heat Pump
f	Factor of energy mix
FC	Fuel Cells
GTC	Gas Turbine Cycle
GTCC	Gas Turbine Combined Cycle
HP	Heat Pump
HPP	Heat Pump Plant
HRSG	Heat Recovery Steam Generator
MCFC	Molten Carbonate Fuel Cell
PAFC	Phosphoric Acid Fuel Cell
PE	Primary Energy
PEMFC	Polymeric Electrolyte Membrane Fuel Cell
σ	Electricity losses of a CHP plant [kW_{el}/kW_{th}]
SNG	Substitute Natural Gas
SOFC	Solid Oxide Fuel Cell
STC	Steam Turbine CHP
W,Q	Energy [kJ]

Indices:

a	absorber
AHP	Absorption Heat Pump
b	boiler
c	condenser
CHP	Combined Heat and Power
com	combustion
cr	Convection & Radiation
d	distribution
el	electrical
elHP	electrical Heat Pump
f	fuel
fl	flow line
fr	firing residue
h	heat
HP	heat Pump
ib	incomplete burning
nda	no data available
pe	primary energy
pp	power plant
rl	return line
th	thermal
thm	total heat method
tot	total
wg	waste gas
η	efficiency
ξ	heat ratio

1. Introduction (Part III)

This report is one part of the IEA research project "District Heating and Cooling in Future Buildings". The main objective of this project is to perform joined research to sort out the new conditions for the future expansion of DH and DC regarding forthcoming developments in building stock. District heating with CHP-plants and district cooling are considered as those energy supply systems with the largest primary energy saving potential for industrial nations and the biggest reduction of environmental damage. The following points, which have an essential influence on the design of future energy supply systems, are discussed in the frame of the main project:

- Development of heating and cooling load and energy consumption patterns
- Potential for increased energy efficiency and energy savings by fitting new and older local heating and cooling plants into parts of DH and DC systems
- Environmental benefits of the increased energy efficiency by DH and DC compared to local heating and cooling plants

The following part examines the possibilities for primary energy savings by the use of district heating systems in contrast to local heating systems.

The report is divided into five chapters. In chapter two the system components for district heating generation and distribution are described. The combined heat and power generation (CHP) and a brief description of fuel cells are presented. Furthermore, the possibilities for heat pump plants are considered.

In chapter three the different types of local heating systems are described. Apart from the typical systems fired by fossil fuels, absorption and electrical heat pumps are also considered.

In chapter four the different systems are compared primarily from an energetic point of view. The energetic evaluation of heat generation with CHP is problematic and different valuation methods are therefore described briefly.

In chapter five a short summary and evaluation of the results of the report will be given. However, a favourable evaluation of primary energy savings can only be made under a specific energy requirement situation and available primary energy sources.

For a primary energy evaluation of the different processes the following details are needed:

For the CHP process:
electrical and thermal efficiency, power and heat ratio and the influence of the temperature

For DH:
thermal efficiency of the DH distribution and ratio between base and peak load

For local heating:
boiler and total boiler efficiency / COP and COP_{tot}

All data in this report are given for the net calorific value.

1.1. Situation of Heat Supply World-wide

The heat supply of buildings worldwide is still mainly guaranteed by fossil fuels. In Europe however district heating supply has increased in the last decades to reduce the primary energy need by using combined heat and power plants (CHP).

Fig. 1 shows the heating systems for space heat in selected European countries. The missing amount in each country is provided by other sources.

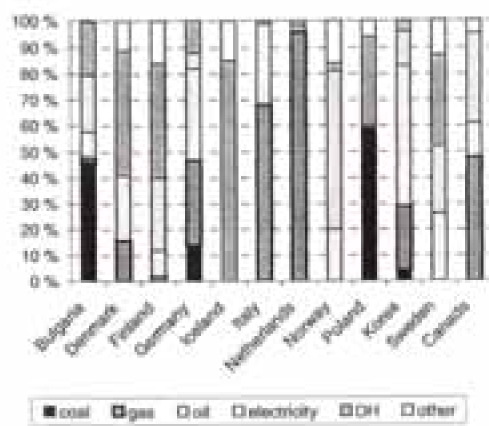


Figure 1 Type of residential heating in selected countries /1/

District heating is used primarily in Eastern Europe, Germany and several Scandinavian countries. Electrical heating systems are spread particularly in those countries in which the electricity is mostly produced by hydropower or nuclear energy.

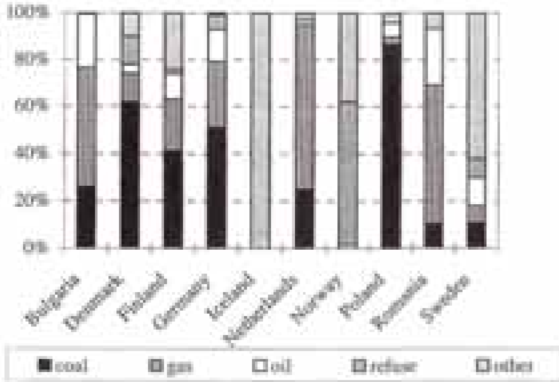


Figure 2 Primary energy to produce district heating /1/

Fig. 2 shows the input primary energy sources for district heating generation. In Iceland district heating produced by geothermal energy is predominantly used. In Finland the share of the other primary energy consists mostly of heat generation from peat. In Norway district heating is produced partly electrically. Sweden has a particularly interesting composition of DH. Besides the classic primary energy sources (coal, oil, gas, refuse), there is DH from regenerative power generation, too (biomass, peat). In addition, heat pumps and industrial waste heat are used in large-scale units (see Fig. 3).

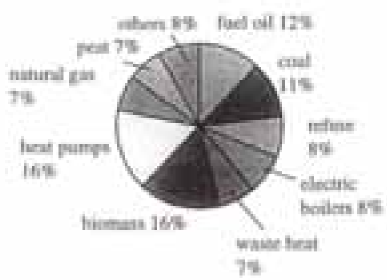


Figure 3 Primary energy used for district heating in Sweden /1/

Fig. 4 shows the district heating produced 1995 in different countries. The heat produced with CHP is marked black. Large networks in Europe were set up in many East European countries and in Germany, Sweden, Finland and Denmark.

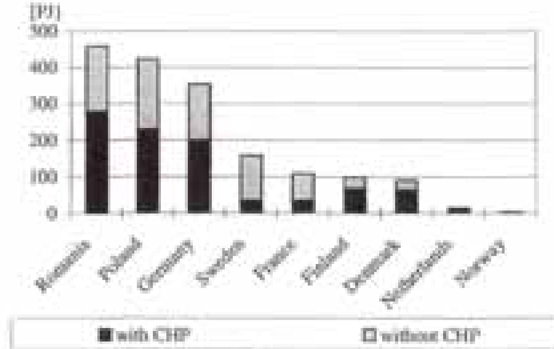


Figure 4 Heat production for district heating /2/

Fig. 5 shows the primary energy source for the electricity production. In Sweden and France electricity is predominantly produced by the nuclear energy, while Norway and Brazil use their geographical advantage to produce electricity mostly by hydropower. How electricity is generated is a main criterion to calculate the primary energy savings of CHP-processes.

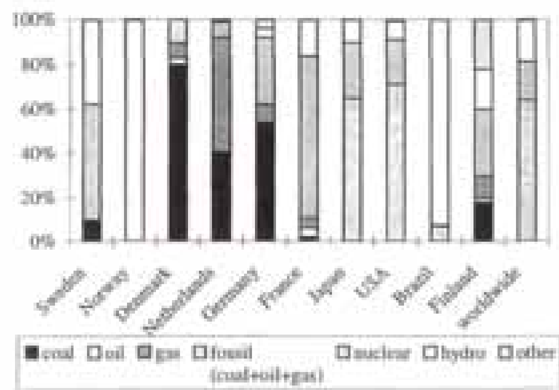


Figure 5 Primary Energy for electricity production /3/

1.2. Situation of Heat Supply in Germany

The final energy consumption of private households in Germany is to more as 75% by space heating (Fig. 6 /4/). It is still about 30% of the total energy consumption /5/, and is produced by the energy sources shown in Fig. 7 /6/.

Since reunification, the share of district heating has increased clearly because the district heating has a much larger market share in East Germany. District heating now provides about 12% of the total heat distribution.

Apart from the district heating the share of coal has also increased after reunification. The reason is that many local heating systems in East Germany are still fired by brown coal. This share is declining as expected and will diminish further.

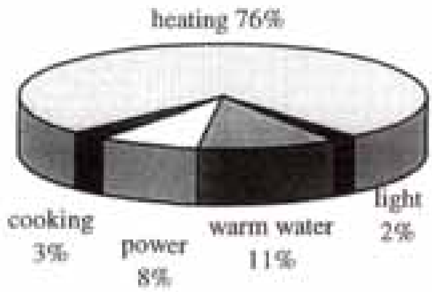


Figure 6 Proportions of the energy consumption of residential buildings (Germany)

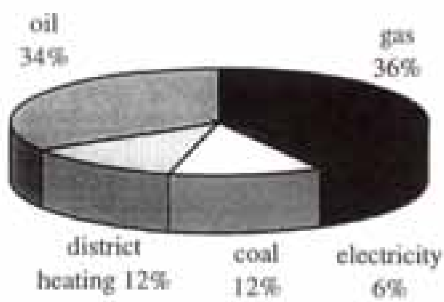


Figure 7 Different energy sources for heating of residential buildings (Germany)

Unlike district heating with CHP plants, which stagnates in Germany at the moment, the share of the CHP with block heat and power plants (BHPP) for single units increases. Especially those units with large heat base loads (e.g. hospitals, swimming pools, shopping malls and also smaller neighbourhoods and industry) are interesting for the use of CHP-processes.

At the end of 1996 about 3.000 BHPPs were installed with a performance of approximately 1600 MW_{el} and about 300 gas turbines with a performance of 4000 MW_{el}. This corresponds to a share of approximately 5% of the German electricity generation. With the actual growth an increase up to 10% is expected in future.

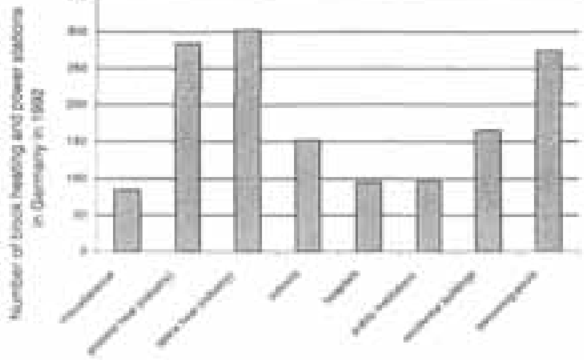


Figure 8 Area of the use of BHPPs /7/

2. District Heating Systems

The term "District Heating" is used for the central generation and distribution of heat by hot water or steam to provide heat and warm water for residential housing and industry.
The advantage of district heat for the customer is the simple availability and the good supply guarantee; the customer needs no own heating system. In addition district heating supply results in a reduced energy demand by efficient use of energy, and therefore in a reduced consumption of primary energy by waste heat utilisation of industrial processes or CHP-Systems.

2.1. Combined Heat and Power Plants

The simultaneous generation of mechanical or electrical energy and useful heat in one plant is called Combined Heat and Power process (CHP). All heat and power engines and combustion engines are suitable for the CHP-system. By using the CHP-system the demand of primary energy can be reduced clearly compared to the separate generation of electricity and heat.

The disadvantage of CHP-systems is that the demand of heat and electricity of the customer can deviate strongly from each other, whereas heat and electricity is always generated at the same time. To use CHP in the most efficient way, the heat demand is divided into base and peak load. Only the base load is generated by CHP plants, while the peak load demand is provided by peak boilers. Additional heat storage systems are sometimes integrated into the DH networks to guarantee longer utilisation periods and higher efficiencies.

Typical CHP systems are steam turbine and gas turbine heat and power plants. However in the future an increased use of fuel cells can be expected.

Heat pump plants are also used to provide heat. They are especially interesting, if electricity and waste heat are available under good primary energetic conditions and additional heat sources with a high temperature level can be acquired with moderate costs (e.g. from rivers or wastewater from industrial processes).

2.1.1. Steam Turbine CHP (STC)

Independent steam turbine power plants (i.e., steam turbines which are not just a component of a larger plant) are available in sizes ranging from 5 MW_{el} to over 1000 MW_{el}, and are the most common type of power plant in use world-wide. As a component in a larger plant, steam turbines are available in sizes of less than 1 MW_{el}. One of the advantages of this technology is the ability to use a wide variety of fuels, including solid fuels and waste materials. The basic elements of steam turbine CHP are illustrated in Fig. 9, and can be briefly described as follows.

Fuel and air are combusted in a boiler generating steam. To increase the efficiency of the steam turbine cycle, the steam is normally superheated. The steam exits the boiler and is directed to the steam turbine, where the steam expands through the turbine, turning the turbine blades, which are connected to the electric generator shaft. In a backpressure turbine, the steam is fed into a heat exchanger where thermal energy is transferred at a relatively low pressure to the district heating loop. If higher pressure steam is required, some steam is extracted through ports in the turbine prior to full expansion at the turbine exhaust. In a condensing turbine, the steam is condensed using a cooling tower, ground water or surface water, exiting at less than atmospheric pressure. Since turbine efficiency is directly related to the difference between inlet and exhaust steam pressures, condensing (non-CHP) turbine plants provide the highest electric efficiency.

