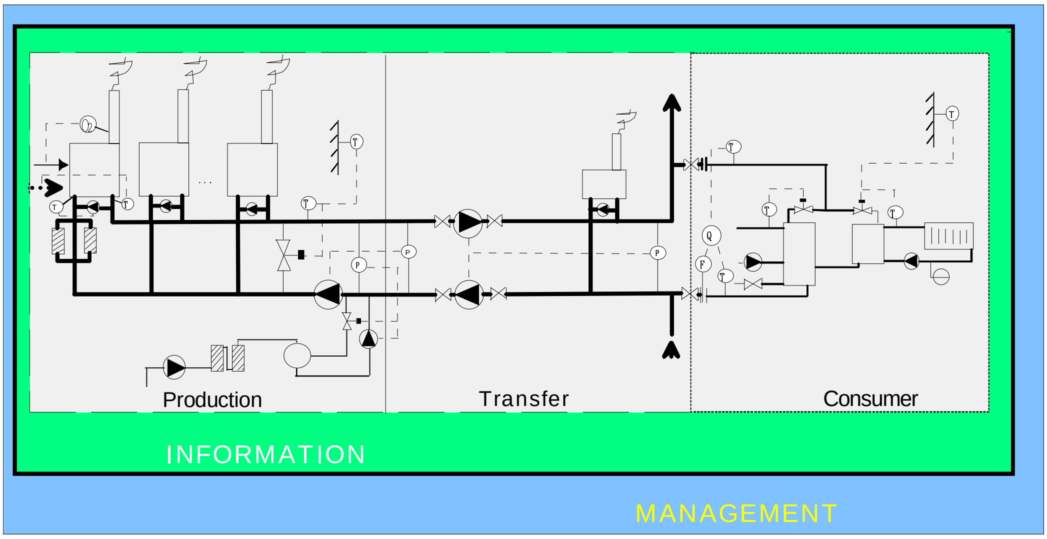
2071

VTT RESEARCH NOTES

VTT TIEDOTTEITA

Kari Sipilä, Aulis Ranne & Tiina Koljonen

Modular district heating system MODiS



TECHNICAL RESEARCH CENTRE OF FINLAND

ESPOO 2000

VTT TIEDOTTEITA – MEDDELANDEN – RESEARCH NOTES 2071

Modular district heating system
MODiS

Kari Sipilä, Aulis Ranne & Tiina Koljonen
VTT Energy

TECHNICAL RESEARCH CENTRE OF FINLAND
ESPOO 2000

ISBN 951–38–5782–4 (soft back ed.)
ISSN 1235–0605 (soft back ed.)

ISBN 951–38–5783–2 (URL: http://www.inf.vtt.fi/pdf/)
ISSN 1455–0865 (URL: http://www.inf.vtt.fi/pdf/)

JULKAISIJA – UTGIVARE – PUBLISHER

Valtion teknillinen tutkimuskeskus (VTT), Vuorimiehentie 5, PL 2000, 02044 VTT
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Technical editing Leena Ukskoski

Otamedia Oy, Espoo 2001

Sipilä, Kari, Ranne, Aulis & Koljonen, Tiina. Modular district heating system MODiS. Espoo 2000, Technical Research Centre of Finland, VTT Tiedotteita – Meddelanden – Research Notes 2071. 142 p. + app. 20 p.

Keywords MODIS, district heating, heat generation, boilers, pipelines, substations, pumps, measuring devices, automation systems, information systems

Abstract

MODiS (Modular District Heating System) products were developed during the project for either building an entirely new district heating (DH) system or for renovating and extending an existing system. Good planning of the parts that constitute DH systems, optimal implementation and functioning, short construction time, and significant lengthening of the service life of the whole system were also important objectives. The products are therefore able to fulfil a wide range of consumer requirements in the district heating systems of the East European countries.

MODiS products comprise highly integrated prefabricated and pre-tested modules, where the modules themselves may be boilers, pumping stations, substations, metering devices, automation equipment, planning tools, information and management systems, etc. The modules are all physically and electrically compatible and have their own local measurement and automation systems, which can be connected to the open MODiS information system.

The MODiS system essentially consists of a closed two-pipeline system, in which the water flow is regulated by pumps. Combined heat and power production units are connected to the network via a heat exchanger. The boiler plant is connected directly to the heat transfer network but consumers are mainly connected indirectly. In this way the oxygen content of the district heating water can be kept at a low level and pressure variation in the district heating network is less dependent on consumer equipment.

Combined Heat and Power (CHP) production, when connected to a DH system, needs about 40% less fuel than the corresponding separate boiler and condensing power plant production. A similar reduction of combustion-related emissions can be achieved and heat outlet from the condensing power plant into the surrounding water or air can also be avoided. The boiler plants, generally of the three-pass type with thermal efficiency of up to 90% without economisers, are designed to be delivered in complete operational units. Pipes, which are made of carbon steel, are covered by fixed rigid foam insulation. A waterproof plastic duct covers the pipeline. The basic connection configuration of a consumer substation is divided into the space heating side and the domestic hot water

side. Energy consumption is measured so consumers pay for just that amount of energy, which they use.

The MODiS Concept tool was developed by VTT Energy for the rough planning of a MODiS district heating system. As a result, the MODiS Concept model can give the budget for a DH-system divided into the boiler plant, the district heating pipelines and the consumer substations. The annual investment and running cost of the system are evaluated, as is the cash flow at the decided district heating tariff. A dynamic simulation model for MODiS was also created with a real time simulation tool called APROS. The simulator can be used for studying normal operation, behaviour under emergency conditions, and process failures. The APROS simulation program has also been used to investigate an ejector connection in an apartment building and for analysing the operation of the ejector in relation to the entire heating system. Replacing an ejector system with a heat exchanger system gives energy saving of nearly twenty percent. A DH system in a Russian district heating zone was modelled with the programs. A knowledge-based tool, PIPECOR, has been developed and it estimates the corrosion resistance of carbon steel district heating pipes in the various water types used for heat transfer. The program estimates the remaining service life of the pipelines under the defined conditions, and the current corrosion rate.

Renovation principles for the East European district heating systems have been developed during the project. It is also clear that the buildings themselves will also require basic renovation to further lower the heat demand. This could be done by adopting the methods used in Finland during the energy saving program that was carried out following oil crises in the 70's and 80's.

Preface

The MODiS (Modular District Heating System) project was initiated in 1996 and continued for 3.5 years. The total budget was 54 mill. FIM, of which 60% was provided by private companies and 40% by Tekes, the Finnish Technology Agency. The Finnish partners were:

- Basepoint Oy
- Cetetherm Oy
- Electrowatt-Ekono Oy (Energia Ekono Oy)
- Finnish District Heating Association
- Finreila Oy
- Helsinki Energy
- Kolmeks Oy
- Komartek Oy
- KWH Tech Oy
- Naval Oy
- Process Vision Oy
- RTA Yhtiöt Oy
- Savcor Oy
- Sermet Oy
- TAC-Com Oy
- Tampere University of Technology, Construction Economics
- Tietosavo Oy
- Vantaa Energy Oy
- VTT Energy (Technical Research Centre of Finland)
- Tekes (Finnish Technology Agency)
- Technology Agency Oy

Dr. Eino Rantala in Technology Agency Oy was a co-ordinator in the project. There were also partners from Russia and the Baltic countries.

This report describes the MODiS district heating system including the heat production and transfer as well as heat consumption in the consumer substations. The information and management systems are described, and the product family and the connections between products are also outlined. In addition, environmental issues relating to district heating systems, that utilise combined heat and power production, are evaluated. Models created for the MODiS system are presented in the report along with example case studies.

We would like to acknowledge the co-writers of this report: H. Sulankivi & T. Peuhkurinen from TUT (East European DH systems in Ch. 2), J. Putkonen from Savcor Oy (Water treatment and corrosion monitoring in Ch. 2), Pertti Sahi from Vantaa Energy Oy (DH-pumps in Ch. 2), R. Koskelainen from TAC-Com Oy (Local and remote network communication in Ch. 3) and T. Eklund from Helsinki Energy (Management System in Ch. 4). The software companies have provided written descriptions of their programs in the Appendix-A.

Two other reports have also been published; East European District Heating Systems (Local DH-system description in the target area) by Tampere University of Technology and the MODiS System Folder (MODiS products) by Electrowatt-Ekono Oy.

Espoo 3 August, 2000

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Appendices

1. Introduction

The term "district heating" refers to a system of heating that serves a group of buildings, with no exact set limits. The heat is produced in hot water or steam boilers, or combined heat and power plants, and is conveyed to consumers by means of hot water or steam running through insulated pipelines. District heat is green energy at its best!