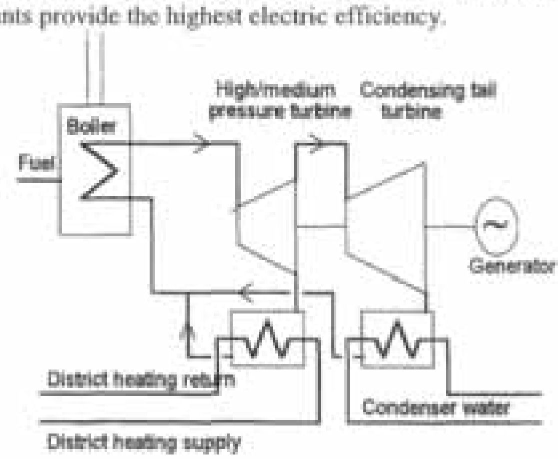


Figure 9 Schematic for CHP with steam turbine, including a condensing tail turbine

As illustrated in Fig. 9, some CHP steam turbine plants include a condensing tail turbine (the low pressure turbine in the figure) to increase the electric output regardless of district heating demand. In some steam turbine plants a reheat cycle is used, in which steam is extracted from the turbine and reheated during the expansion process. Reheat cycles, with one or two reheat points, improve the overall thermal efficiency because the average temperature of the heat supply is increased. Steam turbine plants usually also include a regenerative cycle in which steam is extracted from the turbine and used to preheat boiler feed water */8/*.

Table 1 Technical data for steam turbine heat and power plants

types	back pressure HPP extraction condensing HPP uncontrolled extraction condensing HPP
performance	5 - 1000 MW_{el}
fuels	all fuel types (coal, oil, biomass, ...)
elec. efficiency (net)	up to 45 % (total condension) 15 - 35 % (with heat extraction)
total efficiency	85 - 88 %
temperature level of heat extraction influence of heat extraction	60 - 200 °C η_{tot} = const, η_{el} = 0,35 at T_c = 60 °C η_{el} = 0,2 at T_c = 200 °C
operating method	total condensing operation total CHP operation (back pressure HPP) variable operation
power to heat ratio σ	0,3 - 0,7

2.1.2. Gas Turbine Combined Cycle / Gas Turbine Cycle

The gas turbine combined cycle (GTCC) as well as the simple gas turbine cycle (GTC) are increasingly common configurations. Fig. 10 illustrates an example of a combined cycle, showing components for both condensing and CHP options. Temperatures and pressures vary depending on the particular combined cycle configuration. This figure shows one example for illustrative purposes.

Natural gas is combusted in the gas turbine, producing electricity and hot flue gases. The hot flue gases enter the Heat Recovery Steam Generator (HRSG), where heat is recovered to produce steam (and, in some CHP operations, hot water). Output can be increased through supplemental firing, in which additional fuel is combusted using the high oxygen content in the exhaust gas. Supplementary firing can improve the overall efficiency and electric efficiency at part-load conditions.

Steam is used to produce additional electricity in a steam turbine; in the example shown, 32 MW_{el} in condensing mode. The steam cycle usually has 2-3 pressure levels; the higher steam pressure to enhance the electric efficiency and the lower pressure to enhance the heat recovery efficiency. To increase the overall efficiency a district heating economiser can be installed in the HRSG.

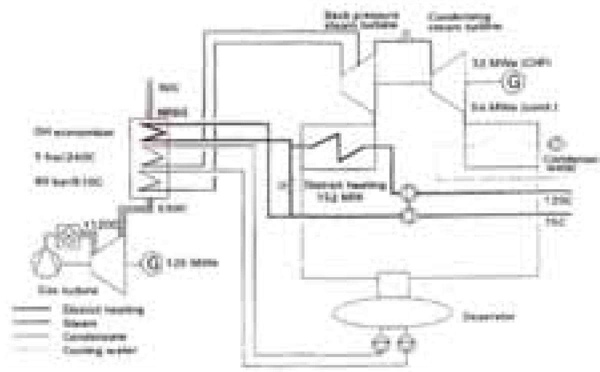


Figure 10 Schematic of a gasfired combined cycle CHP plant

The GTCC in condensing mode can reach an electric efficiency around 50%, with an efficiency above 55% possible in larger facilities with multiple steam pressure levels. The design of particular facility is based on an optimisation relative to a higher overall efficiency and the additional cost and complexity of more steam pressure levels.

Table 2 Technical data for GTCC and GTC

types	GTC	GTCC
performance	1 - 150 MW_{el}	20 - 300 MW_{el}
fuels	gas, oil, gasified fossil fuels	gas, oil, gasified fossil fuels
elec. efficiency (net)	25 - 35%	43 - 56 %
total efficiency	85 - 90 %	82 - 90 %
temperature level of heat extraction influence of heat extraction	80 - 400 °C η_{tot} = 0,9, T_c = 80 °C η_{tot} = 0,8, T_c= 250 °C η_{el} = constant	40 - 180 °C η_{tot} = 0,9, T_c = 80 °C η_{tot} = 0,82, T_c = 180 °C η_{el} = 0,5 , T_c = 40 °C η_{el} = 0,38 , T_c = 180 °C
operation method	operated according to the heat / power demand	operated according to the heat / power demand
power and heat ratio σ	0,4 - 0,65	0,8 - 1,2

2.1.3. Block Heat and Power Plant

Block heat and power plants are CHP plants with combustion engines. In general they are fired by diesel or natural gas but also allow the possibility to use waste and biogas and gasified wood. Their main advantage is that they can be installed very close to the customer and the produced heat can easily be distributed to local heating stations.

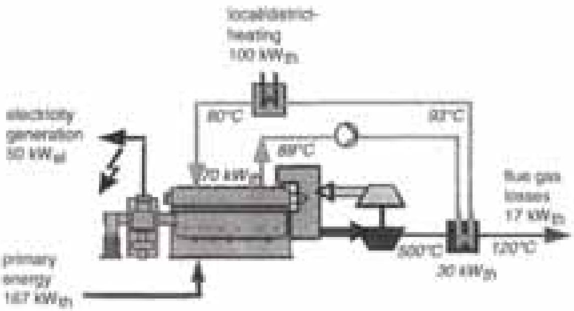


Figure 11 Schematic of BHPP with Gas engine

BHPPs can be divided into the following groups:

- Normal and hot cooled BHPP - engine
- Otto engine / diesel engine
- Differentiation by fuel (substitute natural gas (SNG), diesel, oil or natural gas)

At a BHPP the temperature level for heat generation from waste gas is about 600 °C and from cooling water around 90 °C (cylinder or oil cooling). With the separation of the heat sources (waste heat and cooling water) it is possible to generate steam with BHPP.

The electric efficiency of BHPPs can reach more than 40% especially for larger diesel BHPPs. With a combined generation of thermal energy total efficiencies up to 90% are possible. Since BHPPs only offer poor part load efficiencies, especially gas Otto engines, the total performance is often split into several modules. Depending on the required heat, the number of working modules can easily be adjusted.

Hot cooled engines have lower thermal efficiencies (about 50 - 55%) than normal cooled engines, because the temperature level of the cooling oil is higher and the oil is cooled external.

The maximum cooling water outlet temperature of hot cooled engines is about 120 °C. Further heating can be realised with waste gas heat exchanger. The cooling water of normal cooled gas engine is heated up to 85-90 °C.

Table 3 Technical data to BHPPs with combustion engines

types	hot cooled engines (up to 120 °C waste heat) normal cooled engines (up to 85 °C waste heat) otto engines, diesel engines
performance	0,05 - 50 MW$_{el}$ (Otto engines up to 2 MW$_{el}$)
fuels	natural gas, SNG, gasified fuels, oil
elec. efficiency (net)	24 - 44 %
total efficiency	85 - 88 %
temperature of heat extraction influence of heat extraction	60 - 200 °C n_{tot} = const, n_{el} = 0,35 at T_c = 60 °C n_{el} = 0,2 at T_c = 200 °C
operation method	operated according to power demand (with emergency cooling) operated according to heat demand
heat to power ratio σ	0,45 - 2,6

2.1.4. Fuel Cells

Fuel Cells (FC) convert chemical energy directly into power and heat. This kind of CHP technology represents a new development. Only some systems of FCs are available at the moment. Because of their advantages compared to standard CHP-technologies and their potentials to extend the field of application of CHP, they are discussed here.

Because of the direct conversion there is no limitation by the Carnot efficiency and therefore electric efficiencies above 60% can be reached. Today, most available cells have an electric efficiency of about 40%, which can decrease to 30% due to ageing.

The total efficiencies of FC are comparable to BHPPs with low performances, only the electric efficiency is higher. Apart from the low emissions of harmful substances and noise, fuel cells have the advantage of good part load conditions. Therefore FC-CHP plants can be designed for much higher base loads than conventional BHPPs and modular-type design is not necessary.

The development of the Phosphoric Acid Fuel Cell (PAFC) has progressed lately and the company ONSI Cop. can offer modules with performances of 200 kW_{el} since 1995. 69 units of this type were in use in 1997 and the total working time of all units exceeds 500.000 h /9/. Phosphoric acid is taken as an electrolyte. The working temperature of those units is about 170 - 200 °C. PAFC are running with natural gas, which needs to be reformed with steam at a temperature of 700 - 900 °C. After the following shift reaction at 400 °C the gas of CO_2 and H_2 can operate the fuel cell.

Flow temperatures up to 75 °C are possible with PAFCs (high temperature extraction is also offered with 120 °C/70 °C). The return line temperature should be between 30 and 50 °C. In the near future PEMFC (polymeric electrolyte membrane fuel cells) are expected to supply decentralised district heating networks. The Canadian Company Ballard is testing a prototype with a performance of 250 kW at the moment. By the end of 1999 a unit with 250 kW will be installed in Switzerland. It is considered that in the future PEMFCs can be very interesting for decentralised CHP plants without complex district heating networks (concept from Sulzer-Hexis).

MCFC (Molten Carbonate Fuel Cell) have been tested by the companies MC Power and ERC with 2 MW and 250 kW prototypes.
A pilot project from MTU Friedrichshafen with a 300 kW prototype has just started in Germany with MCFC. They are normally chosen for base load operation because of the high energy demand to heat up these FC in the starting period. They need a continuous CO_2 supply. Therefore gases, with a high content of CO_2 (SNG, biogas, gasified fuels) are particularly suitable.

SOFC (Solid oxide fuel cells) are still in its initial test stage. They are expected to realise high electric efficiencies with a simultaneous process steam generation (the electric efficiency is higher due to its internal gas reforming).

Table 4 Technical data for fuel cells

type	PAFC	PEMFC	MCFC	SOFC
performance (aspired)	50 kW_{el} - 10 MW_{el}	5 - 1000 kW_{el}	10 - 100 MW_{el}.	5 kW_{el} - 100 MW_{el}
fuels	natural gas (hydrogen)	natural gas, SNG, (hydrogen)	hydrogen, methanol, CO_2, natural gas	natural gas, methanol, gasified coal, hydrogen
elec. efficiency (total, incl. reforming)	40%	up to 45%	50 - 55%	50 - 60 %
thermal efficiency	45%	up to 40%	> 40 %	up to 40 %
temp. level of heat extraction working temp. influence of heat extraction	80 °C / 120 °C 200 °C n_{el} = constant n_{th}=0,42 (T=50 °C) n_{th}=0,13 (T=80 °C)	80 °C 120 °C	n.d.a. 650 °C	n.d.a. 800 - 1000 °C
operation methods	according to power demand according to heat demand	according to power demand according to heat demand	according to power demand according to heat demand	according to power demand according to heat demand
power to heat ratio	about 1	about 1	up to 1,5	up to 2
stage of development	available on market	demonstration, begin of commercial use	begin of demonstration	begin of demonstration
applications	BHPP	BHPP, local unit	larger plant	BHPP, local unit, larger plant

2.2. Heat Pump Plants

Heat Pump Plants (HPP) are used instead of or combined with conventional heat and power plants. In combination with BHPPs they are often called total energy plant or tandem plant. Compared to standard BHPPs with constant heat to power ratio σ , heat pump plants offer a variable ratio between heat and power.

The following heat sources can be used for heat pump plants:

- Industrial waste heat
- Sea or river water
- Ground water
- District heating supply or return line

If district heating is used as a heat source, the heat pump only transforms the district heating to the desired temperature level. It is interesting for customers with a need of high temperature heat or to extract heat at a low district heating temperature. Especially thermal-driven absorption heat pumps offer a good opportunity from a primary energetic point of view. Electrical heat pumps as well as absorption heat pumps are suitable for heat pump plants (see /10/). The data for heat pumps is given in chapter 3. Because of the larger design and the more favourable working conditions, (especially higher temperature level of the heat sources) heat pump plants may offer higher COPs. The following table 5 shows the figures of heat pump plants.

Electrical-driven HPPs are an interesting option for countries with electricity produced by hydro or nuclear power. Thermal HPPs are best used, when waste heat on a temperature level of 120 - 200 °C is available.
Another interesting alternative is the installation of cold district heating networks. The supply line temperatures are dropped to 30 – 40 °C and electrical heat pumps at the customers' site raise the temperature individually to the desired level.