1.1 MODiS principle

MODiS, the Advanced Modular District Heating System, comprises highly integrated prefabricated modules, where the modules themselves may be boilers, pumping stations, substations, metering devices, automation equipment, planning tools, information and management systems, etc. The modules and their components are tested at the factories prior to delivery. MODiS, which is a very flexible system, can be used for building an entirely new district heating system or for renovating and extending an existing system, and is thus able to fulfil a wide range of consumer requirements. The modules are all physically and electrically compatible and have their own local measurement and automation systems, which can be connected to the open MODiS information system. The MODiS information system connects all the modules together electrically, so that information can be sent from each device to the energy business management level, and vice versa. MODiS, with the inclusion of the relevant technical and economic details, thus forms both a far-sighted approach and a strong backbone for the building and development of district heating systems.

1.2 Working packages (WP) in the MODiS project

1.2.1 Targets of the WPs

The MODiS project was divided into Working Packages (WP), which have been guided by both the product development interests of companies in the heating industry, and the targets of the MODiS family. In addition, requirements and rules are to be developed for new components that will later be added to the MODiS product family. Each of the project partners has been involved in a working package through which, from their respective fields of expertise and interest, they have supported the basic development work. The essential condition was that this work had to serve the R&D work of the industry. WPs 1 and 2 were related to general definition and development. The seven MODiS working packages are decribed in brief in Table 1, and in more detail in Table 4.

Table 1. MODiS Working Packages (WP).

WP	Name	Targets
WP0	Basic requirements for MODiS	The target of WP0 was to identify the end-users, energy suppliers and the companies' basic requirements, and to make performance-matrices for MODiS.
WP1	Modelling and compability	The target of WP1 was to define, describe and model the MODiS product family and the connections between the products.
WP2	Pilots in the target area (Pilot programmes)	Pilot programmes support the industrial development work by testing the compatibility and operability between the product family's system, modules and components.
WP3	Energy management and control systems	The aim of this WP was to develop open and compatible measurement, control and regulation systems.
WP4	Planning, operation and maintenance	The target of WP4 was to establish rules to facilitate planning, marketing and contracting.
WP5	Transport network and delivering piping	The target of WP5 was to develop products, modules and systems based on the MODiS principle, according to plans provided by the companies
WP6	Organization, management and finance	Organizing and managing the support systems based on the MODiS principle
WP7	Political lobbying and marketing	The WP7 target was to lobby and market the MODiS system in the target area and to obtain support from financial institutions.

1.2.2 The roles of the MODiS partners in the WPs

All the MODiS partners have taken part in WPs, and their respective roles are presented in Table 2. The positions the partners occupy in the MODiS concept are shown in Figure 1. The partners, having developed the MODiS concept and model in the light of their expertise and from their own vantage points, will in turn develop their products in accordance with MODiS principles. Collectively, the partners will define the interface of the products with the MODiS product system family.

At the beginning of the project in 1996 the companies were asked to define their needs for research, development and testing. The expertise and experience of the companies in the target area were also included. The companies in Moscow and St. Petersburg in Russia, Tallin in Estonia, Riga in Latvia, Vilnius in Lithuania and Gdansk in Poland were among the most experienced.

The starting point for product development and cooperation between partners, and the boundaries between the partners' respective products were also established. Over 70% of the partners saw the potential for cooperation with at least three other partners and they also discovered obvious boundaries that delineated their own products from the products of those partners. The completion rate of 0 to 90% of the partners' products for the target market was evaluated at the beginning as well (100% being completely ready for market). The partners were asked to define their targets for the production, distribution, consumer, connection, information, and planning side of the MODiS system in the project.

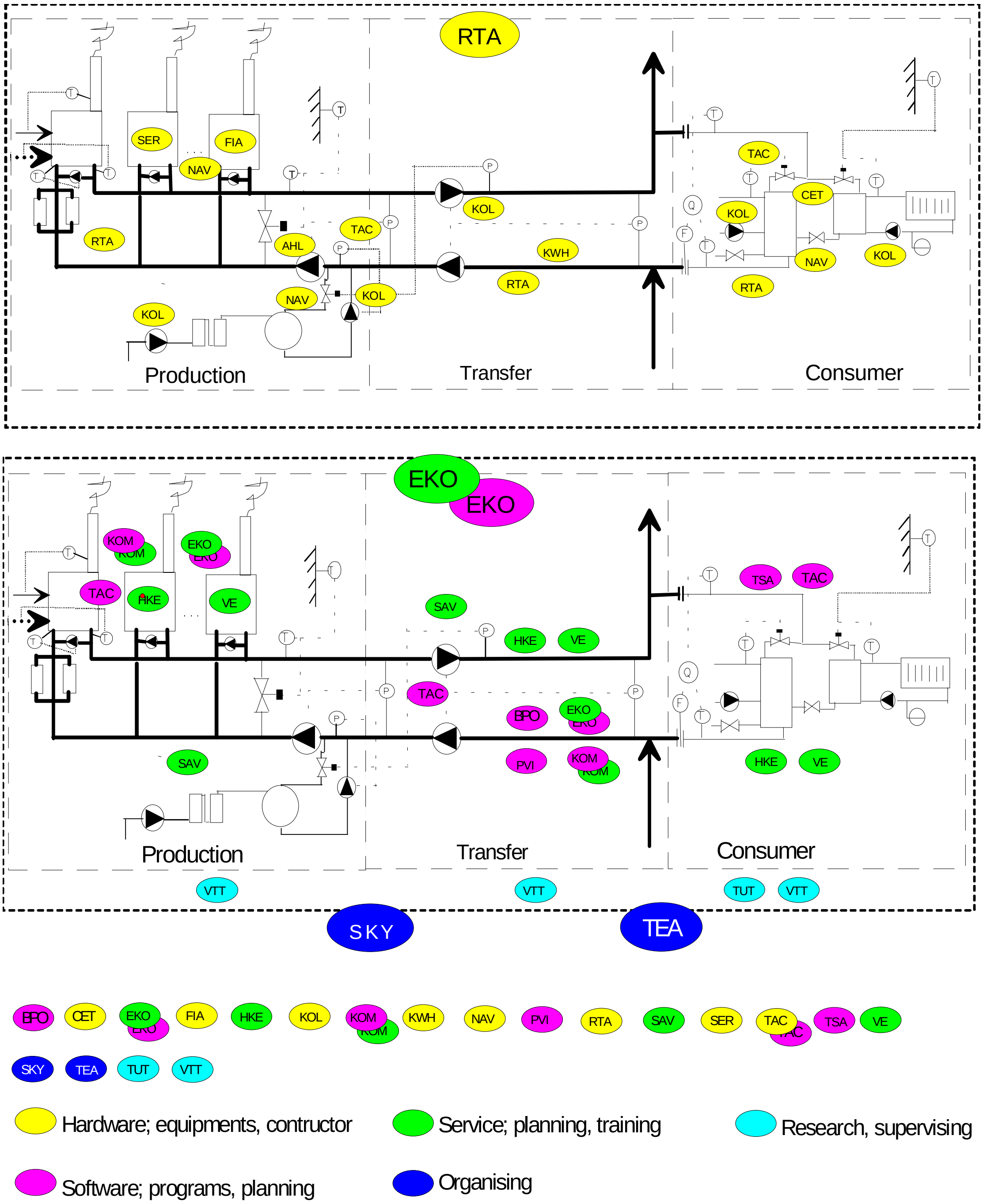

Figure 1. MODiS partners´ positions in the MODiS concept.

Table 2. The role of the MODiS partners in the MODiS product family.

Nr.	Company	Acronym	Market role	Obj in MODiS
1	Ahlström Pumps	AHL	Pump manufacture	Network
2	Basepoint	BPO	Software for DH-network	Information, Management
3	Cetetherm	CET	Heat exchanger and DH substation manufacture	Consumer Equipment
4	Ekono Energy	EKO	Designer, planning tools developer	Information, Management,
5	Finnish District Heating Association	FDA	Support for DH-technology marketing	Marketing support
6	Finreila	FIA	Comprehensive supplier in energy engineering	Heat production
7	Helsinki Energy	HKE	Energy supplier and DH-technology user	Operation & maintenance
8	Kolmeks	KOL	Pump manufacture	Network, Consumers
9	Komartek	KOM	Software for DH-system	Information, Management
10	KWH Tech	KWH	Pipe manufacture	Network
11	Naval	NAV	Manufacture of ball valves for DH-system	Heat production Network, Consumers
12	Process Vision	PVI	Simulation and planning of DH-network	Information Software
13	RTA Yhtiöt	RTA	Constructor	Constructor
14	Savcor	SAV	Corrosion technology	Production, Network
15	Sermet	SER	Manufacture of boiler plants	Heat production
16	TAC-Com	TAC	Software for information	Information technology
17	Tampere Univ. of Tech, Construction Economics	TUT	Research, R&D methods, marketing	R&D support, Marketing
18	Tietosavo	TSA	Software for DH-systems	Information, Management
19	Vantaa Energy	VE	Energy supplier and DH-technology user	Operation & maintenance
20	VTT Energy	*VTT*	Research, R&D, modelling	R&D support
21	Tekes	TEK	Sponsor for technolgy R&D	Support for marketing
22	Technology Agency	TEA	Consult in energy markets	Coordinator, Support for marketing

1.3 Markets for MODiS concept

The world market for district heating is estimated to be about 4200 TWh (150 000 PJ), of which the Finnish market is about 0.6%. The world-wide district heating market with technical details in brief, is presented in Table 3. The district heating consumption market is expected to increase by about 8% in the next 10 years, and the total length of the DH-network is estimated to increase by about 6% in the same time period. The low growth is based on the fact that the East European market mostly involves renovation work. The growth in demand could be covered in large part by the energy saved as a result of DH-system renovation.