Table 5 Technical data for heat pump plants

type	electrical /mechanical HPP	thermal HPP
performance	0,5 - 30 MW_{th}	0,5 - 10 MW_{th}
driving energy	electricity	thermal energy (temperatures between 120 - 200 °C)
refrigerant	ammonia (R 717), R 124a, R 134a (R 114)	water - ammonia, water - LiBr
coefficient of performance (COP)	3 – 5	1,3 - 1,7 (excl. efficiency of burner), 1,2 - 1,4 (incl. efficiency of burner
temperature level of heat source	3 - 40 °C	4 - 40 °C
temperature level of useful heat	50 - 85 °C (120 °C with R114)	40 - 100 °C

2.3. Heat Plant / Heat Distribution

In district heating systems peak load heat plants are used besides CHP-plants for economic and operational reasons and to guarantee uninterrupted service.

Because of seasonal and daily variation, the heat demand is divided into base and peak load. While the base load is often provided by CHP, the peak load is mostly generated by peak boilers. Alternatively, conventional heating systems (electricity, natural gas) at the customers' site can cover peak load. This system is popular in the Netherlands. Another possibility is the use of long- or short-term heat storage systems. Depending on the type and size of the storage additional heat losses has to be accepted.

A classification of the heat demand into base and peak load is necessary for economic reasons, because only during base load the equivalent full load hours (EFLH) are large enough for capital intensive CHP-plants. A CHP-plant designed for 50% of the maximum heat demand can supply more than 90% of heat, depending on the demand characteristics.

To cover the peak load, oil-fired peak boilers are often used. Although higher variable costs have to be considered, they cause lower fixed costs. Other fuels can also be taken into account; those boilers are described in chapter 3.1.

Heat plants fired by natural gas reach total efficiencies about 88 - 90% including heat losses of the boiler by operation stop.

Table 6 Technical data for peak load boilers and heat distribution

boiler:	
range of performance	0,5 - 30 MW_{th}
driving energy	electricity, oil, natural gas, coal , biomass
design	50 - 80% of maximum DH performance 5 - 20% of heat supply
total efficiency	80 - 90%
district heating distribution:	
distribution efficiency	0,85 - 0,95
temperatures (supply line /return line)	55 - 130 °C
electricity demand	0,018 - 0,03 kWh_{el}/kWh_{th}

3. Local Heating Systems

Local heating systems are systems with decentralised heating. The fuel or electricity is transported to the customer and transformed into heat at the customer's place. Local heating systems are:

- Heating systems with fossil fuels (heating with gas, oil, wood)
- Electrical driven heating systems (electrical storage heating, direct heating)
- Heat pumps (gas fired absorption heat pumps, electrical heat pumps)

3.1. Heating Systems with Fossil Fuels

For the energetic assessment of heat generating units efficiency is defined as follows:

eq.1 $$\eta_b = \frac{\dot{Q}_b}{\dot{Q}_f} = 1 - (q_{wg} - q_{ib} - q_{cr} - q_{fr})$$

The efficiency of the boiler η_b is the ratio of the boiler performance and the primary energy input (enthalpy flow of the fuel). It includes the losses from waste gas (q_{wg}), incomplete burning (q_{ib}), convection and radiation (q_{cr}) and unburned material in the firing residue (q_{fr}).

For conventional gas and oil heating systems waste gas losses and convection and radiation losses are the fundamental losses. Incomplete burning and unburned material have to be considered when firing with wood.

Waste gas losses are determined by the waste gas temperature, heat losses from convection and radiation by the quality of insulation, boiler temperature and downtimes.

Modern boilers have reduced waste gas losses to about 8% (waste gas temperatures of 160 °C) condensing boiler to 3%. Convection and radiation losses have diminished to 1-2%.

The total efficiency of boilers η_{tot} is the ratio between the generated useful heat Q_c and the fuel input heat Q_f in a defined period. Modern boilers have to be compared with the standardised efficiency $\eta_{tot,st}$ as described in DIN 4702 [1]. It is useful for the energetic assessment, because part load conditions and downtimes of the burner are already considered.

For the evaluation of local heating systems it is better to use standardised efficiencies as to use total boiler efficiencies. We have to take into account that the value of total boiler efficiencies are

- only exactly, if we measure this value,
- this value of course depends on the weather (cold year/warm year)
- we can only get an approximation of η_{tot} by calculation

The standardised boiler efficiency $\eta_{tot,st}$ is basis of the planning of heating systems in Germany at first. It does not take into account the dimensioning of the boiler, habits of heating and the kind of the building. As experience shows, η_{tot} is 1 to 2 % lower than the standardised total boiler efficiency ($\eta_{tot,st}$).

Table 7 shows the efficiency and the total efficiency of local heating stations:

Table 7 Efficiency and total efficiency of local heating stations [2]

type of boiler	Efficiency η_b	total efficiency $\eta_{tot,st}$ (excl.warm water generation)
oil	0,88 - 0,92	0,83 - 0,86
gas boiler	0,91 - 0,94	0,84 - 0,88
condensing boiler (gas/oil)	1,04 - 1,09	0,98 - 1,06
wood fired single stoves	0,4 - 0,6	0,4 - 0,6
boilers (fired by wood pieces)	0,65 - 0,8	0,7 - 0,8
boilers (fired by wood chips)	0,75 - 0,85	0,7 - 0,9
large boilers	0,7 - 0,9	n.d.a.

In the following chapters the different heating technologies and their advantages and disadvantages are described.

3.1.1. Gas Heating

Advantages:

- Waste gas with a high percentage of water and therefore low CO_2-emissions, clean burning
- Little cleaning and service necessary
- No fuel storage necessary

Disadvantages:

[1] The standardised boiler efficiency is calculated for five different daily average boiler efficiencies for five different part load situations.

[2] Values refer to the lower heating value of the fuel.

- Fuel distribution by installed tube systems (much lower costs compared to district heating)
- Price changes take effect immediately because of missing storage capacity

Gas heating systems can be divided into burners with and without ventilation. Burners without ventilation need specific design and are mostly used for smaller units (up to 1000 kW_{th}) with the advantage of very quiet working process, while burners with ventilation are similar in design compared to oil heating systems. They are built in all sizes up to large industrial plants.

3.1.2. Oil Heating

Advantages:

- Price changes effect slower because of storage capacity
- No distribution from a network (gas/ district heating) is required, and therefore ideal for remote houses

Disadvantages:

- More cleaning compared to gas is necessary
- Storage tanks are necessary and therefore more space is required

Over the years the oil heating has been under permanent development. Especially it is possible today to work with low water temperatures without corrosive condensation of the waste gas. This is achieved by a special design of the boiler walls or the increased temperature of the walls above dew point. Especially the convection and radiation losses can be decreased fundamentally. Therefore the over all efficiency can be increased.

3.1.3. Heating with Wood Boilers

Wood-fired heating systems are especially popular in countries with large forests and wood industry. Fuels are wood pieces and residues from the forest and waste products from the wood industry. In 1991 4,5 mill. m^3 of wood residues were collected from the forests in Germany, which is equal to 1,2 mill. l of oil. In addition, other renewable fuels like straw and peat can be used.

Wood contains hardly any sulphur. Only nitrogen oxide, tar condensates have to be controlled in the waste gas (and require controlled combustion). The calorific value of wood depends strongly on the moisture of the wood, which should be lower than 20%. Wood with moisture of 15% has a calorific value of about 14-16 MJ/kg.

Wood-fired heating systems are designed as single units (single stoves, tiled stoves, open fireplaces) and as central heating systems. Single units are only used to heat single rooms and have very low efficiencies. A controlled combustion is not possible. Wood fired central heating systems use water as heat carrier and require a more complicated design to reach a better combustion and to be able to compete with oil and gas heating systems.

The following constructions are possible:

1. Burn-out-furnace, furnace for wood pallets with burning from upside/downside. They have low efficiencies and difficult control responses and are used for warm water generation
2. Furnaces fired by wood chips (with automatic wood supply)
   They have better efficiencies but more complicated design.
3. Underfeed or stoker furnace
   Also better efficiencies. Higher investment costs
4. Wood injection combustion (for chips or wood dust)
5. Change-over furnace
   Bivalent firing with wood (main heating period) and oil/gas (for interseasonal period)

3.1.4. Condensing Boiler (Gas / Oil)

The application of the condensing boiler technology presupposes that the fuel contains hydrogen. The higher the hydrogen ratio, the larger is the energy profit achieved by steam condensation, which is theoretically around 11% for natural gas and 6% for oil /11/. Today, even gas heating systems with small performances and a low temperature level already reach total efficiencies on the calorific value (net) of around 91-93%. Heat generators of larger performance with double effect or modular burners obtain approximately 94 to 95%.

A considerable increase of the total efficiency can be reached if the enthalpy of vaporisation of the steam in the waste gas is used. In conventional heating systems this enthalpy leaves the system unused through the chimney. By lowering the waste gas temperature the steam in the waste gas condenses and even the sensible heat is gained more effectively. Depending on construction, performance and operating mode total efficiencies of 100 to 109% for available condensing boilers can be reached today.

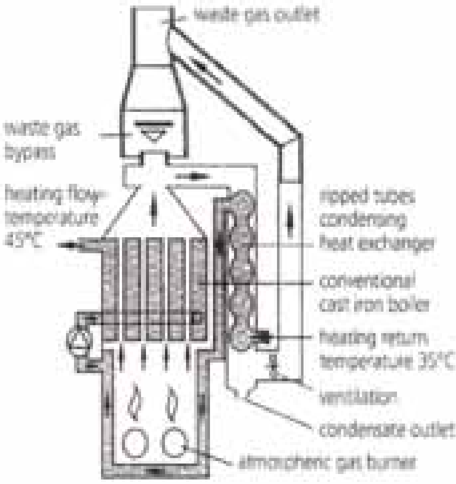


Figure 12 Typical construction of a condensing boiler with atmospheric gas burner

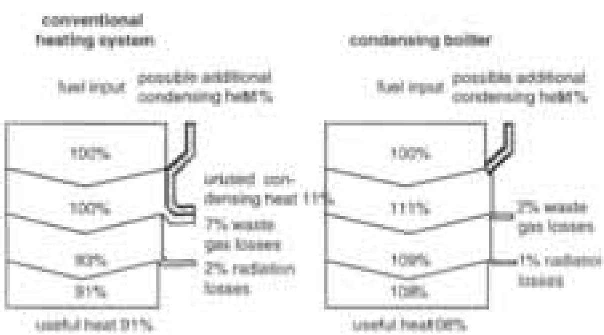


Figure 13 Energy balance of conventional and of condensing boiler systems with warm water temperatures of 40/30 °C

Fig. 14 shows the dependence of the efficiency on the return temperature. It demonstrates that low return line (or back flow) temperatures are an important prerequisite for an effective use of the condensing boiler.

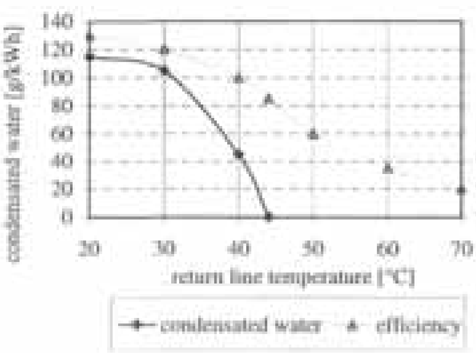


Figure 14 Efficiency and amount of condensed water of condensing boilers depending on the back flow temperatures

To use the condensing effect, the waste gas temperature has to be lower than the dewpoint temperature of the natural gas, which is 56 °C. A total condensation of the steam is obtained at a return line temperature lower than 40 °C. In this case the waste gas temperatures are only 46 °C.

It is obvious that a complete use of the condensing advantage is only possible with low temperature heating systems (underfloor central heating). But also with design temperatures of 50/70 °C a total condensation can be reached for most of the year.

Per one m^3 of natural gas, about 1.7l condensate (-> 1.07 kWh) have to be disposed. Apart from steam the waste gas also contains carbon dioxide, nitrogen oxides, and with the use of fuel oil, also sulphur oxides. These are gaseous in the waste gas but are absorbed however by the condensing water at the heat exchanger surface and in the waste gas unit. These generated acids can lead to damages, if they are disposed into the waste water system in undiluted form.
Therefore in Germany a neutralisation of the waste gas must be provided for condensates with a pH value under 6.5.

3.2. Electric Resistance Heating and Electrical Storage Heating

The electric resistance heating provides space heating the simplest manner. The efficiency is almost 100% since no transformation losses occur during generation heat. Electric resistance heating is used in the form of direct or storage heating systems:

- The direct heating immediately converts the electric energy into useful heat. In Germany it is normally only used as an additional or interseasonal heating system because of high electricity tariffs.

- The storage heating a storage mass is heated by cheap off-peak electricity. The stored heat is released slowly again depending on demand. Cheap off-peak electricity is offered by the electricity suppliers, since it increases the load at night without additional charges. This heating system is suitable for flats and houses but is limited in its distribution. The suppliers will only allow these heating systems until base load conditions are reached at nighttime.