1.3.1 Potential market areas

The infrastructure of Central and East Europe is in the process of being rebuilt. The energy sector has particular importance in these countries and on the demand side space heating is one of the largest users. In many Central and East European Countries up to 40% of primary energy is used for space heating (in Finland about 22%) and the basic technology in this area is district heating. Most of the district heating systems in Central and East Europe are in need of renovation and reconstruction. With modern district heating technology, primary energy use can be considerably reduced. Energy savings of up to 50% have been estimated. These savings will be very beneficial to the environment over the whole of Europe. A reduction in energy consumption also means lower energy costs for the population, thus increasing the standard of living and alleviating social problems that might otherwise distort economic development in the whole of Europe.

1.3.2 New district heating capacity

There is a large DH-market in the Far East. China in particular has a large DH-market. There is a great need for renovation in their old DH-systems and they will also build new town areas based on district heating. Korea is another fast growing DH-area, where there are many town areas planned to be built using district heating.

District heating markets in East European countries are extremely large, approximately 15 times larger than in West Europe. According to Table 3, East Europe accounts for about 85% of the world's district heating capacity, whereas the European Union (with Germany, France, and the Scandinavian countries) represents only about 5%.

1.3.3 Compatibility with existing district heating systems

The MODiS product family has been developed for both the construction of new DH-systems and the enlargement of old ones. The products are planned based on CEN (the European Standardisation Organisation) standards as the products are, at present, primarily produced for the West European DH-market. The whole MODiS product family was modified to make it suitable for the renovation of DH-systems in the East European market

Table 3. Worldwide district heating markets and technical information.

DISTRICT HEATING IN THE WORLD												updated 14.08.2000/lts		c:\data\dhdata.xls/lts			
																grow pot.	
COUNTRY	Prod. TWh	Consump. TWh	Max prod.h h	Capacity MW	Max h load MW	Heat comp. kpl	Length of net km	Nr. of nets	Out. Temp. °C	Return temp. °C	Pressure bar	Pump.typ.	Flow in net	Cons.conn.	Statistic year	Energy TWh/10a	Net. length km/10a
Europe																	
Austria	11,23	9,88	1800	5800	5600	40	2507								1998	8,50	1660
Belarus	80,00	71,73	2500	40000	32000		2500		150(*	70	16	centrifug.	constant	direct		83,00	2700
Bosnia	5,50	4,77							150	70	16	centrifug.	constant	direct		5,22	
Bulgaria	29,82	27,14		13650			2025		150	70	16	centrifug.	constant	direct	1992	33,00	3300
Greece	0,32	0,26		140	213	2	135								1997	0,32	210
Croatia	2,46	2,10	2300	1916	921	1	258		150	70	16	centrifug.	constant	direct	1998	3,00	1500
Czech Rep.	53,74	41,39	2300	42506	18230	1928	9600		150(*	70	16	centrifug.	constant	direct	1998	55,62	10500
Denmark	31,00	27,90	3300	15500	8500	425	23000		120	70	16	centrifug.	regulated	indir./dir	1998	34,01	23300
England	5,30	5,00		119					120/140	70/80	16	centrifug.	regl./const.	indir./dir	1993	5,50	
Estonia	18,03	16,39	2500	5413	6550				150(*	70	16	centrifug.	constant	direct	1992	19,90	
Finland	29,42	27,52	2632	17530	13600	127	8040	367	115	45	16	centrifug.	regulated	indirect	1998	33,55	9500
France	29,90	25,11		20919		372	2867		185	90	22	centrifug.	regulated	indirect	1992	41,00	4800
Germany	98,73	84,20	1939	53796	55560	248	18541	1133	150/130	70	25/16	centrifug.	regl./const.	indir./dir	1998	102,64	18723
Hungary	22,63	19,83	2361	17800	8400	175	2000	320	150	70	16	centrifug.			1993	25,00	3000
Iceland	5,00	4,40		1306		31	2970		100						1997	4,86	3281
Italy	3,02	2,70	1969	2678	2636	27	762		140	80	16	centrifug.	regl./const.	indir./dir	1997	3,40	1320
Latvia	20,60	20,00	2300	2700	2300		980		150(*	70	16	centrifug.	constant	direct	1994	20,86	1080
Lithuania	21,28	15,41	2300	14064	9754	136	2846	52	150(*	70	16	centrifug.	constant	direct	1998	18,79	3200
Macedonia																	
Moldova																	
Netherlands	6,42	5,32		4330	4385	13	2500						regulated		1998	5,87	2700
Norway	1,44	1,27		933	800	21	320								1997	1,40	363
Poland	140,09	114,71		51376		1909	16392		150(*	70	(25)16	centrifug.	constant	direct	1998	139,82	18000
Romania	127,55	121,00	2921	47760	41430		16380		150(*	70	16	centrifug.	constant	direct	1992	130,00	17000
Russia	2669,50	2207,39		1445000			260000		150(*	70	16	centrifug.	constant	direct	1993	2207,00	261000
Schwitzerland	3,81	3,22	2599	1973	1239	24	643		140	80	16	centrifug.	regulated	indirect	1993	3,90	710
Serbia	12,40	10,75							150	70	16	centrifug.	constant	direct		11,90	
Slovakia	70	61		16500					150	70	16	centrifug.	constant	direct	1996	64,12	
Slovenia	2,48	2,15	2268	1870	948	26	453		150(*	70	16	centrifug.	constant	direct	1993	2,60	500
Sweden	43,91	41,39		29000	23488	164	10721		120	70	16	centrifug.	regulated	indirect	1998	50,46	12000
Ukraine	273,00	245,74	2100	156000	141000	196866	44931		150(*	70	16	centrifug.	constant	direct	1997	271,45	45100
	3808,57	3219,68		2010679	377554	201525	431371	1872								3386,70	445237
Asia																	
China	290,00	250,00	2200	18000	13000				150(*	70	16	centrifug.	constant	direct	1990	300,00	
Japan	1,70	1,50													1995	2,00	
Kazakstan																	
Korea	6,00	5,00	2300	4800	1990	6	1300	6	120	70	16	centrifug.	regulated	indirect	1994	8,50	2200
	297,70	256,50		22800	14990	6	1300	6								310,50	2200
America																	
Canada																	
USA # water	16,00	14,00	1400	11700	10000	1440	1500	1440	120	70	16	centrifug.	regl./const.	indir./dir	1992	25,00	3000
# steam	242,00	206,00	1400	175800	147143	2640	22500	2640	120...200		2...15		constant	direct	1992	260,00	24500
	258,00	220,00		187500	157143	4080	24000	4080								285,00	27500
total	4364,27	3696,18		2220679	549687	205611	456671	5958								3982,20	474937,2
																0,08	0,04
									(*new networks 130/70 °C, consumers with indirect connection, boilers with direct connection								

Table 4. Description of the work packages (WP) is MODiS.