Advantages of electric heating are

- Clean working conditions, no air pollution at the customers site
- Easy handling
- No fuel storage
- Easy supply of light, power and heating (no gas or DH supply line)

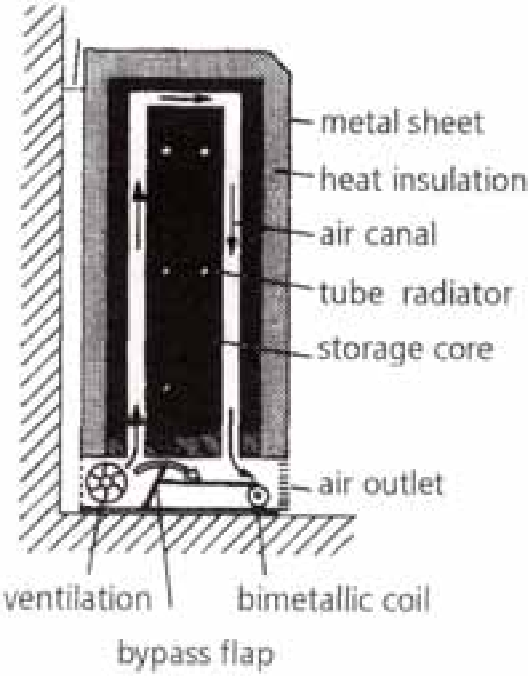


Figure 15 Electrical storage heating

3.3. Heat Pumps

With the heat pump it is possible to extract heat from the surroundings with input work in a circle process and release it on a higher temperature level for heating. The output heat quantity is a multiple of the heat equivalent of the used work.
Groundwater, soil, outside air/released air and waste heat sources are suitable for heat pump operation. To ensure an efficient heat pump operation, the temperature level of the heat source should be as high as possible. For conventional heat sources heat pumps are only favourable with low supply line temperatures (max. 55 °C).

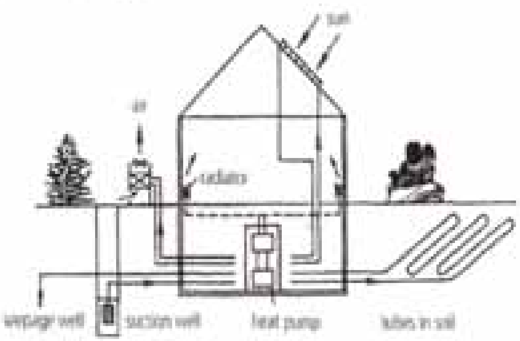


Figure 16 Heat sources for heat pumps

Electrically driven compression heat pumps and heat driven absorption heat pumps are used to heat dwellings. A heat source with temperatures of at least 100 °C is required for thermal heat pumps. Often absorption heat pumps are heated with natural gas or other fossil combustibles.

The useful heat is released on a temperature level of maximum 55 °C. Higher temperatures are possible. In this case, however, the use of heat pumps is energetically and economically not interesting. The best conditions are given for low temperature heating/underfloor central heating with flow temperatures of 35 - 40 °C.

For the description of the performance of heat pumps the coefficient of performance (COP) and the average annual COP_m (also called total COP) is used. The COP is the ratio between the useful heat and the input energy. The COP_m is decisive for an energetic comparison with other heating systems where the input energy and useful heat are balanced over a whole year. COP_m depends very strongly on the chosen operation moduls.

Since at maximum load (coldest days) the performance of heat pumps is poor, an additional, conventional heating is favourable for these conditions. This heating type is called bivalent. An extended heat pump, which can also cover these peaks, is called monovalent. However it is inferior though to the bivalent heating because of the bigger components. The following cases can be distinguished:

Bivalent operation (heating system with at least two heating systems):

1. Bivalent alternative: By temperature below a minimal outside temperature the HP is switched off and only the additional heating is operated.

2. Bivalent parallel: By temperature below a minimal outside temperature the heat demand is covered by HP and additional heating together.
   (only possible for low temperature heating systems)

3. Bivalent part parallel: By temperature below a minimal lower outside temperature the HP is supported by the additional heating system. The HP is used within its operation range.

Monovalent operation: the heat demand is only supplied by the HP.

3.3.1. Electrical driven Heat Pumps

Compression heat pumps consist of a compressor, a throttle valve, a vaporiser and a condenser. A refrigerant is vaporised in the vaporiser at low pressure and the cold vapour is compressed to the condenser pressure. The condensing heat is passed on to the heating system in the condenser. The condensate is expanded with a controlled throttle valve to the lower pressure level (see Fig. 17).

R22, R134a, ammonia and for small heat pump units also propane/butane gas are used as refrigerants. Today „new" refrigerants are examined, too, e.g. CO_2 or water.

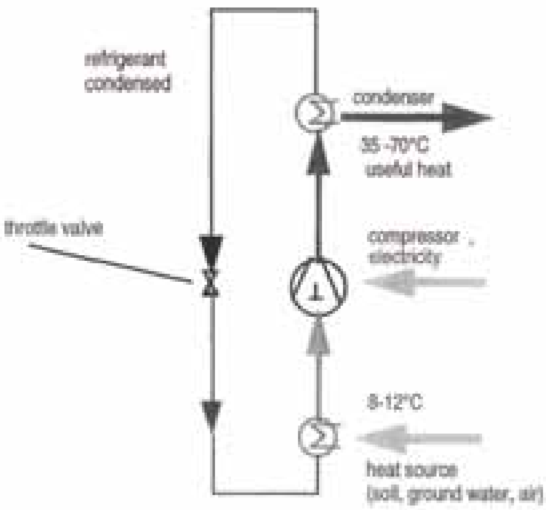


Figure 17 Scheme of an electrical driven heat pump

The COP depends on the evaporation temperature T_c as well as the condensation temperature T_0 (see eq. 2).

eq. 2 $$COP_{HP} = \eta_{c,HP} \cdot \varepsilon_{c,HP} = \eta_{c,HP} \cdot \frac{T_c}{T_c - T_o}$$

With the Carnot coefficient of performance $\varepsilon_{c,HP}$ and the Carnot efficiency $\eta_{c,HP}$ of about 0.5 to 0.6.

Fig. 18 shows flow temperature and the COP depending on the outside temperature.

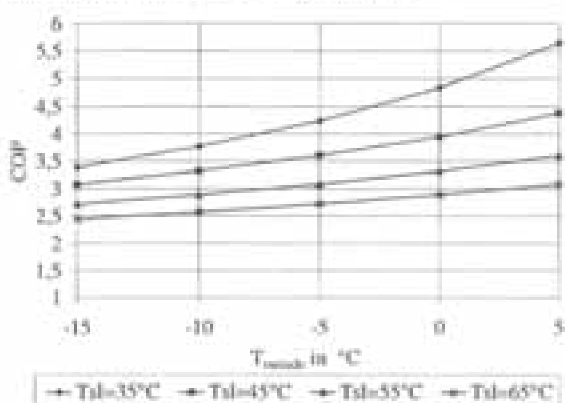


Figure 18 COP of an electrical driven heat pump

3.3.2. Absorption Heat Pumps

Absorption heat pumps (AHP) can also be used for the heating of detached and multiple dwellings. For the driving heat natural gas, oil (fossil fuels) or waste heat is chosen. The AHP is comparable to a compression chiller. The compressor is replaced by a „thermal compressor". It consists of four components: the absorber, solution pump, desorber and expansion valve (see Fig. 19).

The refrigerant (ammonia/water) is released by heat on high pressure level from a hygroscopic solution and falls out in the condenser. The compressor is replaced by a solution pump, which has an electric performance of less than 2% of heat performance.

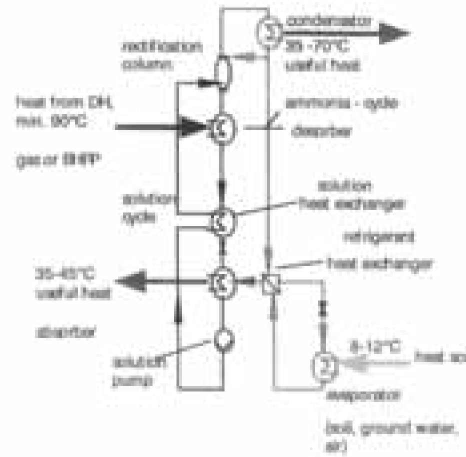


Figure 19 Scheme of a thermal driven absorption heat pump (water-ammonia)

The useful heat Q_U from AHP is the sum of the condensing heat Q_C and the absorbing heat Q_A.

Fig. 20 shows the COP depending on the operating conditions. The internal process temperatures have been used in this illustration. To calculate the external temperatures, the driving temperature difference of the heat exchangers have to be taken into account. To calculate the heat ratio ξ, the efficiency of the burner has to be multiplied with the COP.

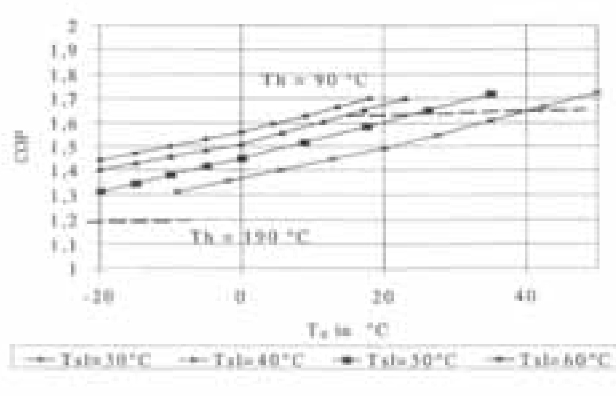


Figure 20 COP of an absorption heat pump /12/

The essential characteristics of heat pump processes are listed in the following table:

Table 8 Technical data for heat pumps

type	absorption heat pump	compression heat pump
range of performance	10 - 50 kW_{th}	10 - 100 kW_{th}
refrigerant	water-ammonia, water-LiBr	R22; R 134a; Propane/Butane, R717
driving energy	thermal energy; fossil combustibles, waste heat	elec. energy
COP (T_{el}=40 °C)	1,45 1,65	3 (low outside temperatures) 4,5 (interseasonal period)
COP_{m} (T_{el}=40 °C) soil heat source air ground water, sea water	 1,55 1,45 1,65	 3 2,5 4
heat ratio ξ_{pm}	1,32 - 1,51	η_{el} =0,38 0,95 - 1,5 η_{el} =0,53 1,3 - 2,1
useful heat	35 - 55 °C	35 - 55 °C (80 °C)

4. Comparison of District Heating and Local Heating Systems

4.1. Remarks on the Energetic Comparison of Different Heating Systems

A comparison between district heating generated by CHP and local heating is very difficult, since the different qualities of electricity and heat can not be ignored.

For an assessment of the electricity and heat generation three methods are introduced; the method using credits for the substituted electricity (chap. 4.2), the total heat method, where the generated electricity is transformed into heat (chap. 4.3), and the total energy method (chap. 4.4) The second method is used by Spurr et al. /8/ for the assessment of chilled water from CHP processes (chap. 4.2).

With the first method the problem of the allocation of the primary energy demand for the coupled products electricity and heat is solved with a credit for electricity.
This strategy derived from economics; electricity produced by the CHP substitutes the electricity produced alternatively in a condensing power plant. This is the common method to assess the heat generation from CHP plants.

The first method is problematic however, because of the quantitative specification of the credit for electricity. This credit depends on a reference object, whose electricity is substituted. There are different possibilities for the specification of the electricity credit:

1. Determination of the electricity credit with the electric efficiency for the complete electricity production of a country (mean value for PE savings)

2. Determination of the electricity credit with a concrete reference object, which is substituted (difficult to determine)

3. Determination of the electricity credit with the most inferior reference object, since these are substituted most likely (largest possible PE savings)

4. Determination of the electricity credit with the newest plants, since these reflect the actual competition with other techniques (minimal PE savings)

These points represent different borderline cases. The actual primary energetic savings, however, should always be in this range.

The second method does not need any reference power station either. Exact results for comparison are obtained, which are depending on the assessment of electricity. Depending on the quality of the transformation of electricity into heat, various conclusions arise (heat pump, electrical heating, etc.).

With the total energetic method no reference object is needed. It is unfortunate that electricity and heat must always be observed simultaneously. It is not possible to assign a specific value to one coupled product. This method will only be introduced briefly as an alternative procedure in this context.

A further problem with the assessment of CHP plants occurs, if electricity and heat are produced predominantly from regenerative primary energy sources. In this case it should be distinguished between regenerative and not regenerative energy sources.