WP1	Model and compatibility	The main R&D targets for WP1 are to define, describe and modelthe MODiS product family and the connections between them. WP1 is guided both by the industry's product development interests and the targetsof the MODiS family. In addition, requirements and rules will be developed for new components, which will be later connected to the MODiS product family. WT11 Definitions - Define principle and technical targets, and the requirements of the MODiS product family - Establish the structure, modules and components of the system WT12 Connections - technical connection of modules and components to the MODiS system family - hardware and software connections to system level communication - compatibility with other infrastructures e.g. electricnet, phonenet etc. WT13 Simulations - components, modules and systems - checking compatibility of components and modules WT14 Documentation - description of the MODiS family; system, modules and components	AHL BPO CET EKO FDA FIA HKE KOM KWH NAV PVI RTA SER TAC TUT TSA VE **VTT**
WP2	Pilots in Finland, and on the market area	The target of a pilot is to support the industrial development work by testing the compatibility and operability between the product family's systems, modules and components. The first pilot programme will utilize existing MODiS product concepts and the first versions of new ideas, whereas the second pilot will involve developed concepts and ideas. The pilot should comply with MODiS targets (in terms of compatibility, product family level, etc.). Tasks for the pilot programmes 1. Definition of the existing technical level, target system definition, plant development details.	BPO CET FDA FIA HKE KOM

		2. Choosing a suitable DH-system for the pilot programme - choosing a new system 3. Implementation - tests for implementation ability 4. Testing - test run - observations - evaluation of results; conclusions - report	KWH NAV RTA SER TAC TUT TSA VE VTT
WP3	Energy management and control systems	The target of WP3 is to develop compatible measurement, control, and regulation systems following the principle of MODiS information. WT31 - Exploitation of the district heating network + short-term prediction of the energy demand and production + control systems for the hydraulic pressure of the network + temperatures in the network WT32 - Control of the heat energy + systems for reading the energy meters + centres for measuring the heat energy consumption WT33 - Water treatment + supply water + quality control of circulating water WF34 - Control of the network operation + information systems + local control: automated pump stations, valves, etc. + remote control: use of pump stations and heat centres WT 35 Protocol for interoperability (-data transfer to other systems, information media)	**HKE** KOM PVI TAC TUT TSA VE VTT

WP4	Planning, operating and maintenance	The target of WP4 is to establish rules to help planners, sellers and contractors WT41 - Planning directions + operating instructions for members of the MODiS product family + technical properties for members of the MODiS product family concerning pressure, temperature, etc. + interchangeable products WT42 - Operation and maintenance + permissable operating range for the temperature, pressure, velocity of the water etc. + equipment and replacement parts.	BPO CET EKO HKE TAC TUT VE VTT
WP5	Transport network and delivering piping	The target of WP5 is to develop products, modules and systems based on the MODiS principle established by WP 1, according to project plans provided by the companies. WT51 - pipes + quality requirements # dimensioning in accordance with EN 253 # assembly in accordance with EN 253 # outer casing and insulation in accordance with EN 253 + steel service pipe # advance resistance to corrosion + assemblies # joint assemblies for outer casing # joint assemblies for steel service pipe WT52 - Valves WT53 - Pumps WT54 - Heat exchange stations WT55 - Connection of the consumer heating systems to the district heating network + heat exchanger connections and hot tap water exchanger connections + regulation systems + compact substations	CET FIA HKE KWH NAV RTA TAC TUT VE VTT

WP6	Organisation, general management, and finance		Organising and managing the support systems based on the MODiS principle	EKO
		WT61	Prediction of the long-term demand	FDA
			- long-term planning programme for network and production	FIA
		WT62	Optimisation of the operation	HKE
		WT63	Tariff and invoicing systems	KOM
		WT64	Data needed for operational planning	PVI
			- consumption & maintenance	TAC
		WT65	Education and training for WP6	TUT
				TSA
				VE
				VTT
WP7	Political lobbying and marketing	WT71	Information about the MODiS concept for financial institutions (WB, EBRD, NIB, etc.)	CET
		W172	Political lobbying in the target countries (in co-operation with Finnish politicians and high-level authorities)	EKO
				FDA
		WT73	Joint marketing of the MODIS concept to local authorities and experts, co-operation with FinEnergy	FIA
		WT74	Ethics regarding the marketing the products of partner companies (trademarks etc.)	HKE
		W175	Joint-ventures between partners, encouraging the acquisition of energy utilities	KOM
		WT76	Preparation of pilot projects based on the MODiS project, pilot financing	KWH

2. District heating systems in the MODiS target area

2.1 General information

The district heating (DH) technology used in the Central and East European countries was mainly developed in Russia in the time of the Soviet Union. As a result, most of the DH systems in the MODiS target area use Russian DH technology.

The Russian DH technology has a history of about one hundred years. Current Russian DH systems differ from the West European DH systems in several ways. The main difference is that the flow of the network is constant, which means that the heat capacity is regulated by means of the supply temperature. The networks are usually designed to operate at higher supply temperatures and network pressures than the West European DH systems. Moreover, in the MODiS target area countries, the consumer is usually connected directly to the DH-system through ejectors and the same DH water circulates in the consumers' radiators. Domestic hot water (DHW) is taken from the DH network, which means that oxygen is leaked into the system causing serious corrosion problems.

After the collapse of the former communist system in East Europe, DH systems have been in a process of change due to the market economy. Fuel and energy prices are no longer subsidised, the ownership of buildings, DH substations and DH network is unclear, heat production plants have undergone privatisation, etc. Generally, DH systems are in bad condition and are in need of renovation and reconstruction. Huge investments are needed to lower operation and maintenance costs, in order to make DH competitive.

Today, the largest district heating network in the world is in Russia. The total length of the Russian DH network (2 pipe system) is estimated to be over 260 000 km. Large DH networks are also found in the Ukraine, Poland, Romania, the Czech Republic and Belarus. The largest DH systems are in St. Petersburg, Moscow, Warsaw and Prague.

2.1.1 Russia

The population of Russia is approximately 150 million and about 70% of all residences use district heating. This percentage is much lower for almost all of the OECD countries, including those with a roughly similar climate and urban/rural mix.

Table 5 shows the types of heat sources in Russia in 1993 and the annual heat supplies (including steam production).

Table 5. Heat production plants in Russia in 1993 [1].

	Number	Annual heat supply		Rated heat capacity
Heat Sources	of plants	PJ	%	GW
Cogeneration utilities and condensing power plants >1000 MW	585	3 996	36.2	295
High capacity DHP > 116 MW	920	1 161	10.5	218.1
Medium capacity DHP 23.3 - 116 MW	5 570	1 538	13.9	280.3
Low capacity DHP 3.5 - 23.3 MW	182 000	2 423	22.0	579.4
Total district heating plants	188 700	5 122	46.5	1 077.8
Autonomous heat generating units	~600 000	1 508	13.6	135.0

Regional electricity companies, called energos, are the principal owners of heat production plants and primary heat transfer networks. The power plants owned by energos are mainly combined heat and power plants (CHP) and heat-only boilers (HOB). The ownership and control of energos varies. Typically, 49% of energos are owned by the Federal Electricity Company RAO EES ROSSII, with the balance split among the employees and private shareholders. Energos charge industrial customers according to estimated use, with prices determined on a per Gcal basis. Central heat supply stations and distribution networks usually belong to the municipal governments. Medium- and low-capacity district heating units and distribution networks for domestic use usually belong to municipal enterprises. Municipalities bill municipal customers according to unit size (i.e. per square metre), and this charge is typically included in the rent for state-owned apartments.

2.1.2 Poland

One of the largest district heating networks in the world is found in Poland, where more than 40% of the total amount of energy consumed is used for heating purposes. About

50% of Poland's total population of 39 million, and about 75% in urban areas, are supplied with district heat. The number of CHP plants in 1993 was 265 (250 in 1995) including 209 industrial CHP's, of which 57 were supplying heat to DH networks. 56 utility plants also supplied heat to DH networks. The number of heating plants was 5 980 (6 940 in 1995) excluding industrial plants, but including 12 utility plants with a heat output capacity of 4 738 MW and 285 bigger communal plants with a capacity of 15 000 MW. The maximum heat output capacity was 52 850 MW (57 210 MW in 1995) and the total length of the pipeline system 14 000 km.

The country's high energy consumption results from years of central economic planning during the communist era, which meant state-controlled low energy prices, lack of metering for space and water heating and no incentives for energy conservation. Since the end of communist rule in 1989 however, fuel supplies and rates are no longer subsidised, forcing both producers and consumers to seek ways to control energy costs. There is currently a great need to reconstruct Poland's economy and infrastructure to ensure the improvement of the environment and energy conservation. The price tag for modernising the Polish energy sector by the year 2010 has been estimated in the range of $10 billion to $US18 billion.

In 1993, there were 313 district heating companies in Poland and in 1995 the corresponding number was 720. Many of the DH companies purchase heat from industrial suppliers (both heat-only and CHP plants) and only about one third have their own heating plants. The majority of DH companies are owned and controlled by municipalities, although small DH plants are often owned by housing co-operatives.

The distribution networks as well as DH plants are generally in rather poor condition, which is particularly evident in smaller towns and rural areas. It has been estimated that production and transmission losses in the Polish DH system are, on average, three times higher than in the EU. Although heat metering is becoming more widespread, costs to consumers are often calculated as a flat rate per square meter of living space. In 1996, to encourage improvements in the production of heating and electrical energy, the Polish Ministry of finance fixed the maximum heat and power rate that a district heating authority may charge its users at 23.66 zloty (ZL) per GJ ($US 7 per GJ).

2.1.3 Czech Republic

The Czech Republic has a population of 10.3 million. In 1993, 63 combined heat and power (CHP) plants and 251 heating plants delivered district heat in cities like Prague, Most, Liberec, Karlovy Vary, Pilzen, Ceské Budejovice, Brno, Zlin, Olomouc, Ostrava, Opatovice, Kolin and Strakonice. In 1995, the number of CHP plants was the same but the number of heating stations had increased to 6 940. Approximately 70% of DH energy is consumed by industry. In 1993, there were 180 district energy companies but in 1995 as many as 1 850. The maximum heat output capacity was 41 300 MW and the length of the pipeline system was 9 600 km in 1993. By 1995, the maximum heat output capacity had grown to 48 885 MW.

According to the country's energy policy, Czech dependence on solid fuels (mainly coal) will be decreased as a primary energy source, from approximately 60% in 1996, to approximately 50% by 2000, and 40% by 2005. Coal will also gradually be replaced as a source of heat, or will be increasingly used for cogeneration.

2.1.4 Hungary

The Republic of Hungary, a central European country, has a population of 10.2 million. In 1995, the number of CHP plants was 44 and heating plants 281. The maximum heat output capacity was 17 800 MW and the amount of heat delivered to pipelines was 81.5 PJ. In 1995, the number of DH companies was 175. Unlike in the above discussion, these numbers have been remained about the same since 1993.

The Hungarian Government has an official energy policy to develop diverse energy supplies and eliminate dependency on imports from the former Soviet Union. It also aims to increase energy efficiency through modernisation of supply structures and better management of electricity consumption; and to attract foreign capital for investment in capital-intensive energy projects. The policy also provides for the gradual contraction of the coal mining industry by merging coal mines.

2.1.5 Latvia

The population in Latvia was approximately 2.4 million in 1997. As the natural resources in Latvia are minimal, about 80% of primary energy has to be imported. DH systems are widespread in Latvia and operate in all major towns, and even a large number of rural towns and villages. Most of the Latvian DH systems were installed between 1960 and 1990. Approximately 60% of all households are connected to DH systems, which are supplied by two CHP plants in Riga, several small scale back-pressure plants and HOBs. Of the 8 000 HOBs operating in 1990, 3 000 were still in use in 1997. In 1995, the share of DH in total heat consumption was 66% (47.5 PJ).

In Latvia, there are several forms of DH system ownership. Generally the DH companies are owned by municipal DH enterprises, which also own some of the industrial and local HOBs. In some cases, DH enterprises are joint stock companies (e.g. Riga, Liepaja) and in a few cases, DH systems are state-owned.

In 1995, the Law on Regulation of Entrepreneurial Activities in the Energy Sector was passed in Latvia. In 1996 the Energy Supply Regulation Board (ESRB) was established, which is under the supervision of the Ministry of Economy. The ESBR grants licences to energy supply utilities, develops methods for tariff calculation, etc. The tariffs for DH and DHW are set on the basis of cost calculations (approved by the ESRB) submitted by the DH enterprises. Subsidies have been gradually removed and state subsidies are only paid to low-income consumers. If the tariffs are set below calculated costs, the municipalities are required to cover the difference.

2.2 Existing district heating systems in the MODiS target area

2.2.1 Fuels

The fuels used for heat production in the MODiS target area are mainly coal, natural gas and oil depending on the location and the availability. Russia contains the world's largest natural gas reserves. Russia also contains almost 25% of the world's proven coal reserves and large oil reserves (around 50 billion barrels). Bituminous coal is the basic and most important source of energy in Poland. It is also exported to Russia. According to 1980 estimates, Polish coal reserves total 150 billion tons and lignite reserves are estimated at 40 billion tons.

Table 6 shows the production and consumption of oil, natural gas and coal in 1996 in the MODiS target area. Up to 40% of this primary energy is used for space heating. The figures below show that for some countries, almost all primary energy is imported. Most of this imported energy comes from Russia. The use of low grade sources of energy, such as waste heat from power plants or industrial facilities, bio-fuels or waste material (e.g. municipal) is small in Russia, and the same is true in other MODiS target area countries as well.

Table 6. Fossil fuel imports and exports of some MODiS target countries in 1997 (1 ktoe = 41,868 TJ) [2] [3].

Country	Import /ktoe				Export / ktoe			
	Coal and coal products	Crude oil	Peroleum products	Natural gas	Coal and coal products	Crude oil	Peroleum products	Natural gas
Belarus	479	10513	346	13480	35	402	2703	
Bulgaria	2392	5970	635	3851	3		1586	
Czech. R.	1081	6947	2757	7612	6231	105	1295	1
Estonia	368		1688	618	35		571	
Hungary	1247	6020	1721	7079	132		1853	
Latvia	104		1654	1058	1		5	
Lithuania	122	5799	806	2001	21	194	3269	
Poland	2923	15705	4516	6486	18515		1563	33
Romania	6063	3881	4029				2962	
Russia	6889	7538	3254	1872	10790	126630	60241	153277
Slovak R.	3728	5259	214	5213	17		2204	
Slovenia	184	635	2225	706	1		75	
Ukraine	5383	9007	6188	52288	1440	5	1347	1177

2.2.2 Heat production

In a typical large district heating system, DH networks may have from one to three combined heat and power (CHP) plants and several hundred, locally stationed, heat only boilers (HOBs) isolated from the main network. The majority of HOBs consist of small and mainly old coal, oil or gas-fired boilers, which cover peak and reserve capacity requirements. Each CHP plant supplies heat to separate parts of the DH network, which are isolated from the main network by shut-off valves. During high demand periods isolated areas are supplied from separate HOBs, while during low demand periods valves may be opened so that CHP plants would supply larger areas [4].

During the summer time, heat production plants are shut down for maintenance of the plant and DH network. The downtime lasts at least two to four weeks. During this period the water circulation in the DH network is also shut off and domestic hot water is not supplied either. During the summer, manual balancing of the network is usually carried out as well. Manual control valves or fixed flanges in the heat substations are adjusted according to calculations, which can lead to an undesired heating effect and subsequent lack of capacity caused by unnecessary consumption.

Approximately two-thirds of all fuel consumed in Russia is utilised in HOBs. Both water and steam boilers are used, of which water systems comprise over 90% of the total. Steam boilers are used if heavy fuel oil with very high sulphur content is utilised or if steam is needed for process heat. When steam boilers are used the DH network is connected by heat exchangers. Boiler plants with a capacity of more than 100 Gcal/h (120 MW) are typically natural gas-fired with oil being used as the reserve fuel. Boiler plants with a capacity between 50 (60 MW) and 100 Gcal/h are usually natural gas or oil fired. Boiler plants of capacity below 50 Gcal/h are mainly gas-fired.

Most of the CHP plants were built or reconstructed after the war. Despite redesigns and upgrades, equipment is generally old resulting in power to heat ratios substantially lower than in West European countries. CHP plants may supply process steam to industry in addition to district heat for cities. This simultaneous supply is widely used in East Europe CHP systems.

2.2.3 Heat transfer networks

Transfer networks are designed for supply/return temperatures of 150/70 °C or 130/70 °C. Pipes are normally dimensioned DN 40 - 1 200 steel pipes. Pipelines with a diameter of more than 300 mm are regarded as transmission pipelines, with a diameter between 300 and 150 mm as main branches, and with a diameter less than 150 mm as branches respectively. The typical distance between a heating station and consumer is 6 to 8 km, though longer distances do exist for the transmission pipelines of large heating plants [5].

Usually, over 95% of the DH network is installed underground. Above ground installations are mainly found in industrial areas. Supply and return pipes are most often laid into concrete ducts but are sometimes also buried directly in soil. Generally, the installation methods vary a lot depending on the construction period and geographical location.

Pipes are insulated and welded on site. Insulation is done using a mineral wool, perlite or bitumen mastic, and the pipes are covered with galvanised steel or gypsum plastic. Pipes with polyurethane (PUR) foam insulation and polyethylene (PE) casing are entering the market, but the development is quite slow. The concrete elements are often sealed with mortar and painted using bitumen coating to prevent ducts from outside water. The concrete duct elements are laid on a sand bedding, which usually has a draining pipe to protect ducts from ground water. Directly buried pipes are of sliding elements with bitumen perlite insulation and wrapped asphalt felt covering. Because of pipe movements, water may easily penetrate to the insulation causing corrosion.

The insulation thickness is usually 40 mm or 50 mm, which is below Scandinavian recommendations. With supply pipelines over DN 250 mm the thickness is 80 mm. The thermal conductivity of insulation in Russia is approximately 0.8 W/m°C, which is about double the Finnish figure of 0.037 W/m°C. The estimated heat loss of DH piping is about 24% of heat production, which is about 2–3 times higher than the Scandinavian figure. This is not only due to thin insulation but also the condition of the insulation and the high make-up water consumption. Insulation thickness may vary a lot and the insulation capability is weakened if it has got wet several times.

Small chambers are usually prefabricated concrete components and large chambers are made on site. Connections to a sewage system are rare. Thermal expansion is compensated by telescope axial compensators, but natural U-loops for compensation are also used.