4.2. Method with credit for the substituted electricity produced by CHP

With this method, a heat ratio ξ is introduced. It is defined by the generated heat $W_{th,tot}$ and the needed input fuel W_f (see for example /13/).

eq. 3 $$\xi = \frac{W_{th,tot}}{W_f}$$

This definition is adapted for the CHP processes with the credit for electricity. The fuel balance is calculated therefore with the difference between input fuel quantity $W_{f,CHP}$ and the substituted fuel quantity for the power plant $W_{f,PP}$.

eq. 4 $$\xi = \frac{W_{th,tot}}{\Delta W_f}$$

eq. 5 $$\Delta W_f = W_{f,CHP} - W_{f,pp}$$

eq. 6 $$W_{f,CHP} = \frac{W_{th,CHP}}{\eta_{th,CHP}} = \frac{W_{th,tot}}{\eta_{th,CHP} \cdot \eta_{d,th}}$$

The distribution efficiency $\eta_{d,th}$ and $\eta_{d,el}$ take the transportation losses into account. Typical values are $\eta_{d,th}$ = 0,90 for heat losses and $\eta_{d,el}$ = 0,965 for electricity.

eq. 7

$$W_{f,pp} = \frac{W_{el}}{\eta_{el,pp} \cdot \eta_{d,el}} = \frac{\sigma \cdot W_{th,CHP}}{\eta_{el,pp} \cdot \eta_{d,el}}$$
$$= \frac{\sigma \cdot W_{th,tot}}{\eta_{el,pp} \cdot \eta_{d,el} \cdot \eta_{d,th}}$$

The power ratio is defined by the quotient of electricity generation and heat generation. The heat ratio is therefore defined as follows:

eq. 8 $$\xi = \frac{\eta_{d,th}}{\left(\frac{1}{\eta_{th,CHP}} - \frac{\sigma}{\eta_{el,pp} \cdot \eta_{d,el}} \right)}$$

It has to be taken into account, though, that the calculated heat ratios of the CHP processes considerably depend on the efficiencies of the replaced electricity generation.

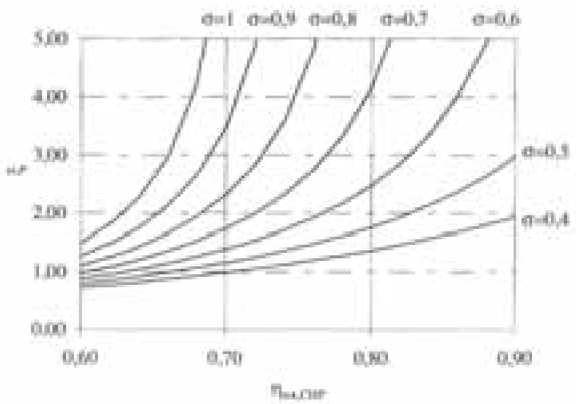


Figure 21 Heat ratio with a reference power plant with an efficiency η_{el}=0.38

Fig. 21 shows the heat ratios depending on the total efficiency and the power ratio of a coal fired power plant (η_{el}=0.38) as a reference object. It indicates that with higher power ratios the heat ratios increase significantly. It happens, when the electrical efficiency of the CHP process gets close to the one of the reference power plant. In the case, that $\eta_{el,CHP} > \eta_{el,PP}$ the heat ratio becomes negative. Just by looking at the electrical efficiency, the CHP plant is then economic.

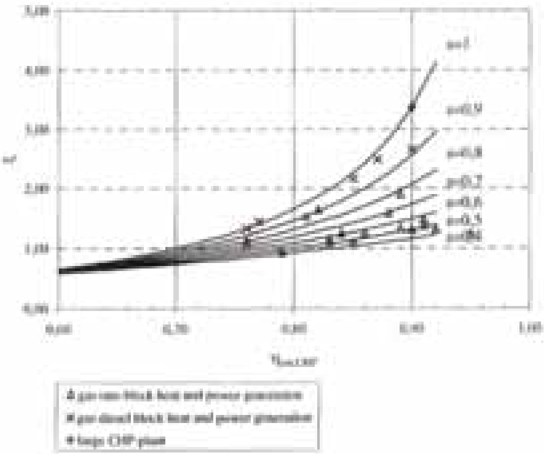


Figure 22 Heat ratio with a reference power plant with an efficiency η_{el}=0.53

In Fig. 22 and in Tab. 9 a modern GTCC power station was the reference object with an electric efficiency of 0.53. Fig. 22 shows the heat ratio depending on the total efficiency and the power ratio. Selected plants are furthermore indicated as datapoints. It can be seen, that large gas diesel BHPPs (1-7 MW_{el}) can reach much higher heat ratios than gas otto BHPPs (0,01-2,2 MW_{el}).

The calorific values calculated for the CHP processes can be compared with the calorific values of single heating plants. For these the calorific value corresponds exactly to the thermal efficiency of the plant.
To determine the heat ratio (ξ_{HP}) of electrical heat pumps, the COP of the heat pump has to be considered as well as the efficiency of the electricity generation ($\eta_{el,pp}$ + $\eta_{d,el}$). For the absorption heat pump (ξ_{AHP}) the efficiency of the combustion (η_{com}) has to be taken into account additionally (see chap. 3.3).

q. 9 $$\xi_{elHP} = \eta_{el,pp} \cdot \eta_{d,el} \cdot COP_{HP}$$
$$\xi_{AHP} = \eta_{com} \cdot COP_{AHP}$$

The following heat ratios (unit: kWh useful heat/kWh primary energy) are calculated with the data shown in chap. 2 and 3 for the different energy supply systems. For the CHP processes a range is indicated, which results from the choice of reference power stations mentioned in the previous chapter (η_{el} = 0.38 - 0.55).

Table 9 Overview on heat ratio of different heat generation

	fuel	power and heat ratio σ	electrical efficiency η_{el}	thermal efficiency η_{th}	COP_m	heat ratio ξ kWh heat / kWh PE [II)]
GTCC – CHP [I) IV)]	natural gas	1.00	0.45	0.45		-1.28/2.25
STC – CHP [I) IV)]	coal	0.46	0.27	0.58		1.67/0.97
heat plant [I) IV)]	oil, coal			0.88		0.72
BHPP – otto engine	natural gas	0.70	0.35	0.50		8/1.2
BHPP – diesel engine	natural gas	0.98	0.42	0.43		-1.93/1.64
Fuel Cell (PAFC)	natural gas	1	0.4	0.4		-3.02/1.31
electrical heat pump [III)]	electricity				2.5/4	0.95/1. 5
absorption heat pump	natural gas				1.4/1.6	1.32 - 1.51
natural gas boiler	natural gas			0.91/0.94		0.91 - 0.94
fuel oil boiler	oil			0.88/0.92		0.88 - 0.92
gas condensing boiler	natural gas			1.04/1.09		1.04 - 1.09
electrical heating [III)]	electricity			1		0.38
heating by biomass	*wood, ..*			*0.7/0.9*		*0.7/0.9*

I) The distribution efficiency for district heating and electricity has to be taken into account ($\eta_{V,th} = 0.90$, $\eta_{V,el} = 0.965$)

II) The heat ratio for the CHP-plants is calculated with a substituted electricity with $\eta_{el} = 0.38$ (first column) and 0.53 (second column)

III) electricity supply generated with $\eta_{el} - 0.38$

IV) 20% of the heat supply by peak load boilers (total efficiency 80%)

With the given details the highest heat ratios are reached with GTCC-CHP. The heat ratio of the chosen STC-CHP is only insignificantly more favourably than a condensing boiler. However it has to be taken into account that fuel used is coal, which could otherwise fired only much poorer for heat production.

Electric heat pumps have heat ratios up to 1.5, which is about the same range as for heat driven absorption heat pumps. In any case heat pumps used as single heating systems are a good solution if CHPs incl. district heating distribution systems cannot be used. The heat ratios are clearly larger than the one of condensing boilers and other heating boilers provided that HPs are designed for favourable operating conditions.

Electric heating and the heating with biomass have the poorest heat ratios. For biomass it is acceptable though because of its regenerative character.

The calculation with the credit for electricity is only valid, if the electricity from CHP substitutes the electricity generation with fossil fuels. If the CHP share reaches a certain limit, it is possible that it replaces the electricity from CHP itself or from regenerative sources. In this case heat and power can be considered equal and the primary energy efficiency corresponds to the total efficiency.

For the assessment of electricity generated with regenerative carriers, the factor f is introduced. It characterises the share of non-regenerative energy sources to the total primary energy consumption (unit: kWh $PE_{n.r.}$/ kWh PE_{tot}). Fig 1 shows the dependence of the heat ratio on the composition of electricity generation. Only the factor f is used for the calculation of the electricity credit.

The factor f for selected countries is:

Norway	0.01	Germany	0.62
Sweden	0.10	Japan	0.65
France	0.11	Brazil	0.07
USA	0.71	Denmark	0.90
Netherlands	0.92	world	0.64

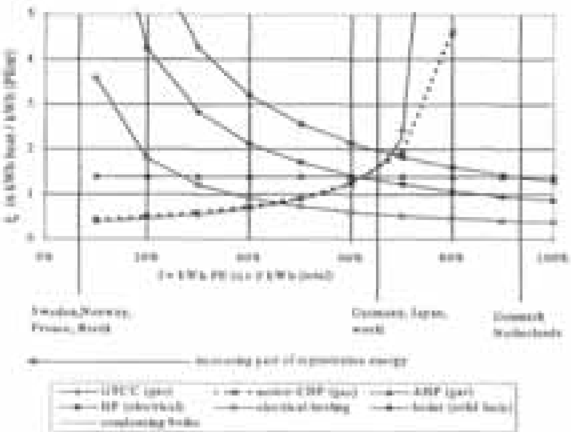


Figure 23 Heat ratio corresponding to different mix of electricity

If f reaches zero, the heat value ξ (kWh heat / kWh $PE_{n,r}$) for CHP plants approaches the thermal efficiency η_{th}, with the use of electricity the total efficiency η_{tot}. The heat ratios for the CHP plants shown in Fig. 23 are calculated with the efficiencies from Tab. 9.

These considerations are probably too pessimistic, because countries with a high percentage of regenerative energy sources will probably replace the few conventional power plants first. In this case the factor f can be set to 1. Furthermore, we also have to take into account that the transport of electricity from one country with surplus of electricity from regenerative sources to another country with electricity generation by non-regenerative energy sources could be possible (e.g. from Norway to Germany). In this case, the factor f can be set to 1, too. For countries like Norway, Sweden or Brazil, a CHP-system with fossil fuels will only save primary energy from non-regenerative sources if electricity exports to other countries are possible or in individual cases. In this case, district heating is only favourable with the use of waste heat or large heat pumps (driven by electricity produced from renewable sources). In Germany, Japan and the Netherlands however, CHP plants result in major primary energy savings compared to local supply with boilers.

4.3. Total Heat Method

This method uses almost the same ideas as the method described in the chapter before. The only difference is the avoidance of a defined reference object. The idea is to transform the electricity produced by the CHP plant into heat. To take account of the different quality of electricity and heat, this transforming process is realised with a heat pump. The heat ratio ξ_{thm} is then calculated as follows:

eq. 10 $$\xi_{thm} = \eta_{th} \cdot \eta_{d,th} + \eta_{el} \cdot \eta_{d,el} \cdot COP_m$$

The results of the total heat method are slightly different to the method with the credit for electricity. The ranking of the processes remains the same. Only the difference to the local heating systems is reduced. Tab. 10 shows the calculated heat ratios for different CHP systems.

Table 10 Overview on heat ratio of CHP plants calculated with the total heat method

	fuel	power and heat ratio σ	electrical efficiency η_{el}	Thermal efficiency η_{th}	heat ratio (total heat method) ξ_{thm} kWh heat / kWh PE III)
GTCC - CHP I) III)	natural gas	1.00	0.45	0.45	1.34 / 1.86
STC - CHP I) III)	coal	0.46	0.27	0.58	1.08 / 1.4
BHPP- otto engine	natural gas	0.70	0.35	0.50	1.18 / 1.58
BHPP- diesel engine	natural gas	0.98	0.42	0.43	1.26 / 1.75
Fuel Cell (PAFC)	natural gas	1	0.4	0.4	1.2 / 1.67

I) The distribution efficiency for district heating and electricity has to be taken into account ($\eta_{V,th} = 0.90$, $\eta_{V,el} = 0.965$)

II) 20% of the heat supply by peak load boilers (total efficiency 80%)

III) assessment of the electricity with HP process, COP_m =2.5 (first column), 4 (second column)

4.4. Total Energy Consideration of CHP

This method for the assessment of CHP described by Alefeld /14/ is a causal orientated method. Based on thermodynamic laws, system efficiencies are calculated for the combined generation of heat and power. A comparison between local heating stations and different CHP systems is possible. With the causal orientated method no reference plants need to be defined.
An energy balance is devised with the first thermodynamic law and the quantities primary energy Q_{pe}, electrical performance P_{el}, heat performance Q_h, and waste heat Q_{rh}:

eq. 11 $$Q_{pe} = Q_h + P_{el} + Q_{rh}$$

The second thermodynamic law determines that

eq. 12 $$P_{el} = P_{el}\left(Q_{pe}, Q_h, Q_{rh}\right)$$

and therefore a connection exists between the generated electrical performance P_{el} and the generated heat performance Q_h. With the elimination of the variable Q_{rh} there is the following linearized relation:

eq. 13 $$Q_{pe} = aP_{el} + bQ_h$$

The coefficients a and b are described by the efficiencies and distribution losses. With this relation a division of the energy input is made and a subjective contradiction to the second thermodynamic law is avoided.

With eq. 13, differential system efficiencies for heat and electricity generation can be derived.

eq. 14 $$\eta_{el,Sys} = \left.\frac{\partial P_{el}}{\partial Q_{pe}}\right|_{Q_h}$$

and

$$\eta_{th,Sys} = \left.\frac{\partial Q_h}{\partial Q_{pe}}\right|_{P_{el}}$$

With these efficiencies different local heating systems, CHP systems and combinations of CHP plants are comparable. The derivatives of different system efficiencies can be found in /15/.