2.2.4 Pumping

As mentioned before, all the DH circulation pumps are constant speed pumps and therefore the only way to control the water flow is by throttling. The capacity of the pumps is determined so that sufficient flow rates and pressures are obtained for the individual operation of separate parts of the DH network. However, if several separate DH networks are operated simultaneously, problems often occur in maintaining the needed pressure levels in the furthermost networks and in the highest buildings.

Usually, the DH circulation pumps are installed in the return line before the boilers or heat exchangers. A typical connection is constructed with several parallel pumps with the same head (5–14 bar) and capacity (300–1000 m^3/h). In addition, at least a couple of smaller capacity pumps are installed to operate during lower load periods in the summer. The other possibility is to arrange the pumps so that it is possible to connect them both in parallel and in series. This connection method is more flexible. Supply side pumping is also possible.

To compensate for the pressure losses in the networks and to raise the pressure level of the area, several booster pump stations may exist in the network. In a booster pump station, from one to three pumps are normally installed in the supply and return lines. A booster pump station may also have smaller capacity supply pumps for lower loads. For high elevation areas the head of the supply pump usually varies from 4 to 10–12 bar. In the return pipe a throttling valve reduces the pressure to the level of the main network. A booster pump station is normally equipped with safety valves to avoid water evaporation during power supply failures. The pressurisation of the network is typically done by pressurising pumps, which keep the return pressure constant.

2.3 Consumer connection

Figure 2 shows the different types of consumer connection used in the following text. The most common approach in the MODiS target area is a direct connection for space heating and an open system for domestic hot water (DHW). Indirect systems also exist for space heating and these too are typically open. The heat exchanger may be situated in a group substation or at each building. Closed systems for DHW are still quite rare and usually these only exist in new buildings or in buildings that are considered important [6].

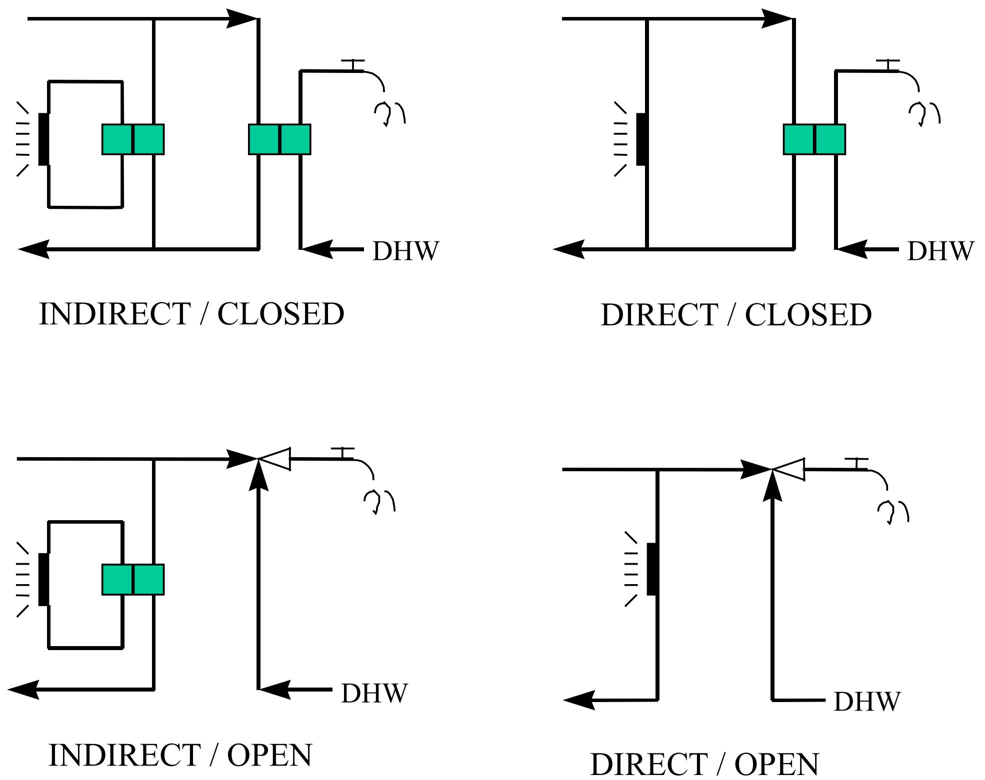

Figure 2. Consumer connection alternatives.

2.3.1 Direct connection

Figure 3 shows the direct connection approach with an ejector, which is the most common consumer connection type in the MODiS target area. The system is open, i.e. DHW is taken directly from a DH network or a secondary network located after a group substation. The supply hot DH water is mixed with cooled return water from the radiators to lower the temperature of the DHW.

Direct connection without an ejector is also possible. This setup is mainly used in industrial buildings, where the installation is based on primary network parameters.

The function of the ejector is to mix supply water from the DH network with return water from the radiator network, and to lower the DH network pressure to the radiator network pressure. Typically, the ejector is not controllable at all, or it may be manually adjusted with a throttling valve. This means that if the consumer heat load is altered, the nozzle of the ejector must be changed. The design supply temperature of a radiator network is usually 95 °C and the design mixing ratio of the ejector 1:2.2. The operation of the ejector is strongly dependent on the DH network pressure. As a result, small changes in the network pressure may considerably affect the heat supplied.

The advantages of the ejector are its simple structure, reliability and low price. The biggest disadvantage is the constant mixing ratio, which means that control of individual heating is impossible and that the network must supply heat according to the consumer at the most remote or unfavourable location. Due to centralised temperature control, excessive heating occurs for some consumers while others may suffer from deficient heating.

Three main implementation opportunities for radiator networks are presented in Figure 4. The most common one is a constant flow, down-feed heating system without a three-way valve or by-pass pipe that would make temperature control possible. The practical method to solve overheating has been to open a window! This usually occurs in the spring and autumn when the supply temperature has to be kept at 75 °C, because of DHW preparation.

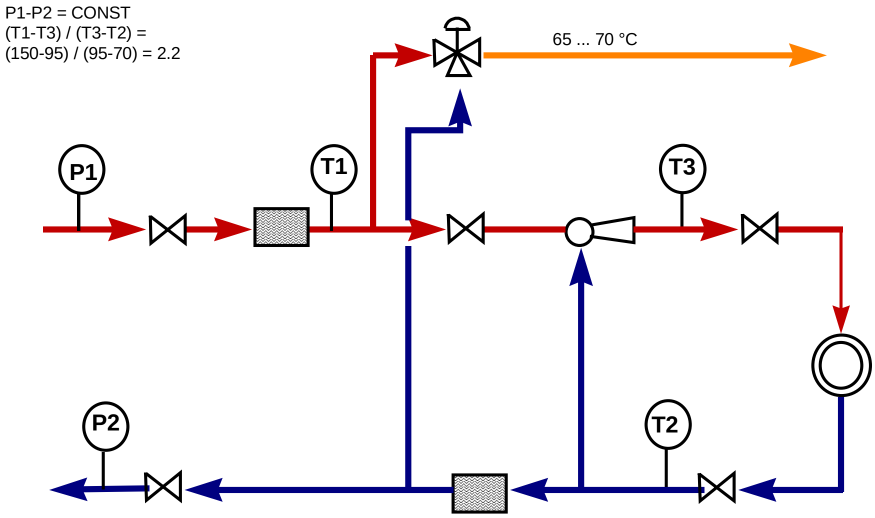

Figure 3. Consumer connection with an ejector.

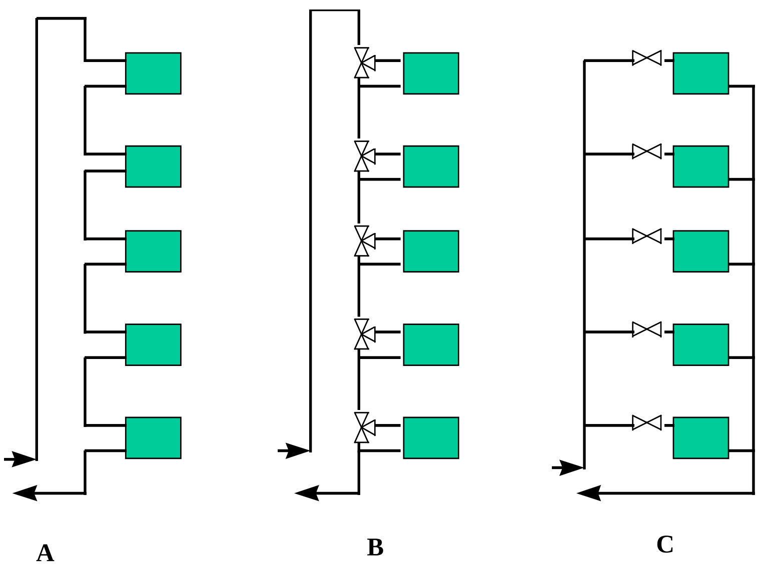

Figure 4. Implementation alternatives for radiator lines.