In Fig. 24 the specific primary energy demand is described depending on the specific heat demand for different energy supply systems. The primary energy and heat both refer to the electrical performance. Depending on the given ratio Q_h/P_{el}, predefined by a concrete object to be supplied (single object, town, country), the maximum possible primary energy savings can be determined directly. With this solution it is also possible, to determine the primary energy savings over a longer period with varying ratio Q_h/P_{el}. Therefore the figure shows, that there are ranges where the alternative with GTCC and condensing boiler can be more favourable than with district heating provided by a gas turbine (for a low ratio Q_h/P_{el}).

To consider electricity generation with renewable sources, only the part of P_{el} is taken into account, which is produced with fossil fuels ($P_{el,tot}$ (1-f)). The result of such consideration is comparable to those in Fig. 24. If the factor f is zero and the energy is generated with condensing boilers, there would be a straight line with a gradient of one.

For an explanation a comparison will be carried out with a single object in table 11 (office building). The ratio of Q_h/P_{el} is calculated for summer time (Q_h=0), interseasonal and wintertime. The interseasonal time is weighted by the factor 2 in order to get annual average.

For this example an electricity and district heat supply with GTCC-CHP is the most favourable option, followed by a GTCC and a heat pump. The worst alternative is the conventional power plant process with gas boiler.

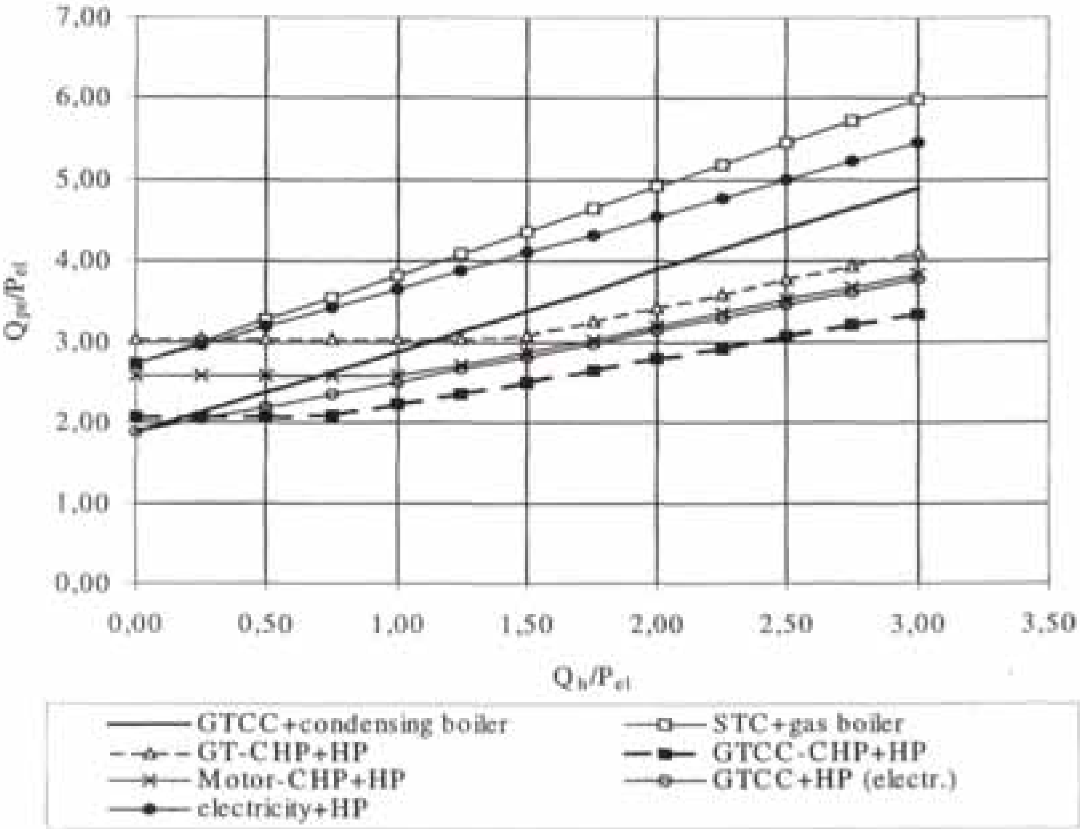


Figure 24 Spec. primary energy demand for different spec. heat demand

The following options are chosen for the illustration:

1. GTCC + condensing boiler: $\eta_{el}=0{,}55$, $\eta_{d,el}=0{,}965$, $\eta_h=1$
2. GTC-CHP + elHP: $\eta_{el}=0{,}34$, $\eta_{d,el}=0{,}965$, $\eta_{th}=0{,}55$, $COP_m=3$, $\eta_{d,DH}=0{,}9$
3. motor-CHP + elHP: $\eta_{el}=0{,}4$, $\eta_{d,el}=0{,}965$, $\eta_{th}=0{,}47$, $COP_m=3$, $\eta_{d,DH}=0{,}9$
4. STC + gas boiler: $\eta_{el}=0{,}38$, $\eta_{d,el}=0{,}965$, $\eta_h=0{,}92$
5. GTCC-CHP + elHP: $\eta_{el}=0{,}5$, $\eta_{d,el}=0{,}965$, $\eta_{d,DH}=0{,}9$, $\sigma=1{,}38$, $\eta_{th}=0{,}4$
6. GTCC + elHP: $\eta_{el}=0{,}55$, $\eta_{d,el}=0{,}965$, $COP_m=3$
7. Electricity mix + HP: $\eta_{el}=0{,}38$, $\eta_{d,el}=0{,}965$, $COP_m=3$

Table 11 Specific PE-Demand of a single building (office building)

Pos.	Variant	$Q_h/P_{el}=0$	$Q_h/P_{el}=1{,}25$	$Q_h/P_{el}=2{,}5$	Q_{pe}/P_{el} (annual average)
1	GTCC + Condensing boiler	2	3,1	4,3	2,73
2	GTC-CHP + elHP	3	3	3,55	3,08
3	BHPP-CHP + elHP	2,7	2,75	3,6	2,85
4	STC + gas boiler	2,8	3,85	5,4	3,56
5	GTCC-CHP + DH (incl. peak boiler)	2	2,4	3,6	2,38
6	GTCC+ elHP	2	2,6	3,4	2,42
7	Electricity + HP	2,8	3,9	5	3,52

4.5 Evaluation of relative Primary Energy Reduction

Subsequent the relative savings of primary energy are calculated by the methods 2 (chap. 4.3) and 3 (chap. 4.4). Method 1 we renounce since with it also negative primary energy savings are possible. As reference supply case the power and heat supply from steam power plants and heat from gas or oil boilers, as this is the typical supply case in Germany, are assumed. The values indicate the savings of primary compared to this supply case.

For the two methods a little divergent values are got. With the method 2 smaller primary energy savings are determined in any case. This can be explained by the fact that different operating conditions are taken into account for method 3. No primary energy can be saved for example in summer since there is no need for heating. For method two, however, we presuppose an always sufficient demand of power and heat. The primary energy savings with method 3 go up to 33 % compared to the reference case. The most favourable result is obtained with a GTCC and district heating. GTCC and electrical HP achieve an almost equal result. Full-coverage use of electric heat pumps (including the heat source installations) and corresponding low temperature heating systems is surely sensible only for new buildings and at detached houses or two family houses. At a larger density of heat demand the concept of district heating supply should be the more suitable strategy, however.

GTCC and condensing boiler only obtain a reduction of the primary energy consumption of 23 %. At this strategy the most modern and at the moment available technology for a separate supply with power and heat is used. But also with this procedure, the reduction of the primary energy consumption or the CO_2 output demanded by the international community should be realised.

In the context of the calculation of the primary energy reduction by method 2 we get a bandwidth, which arises on the assessment of the required heat pump process. The larger values are calculated for a COP of 4, the smaller value for a COP of 2. The highest savings will be obtained by use of GTCC and district heating systems, followed by BHPP and local heating systems. The electric power for electric heat pumps supply is presupposed according to the mix of electricity in Germany. Because of that assumption the values for electric heat pumps are lower than the results shown in table 12.

Table 12 PE-Reduction calculated by Total Energy Consideration of CHP (method 3, chap. 4.4)

Variant	Q_{hi}/P_{el} (annual verage)	PE-Reduction
GTCC-CHP + DH (incl. peak boiler)	2,38	33%
GTCC+ elHP	2,42	32%
GTCC + Condensing boiler	2,73	23%
BHPP-CHP + elHP	2,85	20%
GTC-CHP + elHP	3,08	13%
Electricity + HP	3,52	1%
STC + gas boiler	**3,56**	**0%**

Table 13 PE-Reduction calculated by Total Heat Method (method 2, chap. 4.3)

	PE-Reduction	
	Minimum	Maximum
GTCC – CHP	32%	49%
BHPP – diesel engine	28%	46%
Fuel Cell (PAFC)	24%	44%
BHPP – otto engine	23%	41%
absorption heat pump	31%	38%
electrical heat pump [III]	4%	37%
STC – CHP	16%	33%
gas condensing boiler	13%	14%
natural gas boiler	**0%**	**0%**
fuel oil boiler	-3%	-2%
heating by biomass	-30%	-4%
heat plant	-26%	-31%
electrical heating	-139%	-147%

5. Summary / Evaluation

In this report different local and district heating concepts are presented and the primary energy demand for the heat supply is calculated. The comparison of these systems takes into account the essential primary energy sources (fossil fuels like coal, gas, oil, or regenerative fuels like biomass, water, nuclear power). The share of those carriers varies strongly between each country and influences the assessment of the different systems.

The following generation systems for district heating supply are described in this report:

1. District heating from CHP - plants (GTC-CHP, GTCC-CHP, STC-CHP, BHPP)
2. District heating from heat pump plants
3. District heating from heat plants, waste incinerators or industrial waste heat

The described local heating systems are:

1. Gas and oil boiler, condensing boiler
2. Wood combustion
3. Electrical resistance heating and with and without storage
4. Heat pumps (electrical and thermal)

The problem of all energetic comparison of the different heat supply systems is the cogeneration of heat and electricity of CHP plants. The total primary input energy for those systems cannot easily be divided into the energy needed for heat and into energy needed for electricity. To take into account the electricity produced by CHP plants, three methods are introduced in this report with the following advantages (+) and disadvantages (-):

- Credits for the substituted electricity:

  + Defined value (heat ratio) for the energy needed for district heating
  + Direct comparison between local heating and CHP plants is possible
  - The heat ratio depends on the electrical efficiency of the substituted power plant
  - Negative heat ratios are possible (credit for electricity larger than primary energy demand for the CHP process)

- Transformation of electricity into heat with a heat pump:

  + Defined value (heat ratio) for the energy needed for district heating
  + Direct comparison between local heating and CHP plants is possible
  + Only positive heat ratios
  - Theoretical concept, since heat pumps are not often used for heat generation

- Total energetic assessment:

  + Examination of the total energetic assessment
  + Taking into account of different annual supply situations
  - No primary energetic value (heat ratio) for the heat generation alone

The following assessments refer to the second method although the results of the first and third methods are not fundamentally different:

District heating from GTCC-CHP plants offers heat ratios between 1.2 and 1.8. Therefore CHP plants should be preferred over fossil-fired local heating systems. Only thermal and electrical heat pumps with reasonable operation conditions (low temperature heating, good heat source) can also be a possible alternative.

The heat ratios of central heat pump plants are between 1.3 and 1.5 and are therefore more efficient than local heating systems. Compared to local heat pumps the central generation of heat is only favourable, if a heat source with a high temperature level can be used. Otherwise local HPs should be preferred because of smaller distribution losses.

An interesting solution is the combination of CHP plants and heat pumps with a possible flexible operation (no fixed ratio between heat and electricity).

Since heat plants only generate heat, an increase of the heat ratio above 1 is not possible. Because of distribution losses the efficiency is lower than local heating systems. From a primary energetic point of view, heat plants should be avoided. The only favourable use is to cover the peak load demand. An exclusively thermic use of the energy from biomass or refuse can be preferable but it should be questioned why an additional generation of high quality electricity is not possible.

In conclusion a short 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 [3]
3. CHP + DH
4. Heat pump processes (local or in combination with DH)
5. Condensing boiler
6. Gas boiler, oil boiler
7. Electrical heating systems (electricity from fossil energy sources)

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.

[3] 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).

6. List of Figures / List of Tables

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7. Literature

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Part IV:

Environmental Benefits by DH&DC compared to Local Heating and Cooling Plants

By

Markku Ahonen

4. Environmental benefits by DH&DC compared to local heating and cooling plants (Part IV)

A comparison between the environmental effects of different energy production systems is problematic. Extensive studies are needed to clarify environmental effects profoundly, e.g. detailed life cycle assessment (LCA) of every studied system. Principles and framework of the LCA is standardised /1/, but the whole method is still under development work. Because of the complexity of LCA studies, in this chapter only general aspects of environmental effects of district heating and cooling systems are presented. The comparison between local and district heating and cooling systems are based on information collected from references and on a few calculated examples of flue gas emissions.

4.1 Environmental effects

Energy production for heating and cooling systems has several environmental effects. Figure 4.1 shows an example of a formation chain of environmental effects in the energy production. If environmental effects between different energy production systems are compared, some kind of determined index for valuation of effects is needed. In the LCA studies, the index can be based on evaluated costs of different effects, for example.

The most influential air pollutants are heating or electricity production systems, which require the combustion of fossil fuels. Nuclear power and also hydroelectric power production systems don't have flue gas emissions at all, but they do have environmental effects such as radioactive wastes from the nuclear power production. Hydroelectric power production systems have more effects on nature's aesthetics than producing actual pollutants /2/.

Not only the energy production, but also the energy conversion and distribution systems have environmental effects, too. Especially in the conventional cooling plants conversion of the primary energy to the cooling energy have strong environmental effects.

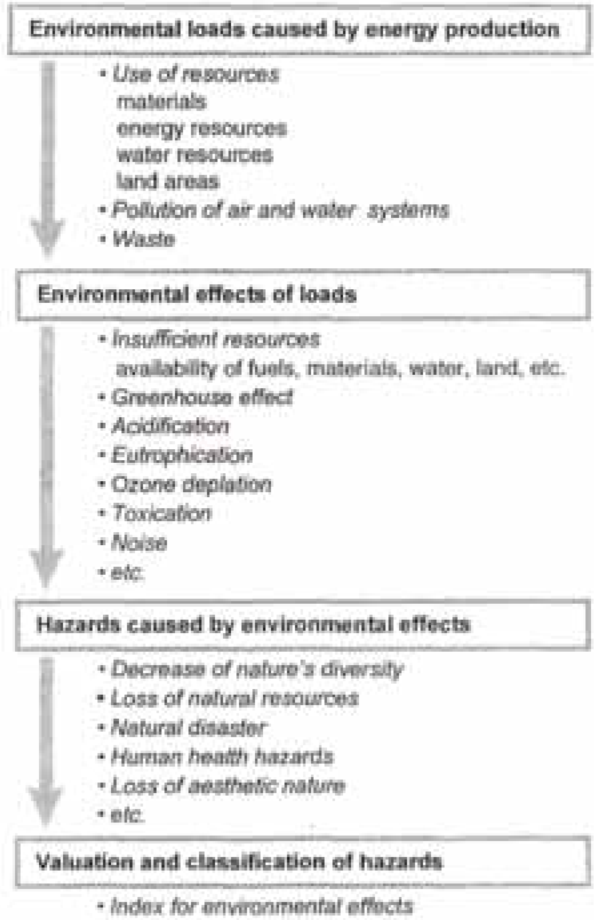

Figure 4.1. An example of a formation chain of environmental effects /3/.

For example electrically driven compressors of the cooling systems require refrigerants. Before the Montreal protocol was signed in 1988, adapted refrigerants were usually chlorofluorocarbons (CFCs). These chemicals are thought to be the primary contributor to the ozone layer depletion in the upper atmosphere /2/. In the Montreal protocol, timetables for ending the production and use of CFCs were established. Later the protocol was revised a few times and the timetables were strengthened, as were done at the meetings in London and Copenhagen.

During the past 10 years, massive work has been undertaken to develop alternative refrigerants for CFCs, because of the Montreal protocol. Every compound of CFC (or HCFC) refrigerant has an individual ending timetable, which vary from 1996 to 2030 /4/.

Maybe the confused situation of conventional refrigerants is one reason for the recent development of district cooling systems. Recently developed district cooling systems don't include refrigerants like CFCs. This kind of systems are e.g. absorption chillers, which are operated by district heating, and sea water cooling systems.

4.2 Flue gas emissions of energy production

The main pollutants released from the combustion of fossil fuels are:

- carbon dioxide CO_2
- carbon monoxide CO
- sulphur dioxide SO_2
- nitrogen oxides NO_X
- unburned hydrocarbons

Carbon dioxide forms the largest component of the products of combustion, and rising concentrations in the earth's atmosphere are a major cause of the greenhouse effect and risk of climate change. It's production is directly proportional to the quantity and composition of fuel burnt /5/.

Carbon monoxide is a poisonous gas, which is produced through incomplete combustion. It can be reduced to negligible levels simply through satisfactory air/fuel control /5/.

Sulphur dioxide is an acidic gas, which is released when burning sulphur-containing fuels such as oil, coal or bio-gas, but not e.g. from natural gas. SO_2 emission is a cause of acid rain and, if allowed to condense, it causes corrosion damage to steel for example in heat recovery systems /5/.

Nitrogen oxides are produced by burning any fuel in air. NO_X formation is strongly influenced by combustion conditions, such as temperature, residence time and air/fuel ratio. In the atmosphere, nitrogen oxides undergo various chemical reactions, which result in ozone formation and smog. NO_X also contributes to acid rain and is one of the major urban pollutants /5/.

Unburned hydrocarbons are largely produced by the reciprocating engines of motor vehicles where poorly controlled combustion leads to small quantities of partially burnt fuel passing through the engine. Unburned hydrocarbons are a major cause of smog and contribute to the greenhouse effect /5/.

4.3 Development of emissions

Emissions vary according to national circumstances, but the average specific CO_2 emissions per unit of primary energy consumption have been slowly decreasing during the past 20 years in almost all western countries (figure 4.2).

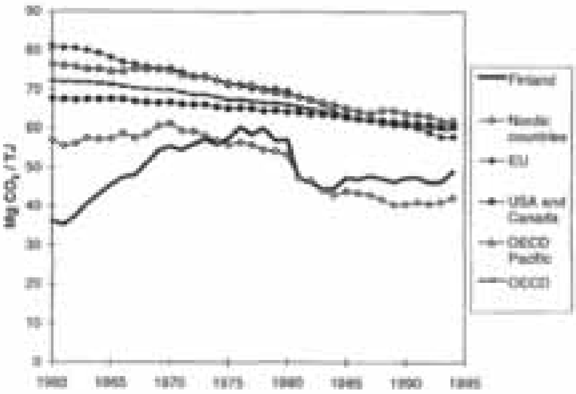

Figure 4.2. CO_2 emissions per unit of primary energy in selected countries /6/.

The trend of average CO_2 emissions have been decreasing for example in OECD countries, in Europe, in USA and in Canada. The average emissions of the Nordic countries are lower than the average in Central or Southern Europe, in USA and Canada or in OECD countries /6/. Table 4.1 shows emissions from electricity production in some European countries according to the reference /7/.

	CO_2 g/kWh$_e$	SO_2 mg/ kWh$_e$	NO_X mg/ kWh$_e$
Norway	0	0	0
Switzerland	16	7	25
Sweden	50	51	44
Austria	218	207	188
Netherlands	459	207	523
Finland	272	423	492
France	71	485	239
Germany	543	1368	438
Italy	546	2711	1592
Denmark	743	2747	2150
Great Britain	485	4398	1441

Table 4.1. Emissions from electricity production in different European countries /7/.

Many countries have a national energy strategy, which contains objectives for the reduction of flue gas emissions, especially CO_2 emissions. The international agreements, like the Kyoto agreement, commit to do measures, so that promised reductions of emissions will be achieved.

In the national energy strategies of many countries combined heat and power production (CHP) is taken up as one solution to achieve international commitments and CHP capacity is growing throughout many European countries all the time. High efficiencies of CHP lead to a reduction in CO_2 emissions compared to conventional separate generation because of more efficient use of fuel /5/.

Below are shown a few examples concerning national energy policies or strategies and environmental protection according to the reference /8/. These examples show that district heating systems and especially CHP production play an important role in national energy and environmental protection strategies.

Finland /8/

The Finnish energy policy has three major goals;

* security
* economy and effectiveness
* safety and environmental acceptability

The protection of the environment, as well as encouraging competition in the energy field, have become more important.

District heating has been an important tool in advancing the realisation of the Finnish energy policy. CHP production has made a significant contribution to the energy saving efforts. The government and local authorities have taken a positive attitude toward district heating.

The regulations for maximum emissions of particles, sulphur dioxide and nitrogen oxides have affected large investments for power plants and bigger boilers. These investments and other measures have weakened the competitiveness of district heating towards individual gas heating or light fuel oil heating. The CO_2 tax has also affected some extra costs for district heating.

Norway /8/

The Norwegian Parliament endorsed the objectives concerning emission restrictions on sulphur dioxide and nitrogen oxides. Regarding the carbon dioxide emissions, a majority of the government advocated a reduction of the emissions to reach a stable level by the year 2000 at the latest. As a result of the environmental requirements, a reduction in the rate of growth in total energy consumption may be necessary, aiming at a levelling out towards the turn of the century. To obtain these goals, an energy price and tax policy allowing for a reflection of the environmental costs is being prepared. This mainly applies to the prices of fossil fuels.

The use of renewable energy sources is encouraged by the government, and may increase the future use of district heating as biomass may be most efficiently used in such centralised plants.

Germany /8/

To have a sufficient and reliable supply of cost efficient energy, a political conception with the following focal points has been fixed:

* priority for energy saving and efficient use of energy
* improvement in the structure of energy demand by reducing the share of fuel oil and increasing the share of coal, natural gas, nuclear energy and - if available on economical conditions - of new and renewable energy sources
* optimal use of domestic energy resources
* broad spread of sources of primary energy imports
* national and international supply on the international energy market in case of disturbance of the energy supply

The district heating - in particular the CHP production - has an important meaning on that occasion. By its intensified use an important part of the total energy consumption will be saved. Because of the high no-polluting energy source and its large effect on energy saving, district heating has a very positive image in the Federal Republic of Germany.

In the frame of environmental protection, large amounts of money have been spent in power stations, in particular in CHP plants.

Denmark /8/

The Danish energy policy has three major goals:

* energy savings
* utilization of domestic energy sources
* safety of the energy supply

In addition, the protection of the environment, as well as encouraging competition in the energy field, has become more important.

District heating has been an important tool in advancing the realization of the Danish energy policy. CHP production has made a significant contribution to energy saving efforts.

District heating has no doubt contributed to an improvement in the environment situation in Danish towns and cities. Through changed methods of producing district heat and installation of exhaust gas cleaning, the outdoor air in Denmark is much better today than it was one or two decades ago.

The Netherlands /8, 9/

The main goals for the Dutch government are:

- reduction of emission of carbon dioxide, according to the Kyoto conference
- introduction of sustainable energy up to 10 % of the total use in the year 2010.
- increase of the energy efficiency
- liberalisation of the energy-market

The long-term policy is to increase the use of sustainable energy (wind, biomass, en photo-voltaic-cells). Especially the electricity-sector has to participate in the sustainable energy development.

Development of CHP and DH still play an important role in the increase of energy-efficiency.

To reach the Kyoto goals the Dutch government started a subvention program 1997 to realise their goals. A lot of new D/H-schemes are as part of this program developed. An important part of these projects contain D/H-connection of greenhouses.

The national government published a new law on 15 December 1995, which prescribes a required "Energy Performance Standard" when a new building is designed and built. The "Energy Performance Standard" is the energy-paragraph in the building code. At review in 1998 has increased the energy performance of CHP and other heat-sources in this standard. A house with a DH-connection reaches a 10 to 20% better value than a house with an individual boiler.

Bulgaria /8/

The national energy policy follows three fundamentals:

- maximum use of indigenous energy sources (mainly lignite) in conjunction with measures necessary for environmental protection
- thrifty use of energy, especially in relation to heat and electricity
- the furtherance of district heating systems, particularly the installation of CHP plants
- the extension of nuclear power plants due to the lack of indigenous energy carriers

To achieve more energy savings, measures have been set in motion to introduce individual heat cost accounting.

CHP production plays a significant role in Bulgaria, especially over the past 20 to 25 years. However, the restructuring of the country from a planned to a market economy has strongly inhibited the growth of district heating systems, although it is known that CHP systems contribute to reducing fuel consumption and thereby cutting pollutants.

Bulgaria has had comparatively stringent environmental legislation for some time. In preparation are also measures for controlling flue gas losses in relation to fuels used and installed boiler output, as well as the introduction of ecological waste disposal systems using modern, environment-friendly technologies.

4.4 Calculated examples of emissions

A great number of factors have to be chosen when emissions of different kind of energy production systems are compared by the help of calculations. These factors are the properties of available fuels, characteristics of burners and boiler plants, energy distribution losses, share of combined heat and power production, etc. And every chosen factor has an effect on a calculated result.

Flue gas emissions from local heating plants can be defined when characteristics of the fuel and boiler plant are known. In the case of district heating or electricity production, the definition of emissions is not so clear. Distribution losses and shares of fuels in production have to been taken account, too. In the case of CHP production, the definition of emissions will become more complicated.

Allocation of emissions to the electricity and district heating production is problematic. Several methods to allocate emissions have been introduced, but none of these methods are standardised.

One method is to allocate emissions to the district heating and to the electricity in the share of their production or sale. Another method is to decrease emissions of the district heating production with a reduction of emissions, which is achieved when condensing power production is replaced by the CHP production. This method is used in the calculated examples shown below. The calculations were done by the Emission calculation application of the Excel worksheet, which was developed at the VTT Building Technology in 1993.