2.3.2 Indirect connection and group substations

As mentioned before, indirect connection with a consumer substation at each building is still quite rare in Russia. Instead, so called group substations provide space heating and domestic hot water (DHW) for several consumers in a relatively large area. As a result, the secondary network may be quite large.

Heat exchangers are mainly of the tube type. In modern substations, shell-and-tube as well as plate heat exchangers are also used. The plate heat exchangers may be dismountable with gaskets, or of the brazed type. The advantage of the dismountable type is that it may be dismantled for cleaning and its output may be increased by adding more plates. On the other hand, gaskets can leak, especially at high DH water temperatures and pressure fluctuations.

The typical secondary network is a 4-pipe system, i.e. there are supply and return pipes for the space heating, a supply pipe for the DHW and a circulation pipe for the DHW. The most common material used in secondary networks is black steel, which is prone to rapid internal corrosion. Air is diffused in the DH water, especially during the summer shut down or during pressure disturbances in the network. Typically, no water treatment is used for domestic hot water and in the worst cases the life of the pipe lines may be less than five years. Because of this rapid corrosion, extra pipes may have been buried next to the pipe lines for use as a backup, so that maintenance disturbances are shorter.

The design temperatures of the secondary network are approximately 95 °C for supply and 70 °C for return DH water. For DHW the design temperature is typically 60 °C, which is sufficient to prevent health risks (thermophilic bacteria, such as Legionella, fungi, etc.).

2.3.3 Water treatment

In the MODiS target area, large transmission networks are usually equipped with water treatment systems, which in design conditions produce enough make-up water for the network. Due to high water losses from the network, however, the make-up water production capacity is seldom adequate. As mentioned before, internal corrosion and deposits are serious problems in DH systems in the MODiS target area.

Make-up water is treated at heat production plants (CHP or HOB), typically with cation exchanger units (i.e. softening plants) and thermal oxygen removal. Smaller HOBs may not have thermal oxygen removal and in some cases have no water treatment at all.

Although make-up water is treated, no treatment is used for water circulating in the transmission networks or the secondary networks after the group substations. Unlike in West European DH systems, the water is not dosed with chemicals to adjust the pH level or oxygen content and circulating DH water is not monitored. Heavy corrosion activity can be shown by measuring the roughness of the pipes, which varies from 0.5 to 2.0 mm (in West Europe 0.05–0.2 mm). The highest corrosion rates have been observed in secondary networks with open connections for DHW.

2.3.4 Automation

The level of automation in the heat production plants in the MODiS target area countries is generally low. This results in lower performance and a higher number of operating and maintenance staff than in the West European systems. The monitoring and control of CHPs, HOBs and separate pump stations are usually carried out from a central headquarters by telephone. Usually, management of the system operation is delegated to the individual heat plants and the main office gives only primary instructions, like when to start or stop the heating season, what is the necessary supply temperature, etc. Energy management systems do not exist, as no measuring equipment, control valves or malfunction indicators have been available. In most cases the supplied energy is measured only at the heat production plants and the operation is monitored afterwards by manually checking reports of heat supply from heat production units.

As discussed above, consumers in a typical dwelling have no possibility to control the heat supply, and the energy consumption of an individual customer is not measured. Instead, the energy demands of residential buildings are roughly calculated as a function of building area (see Table 7). According to model norms the consumption of DHW/person is set at 85–115 l/d and the DHW supply temperature at 65 °C. In practice, the DHW consumption has been estimated to be 150–200 l/d per person.

Table 7. Example of typical heat demand and heat consumption for apartment blocks in the MODiS target area countries.

	Per person	Per m^2
Heat demand	1.9–4.4 kW/person	0.16–0.21 kW/m^2
• space heating	1.4–2.6 kW/person	0.09–0.12 kW/m^2
• domestic hot water	0.5–1.8 kW/person	0.04–0.09 kW/m^2
Heat consumption	4 400–7 000 kWh/a	290–380 kWh/m^2a
• space heating	3 000–5 500 kWh/a	200–270 kWh/m^2a
• domestic hot water	1 400–1 500 kWh/a	70–120 kWh/m^2a

3. A basic definition of the MODiS concept

3.1 Technical solution

The MODiS system can be divided into three levels. The first level includes the heat production, transfer and consumer subsystems as shown in Figure 5. All the subsystems consist of modules based on components made by several producers or individual components, as shown in Figure 6. In the second level every subsystem has its own information system, incorporating measurement, data collection, alarm, control and regulation equipment. The Lonworks technology is used for the interoperable control of the modules in the subsystems. In the future the subinformation systems will all be connected to one main information system, which will allow two-way information transfer. The third level will be management systems, which will utilise the two first levels. The management level consists of general organisational and administrative management systems. The planning, operation and maintenance of the MODiS system, and customer management are also included.

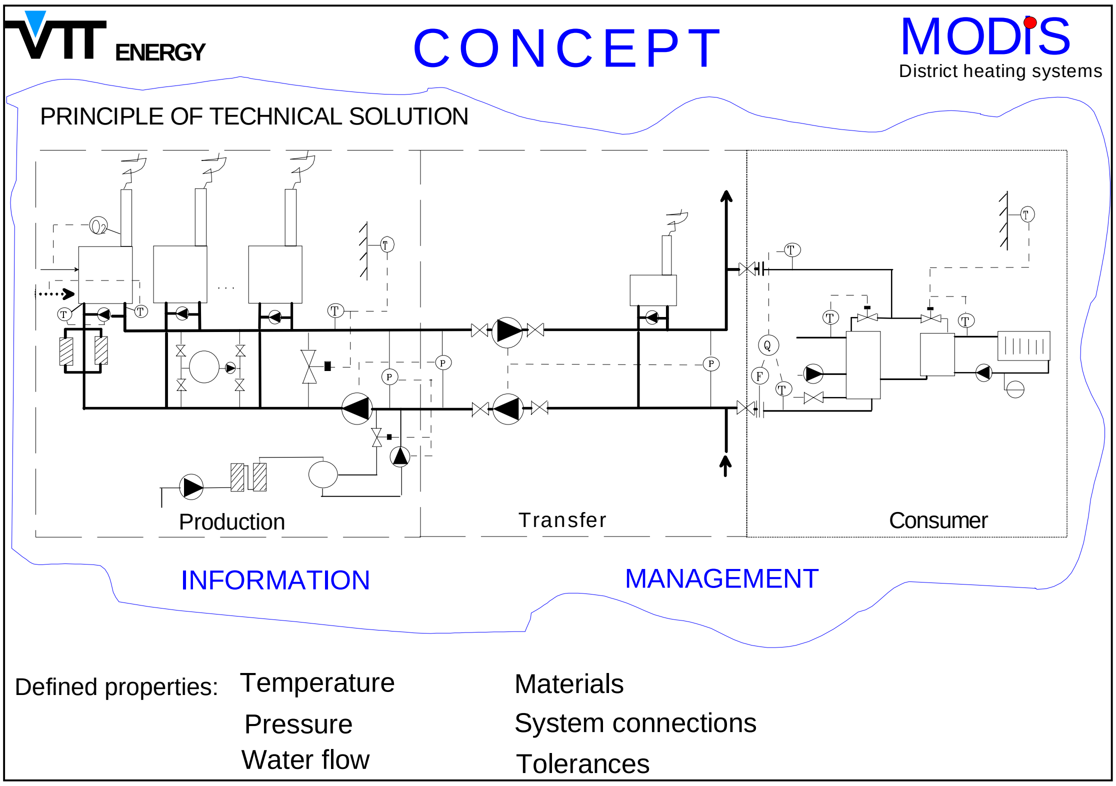

Figure 5. The MODiS concept.