Structures of electricity and district heating production systems, and shares of fuels in Finland have been chosen for a basic case of calculations (fig. 4.3 and 4.4).

These factors have been varied in six fictional cases, and their effects on CO_2, SO_2 and NO_X emissions are defined. Seven calculated example cases are:

- case 1, a reference case
- case 2, all district heating from CHP production
- case 3, all district heating from separated production
- case 4, all heating energy from local light oil heating boilers
- case 5, all heating energy from local natural gas heating boilers
- case 6, all heating with direct electric heating produced by condensing power
- case 7, all heating with direct electric heating produced by nuclear or hydropower

In all cases, specific emission factors of fuels consist of production, transportation, storage and combustion of the fuel. The calculated CO_2 -equivalent emission factor is based on the total emissions of carbon dioxide CO_2, methane CH_4 and nitrous oxide N_2O. Table 4.2 shows the emission factors.

Release of emissions mainly depends on the composition of fuels, but it also depends on the quality and property of the fuel. The quality and property of the fuel likely varies significantly, which of course affects the calculated emissions.

Cleaning of flue gas emissions is not included in the calculations, which have to be taken into account when calculated results are studied. Because of this the calculated SO_2 and NO_X emissions are higher than in reality, but it doesn't affect the CO_2 emissions.

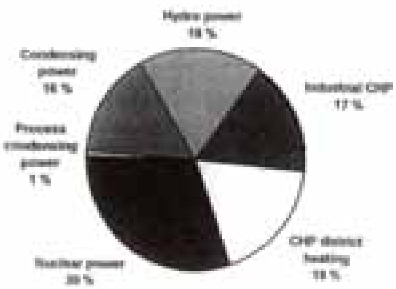

Figure 4.3. The structure of electricity production in Finland /10/.

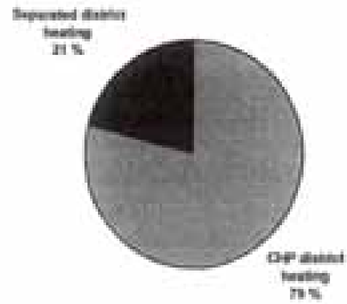

Figure 4.4. The structure of district heating production in Finland /11/.

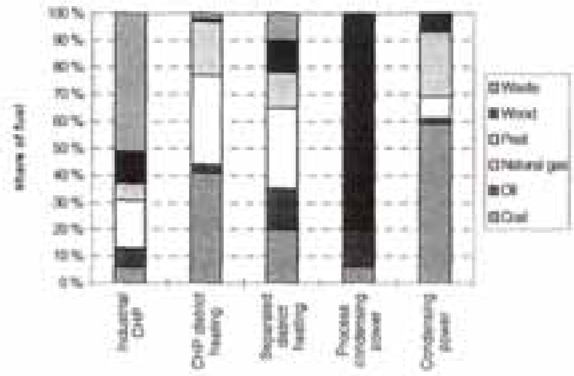

Figure 4.5. Shares of waste and fossil fuels in the electricity and in the district heating production in Finland /10, 11/.

Fuel	CO_2-eq g/MJ	SO_2 mg/MJ	NO_X mg/MJ
Coal	121	479	349
Peat	113	191	272
Natural gas	88	2	245
Heavy oil	94	1079	308
Light oil	90	176	146
Wood	122	2	132
Waste soda-lye	3	132	115
Bark & waste wood	9	2	182

Table 4.2. Emission factors of fuels /12/.

Case 1

Structures of the electricity and the district heating production are from the year 1997 in Finland (fig. 4.3 and 4.4). The production of electricity is 66,1 TWh and district heating is 28,2 TWh. The shares of fuels are also from the year 1997 in Finland (fig. 4.5).

Case 2

CHP plants produce the entire district heating. The shares of fuels in the district heating production are the average of total district heating production in case 1. The shares of fuels in the electricity production are identical with case 1. Compared to case 1, the condensing power production is reduced because of the additional CHP electricity production.

Case 3

No CHP production, which is replaced by condensing power production. The shares of fuels in the district heating production are the average of total district heating production in case 1. The shares of fuels in the electricity production are identical with case 1. All the CHP electricity production is replaced by condensing power production.

Case 4

No district heating production, which is replaced by the production of local light oil heating boilers. The shares of fuels in the electricity production are identical with case 1. The CHP electricity production is replaced by condensing power production.

Case 5

No district heating production, which is replaced by the production of local natural gas heating boilers. The shares of fuels in the electricity production are identical with case 1. The CHP electricity production is replaced by condensing power production.

Case 6

No district heating production, which is replaced by electric heating. The shares of fuels in the electricity production are identical with case 1. Condensing power produces the additional electricity production.

Case 7

No district heating production, which is replaced by electric heating. The shares of fuels in the electricity production are identical with case 1, except that coal in the condensing power production is replaced by nuclear or hydropower (fig. 4.5). Also the additional electricity production is produced by nuclear or hydropower.

Results

The calculated examples give trendsetting results about released emissions in different kind of fictional heating and electricity production systems. As was mentioned above, cleaning of flue gas emissions are not included in the calculations, which have to be taken into account.

Figure 4.6 shows relative CO_2 emissions, figure 4.7 shows relative SO_2 emissions and figure 4.8 shows relative NO_X emissions. The ratio of the emissions in the reference case is one. The emissions in other cases are compared to the reference case 1.

The calculated emissions of the reference case in electricity and heating production are, respectively:

- 294 g/kWh_e and 168 g/kWh_h for CO_2
- 949 mg/kWh_e and 193 mg/kWh_h for SO_2
- 906 mg/kWh_e and 456 mg/kWh_h for NO_X

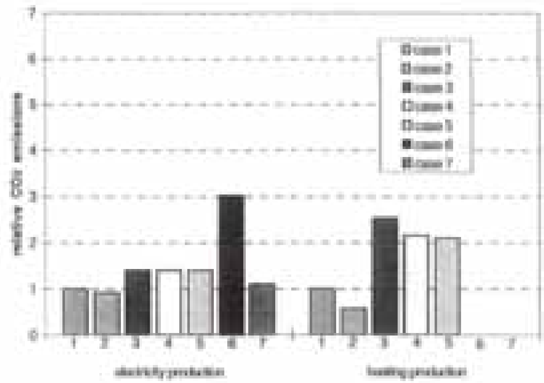

Figure 4.6. The ratio of CO_2 emissions in different cases.

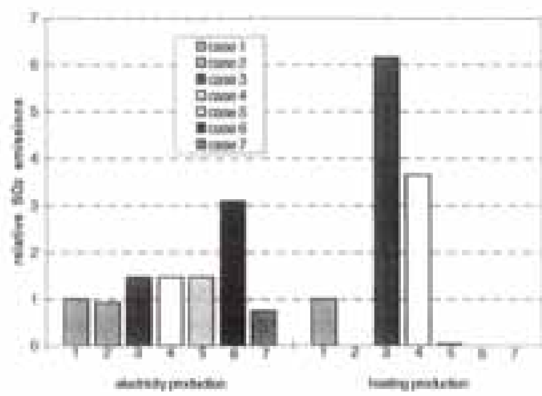

Figure 4.7. The ratio of SO_2 emissions in different cases.

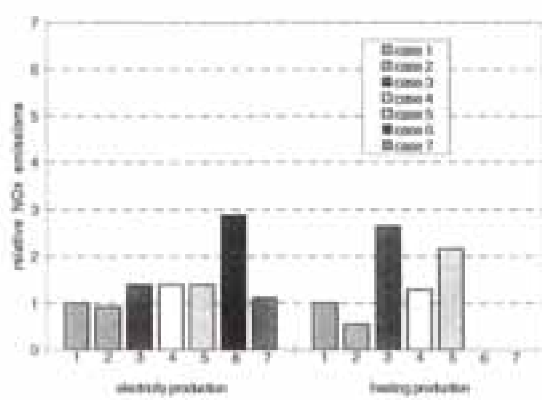

Figure 4.8. The ratio of NO_X emissions in different cases.

In the reference case, the share of CHP production in district heating production is already high, but a reduction of emissions is still possible by increasing the share of the CHP production (case 2). If the CHP production would be replaced by condensing power, emissions will be increased significantly, especially SO_2 emissions (case 3).

Emissions in the local oil heating case 4 are higher than in the reference case 1, but smaller than in the case 3, which does not include any CHP production. In the local natural gas heating case 5, SO_2 emissions are almost zero, but CO_2 and NO_X emissions are higher than in the reference case 1.

In the electric heating cases 6 and 7, emissions of the heating energy production are zero, and all emissions are released from the electricity production. If the additional electricity production for heating purposes is produced by condensing power, emissions are higher than emissions of heating and electricity production together in the reference case 1. If the condensing power is replaced by nuclear or hydropower, emissions of electric heating are decreased significantly.

If the calculated emissions in the case 1 are compared to the emissions in Finland in table 4.1, it can be seen that the calculated CO_2 emissions are in the same level, but the calculated SO_2 and NO_X emissions are about two times greater, than the emissions in table 4.1. This is partly due to the fact that cleaning of flue gas emissions is not included in the calculations. Another possible reason is that in reference /8/ the profitable reduction of emissions in the CHP production has been allocated mainly to the electricity production and not to the district heating production as was done in the calculations.

4.5 Environmental benefits of district heating and cooling

In the earlier study of the IEA's District heating - program potential environmental benefits of district heating and cooling systems compared to non-district systems are shown /2/. These benefits are relevant also today. The benefits are:

- higher efficiency of partial loads
- utilisation of CHP production
- biomass combustion
- limited number of emission sources
- superior operating and maintenance of plants
- technical upgrades
- higher design efficiencies of compressors
- easier to install effective noise control
- easier to supervise condition of fuel storage
- easier to use alternative fuels
- better chance to use alternative heating or cooling energy resources as waste energy
- conversion from one refrigerant to another is simpler

In general, district heating and cooling plants operate at higher efficiencies under partial load conditions, compared to non-district systems /2/. The higher efficiency means more efficient use of fuel and less emission per produced energy unit.

Especially in the CHP production the efficiency is significantly better than in the separated production of electricity and heating. Because of more efficient use of fuel in the CHP production, reductions in CO_2 emissions are achieved compared to the conventional separate district or local heating systems.

In the case of separated heating plants' efficiency and peak load conditions, there is not so great a difference between district heating and local heating systems, if the same fuel is used. The efficiency of district heating systems is decreased because of longer distribution networks.

The efficiency of electrically operated compressors of cooling plants is better in big than in small scale plants (part II fig. 2.1), which is an environmental benefit of the electrically operated district cooling plants compared to the small scale cooling plants.

The district cooling systems, which are not based on electrically operated compressors, have valuable benefit compared to the electrically operated compressors of local or district plants. The electric compressors are not needed for example in cooling plants, which are based on the absorption processes and which are operated by district heating, or in the district cooling systems based on sea water. These kinds of cooling systems don't need refrigerants, which is a clear environmental benefit compared to the conventional cooling plants using CFC refrigerants.

In biomass or wood combustion, CO_2 emissions are considered to be zero, because the CO_2 balance doesn't change. The combustion of biomass or wood releases the same amount of CO_2 as is absorbed in the growth of the burned material /2/. In the future, biomass and wood can be alternative fuels in small-scale plants, too. Utilisation of wood chips in small scale heating plants has been developed recently, and active plants already exist.

The district heating and cooling plants mean a reduced number of emission sources in a community /2/. This is an environmental benefit compared to local individual energy production plants such as local oil heating boilers. Compared to the individual small-scale plants, the installation of facilities to clean emissions from the centralised plants' flue gases are technically and economically more effective.

The district heating and cooling plants also cut down problems associated with fuel delivery, which is also an environmental benefit. The logistics of the centralised plants are more effective than in the decentralised plants. Some central heating and cooling plants have even oil or gas pipelines to facilitate fuel delivery.

Operating and maintenance practices are usually more effective in the centralised plants than in the individual small scale plants. The centralised plants have trained staff, sophisticated monitoring and control systems for operation of the plant. New technical improvements, for example in low NO_X burners and heat recovery scrubber systems, are simpler to install to the large systems than to the small scale systems /2/. All these matters are beneficial for the environment.

4.6 Conclusions

Comparison between environmental effects of different energy production systems is problematic, because various effects occur. If the comparison were done profoundly, extensive studies such as the life cycle assessment of every studied system would be needed. Because of the complexity of environmental effects, the above shown comparisons between local and district heating and cooling systems are mainly based on general aspects collected from different references.

The released emissions are strongly dependent on the available fuels and structure of production, which can be seen from the calculated examples, too. Among the input values of the calculations there are also many other assumptions, which certainly have impacts to the results.

The calculated examples give trendsetting results about released emissions in different fictional heating and electricity production systems, when the cleaning of flue gas emissions are not taken into account. One obvious result is that the CHP production is very beneficial for environment.

Also without any calculations it is well known, that district heating and cooling systems have certain environmental benefits compared to local systems. Many of these benefits are mentioned above. The most significant benefit is the reduction of different emissions. Compared to local systems, this benefit can be achieved, among other things, by the help of

- CHP production,
- higher efficiency of partial loads,
- effective cleaning techniques of flue gas emissions and
- utilising alternative heating or cooling energy resources.

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