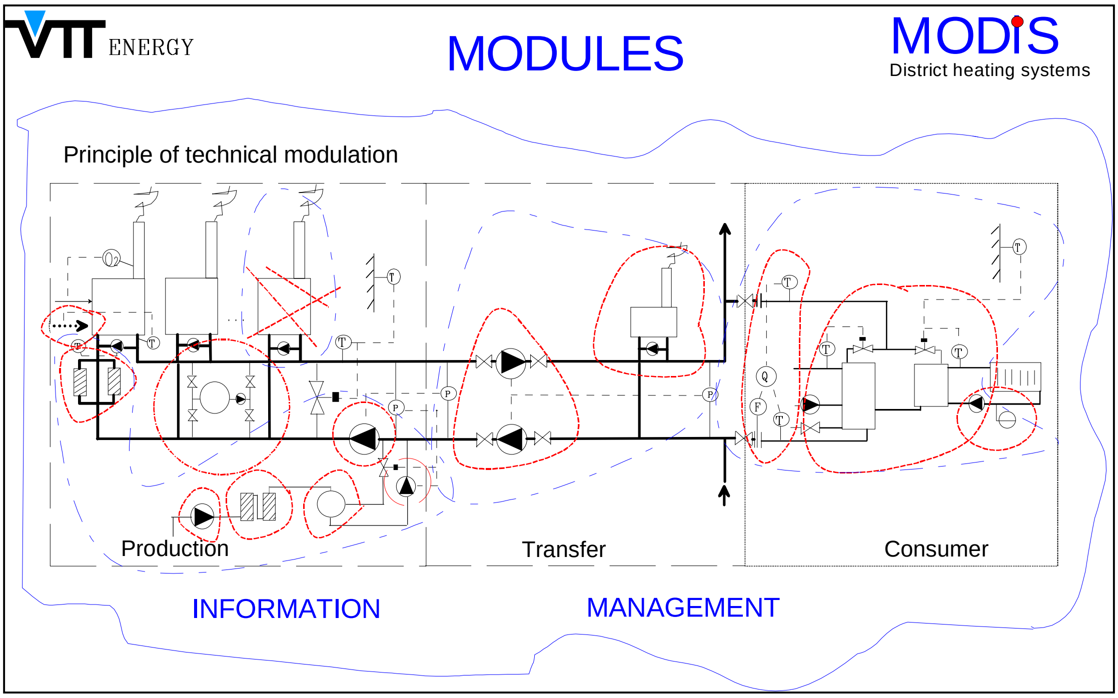

Figure 6. Modular district heating system.

3.2 Technical parameters of the modis system

3.2.1 Parameters for the basic MODIS system

The starting point for the basic MODiS system is the DH-system in Scandinavia and Russia that exists at the moment. At this initial stage, the parameters specified for the MODis system are basically a compromise between the parameters currently in use in Scandinavia and Russia. In Scandinavia the maximum outgoing temperature is 115 °C with a 50 °C temperature drop due to cooling and a typical design pressure of 1.0–1.6 MPa. The outgoing temperature of the Russian DH-system is 150 °C and the pressure 1.6–2.5 MPa. Most of the systems have a constant flow in the DH-network. The cooling in the Russian network is nowadays about 40 °C. Temperatures after the ejector in the secondary side are 90 °C for the outgoing water entering the radiator circle and 70 °C for the return water. The tap water is taken out before the ejector and is regulated to 65 °C by the return water temperature of the radiator circle. The MODIS basic parameters are presented in Figure 7.

The basic idea of the MODIS system consists of a closed 2-pipeline system, in which the water flow is regulated by pumps. Combined heat and power (CHP) production units are connected to the network via a heat exchanger. The boiler plant is connected directly to the heat transfer network but consumers are, except in special cases, mainly connected indirectly to the network. In this way the oxygen content of the district heating water can be kept at a low level. The tap water comes from cold water that has passed through the heat exchanger. The pressure variation in the DH-network is therefore less dependent on consumer equipment.

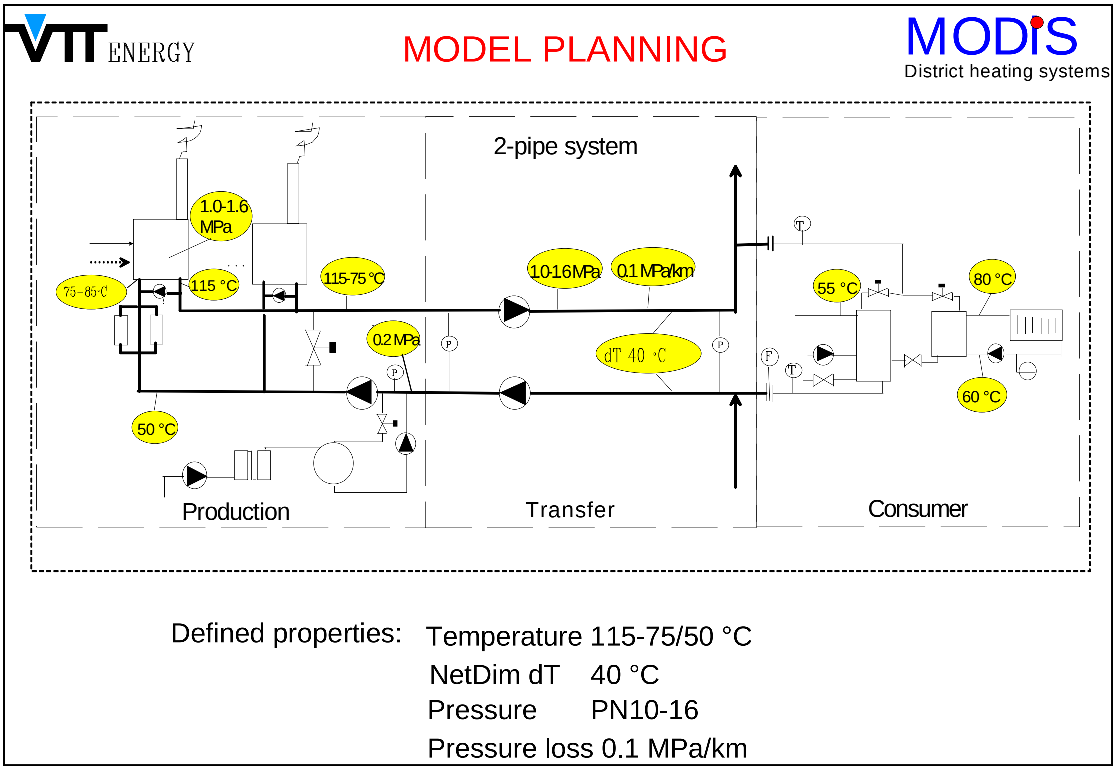

Figure 7. Basic parameters for the MODIS system.

3.2.2 Parameters for the advanced MODIS system

The parameters of the MODiS and Russian district heating systems are presented in Table 8.

Table 8. Parameters of the MODiS and Russian district heating systems.

Parameter	MODIS Basic	RUS Present	RUS Advance	MODIS Advance
Outgoing temperature °C	115	150	130	90
Return temperature °C	50	70	60	30
Cooling °C	40	40	50	50
Pressure in network MPa	1.6	2.5	1.6	1.0
Pressure loss in net MPa/km	0.1	0.1	0.1	0.1
DH-water circulation	Regulated	constant	Regulated	Regulated
Quality of water	FIN	RUS	FIN	FIN

3.3 Heat production

3.3.1 Fuels

The main fuels in the target area are diesel, mazout and natural gas. The properties of these fuels are given in Tables 9, 10 and 11. Shown also in Table 11 are the properties of Finnish fuel oils.

The fuels DA, DZ, DL and DS are produced in accordance with the GOST standard 4749-73 and A, Z, L and ZS comply with GOST standard 305-73. The properties of fuels produced by those standards are similar and they can be used for the same purpose.

Mazout is defined in COST standard 10585-75.

The specific heat capacity (kcal/kg,°C) of mazout can be calculated, if the temperature of the mazout is known.

$$C_T = 0.415 + 0.0006xT,$$

where T is the fuel temperature in °C.

Table 9. Properties of diesel oil by GOST standard.

	GOST 305-73				GOST 4749-73			
Object	A	Z	L	ZS	DA	DZ	DL	DS
Setan number, min	45	45	45	45	45	45	45	50
Division, °C,max 50% distilled 90% distilled	 240 330	 250 340	 280 360	 280 340	 255 330	 280 340	 290 360	 280 340
Viscosity, +20 °C,cSt	1.6–2.5	1.8–3.2	3.0–6.0	1.8–3.2	1.5–4.0	3.5–3.0	3.5–6.0	4.5–8.0
Oxygen,mgKON/100 ml, max	5	5	5	5	5	5	5	5
Ash, %, max	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sulphur, %,max	0.4	0.5	0.5	0.5	0.2	0.2	0.2	0.2
Resin, mg/100ml, max	30	30	30	30	30	30	50	50
Coking (10% remain), %max	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25
Acid, alkali, mech.imp.	None	None	None	None	None	None	None	None
Temperature, °C Fire point, min Flock point, max Solidification point, max	 30 - -55	 35 -25 -35	 40 -5 -10	 35 -35 -45	 35 -35 -60	 50 -35 -45	 65 -5 -10	 90 -10 -15
Test with copper	OK	OK	OK	OK	OK	OK	OK	OK

Russia contains largest natural gas reserves in the world. The gas reserves are mostly located in Siberia. The gas is supplied from Siberia for use in Karelia and the Baltic countries, as well as for export to Europe (and Finland).

Table 10. Properties of mazout according to the GOST 10585-75 standard.

Properties	As used in shipping		Low sulphur		Norm Sulphur		High sulphur	
	F-5	F-12	40	100	40	100	40	100
Density, 20 °C max	-	-	0,91	1,015	0,931	1,015	0,944	1,015
Viscosity, 80 °C max	5	12	8	16	8	16	8	16
Kin viscosity,cSt, 80 °Cmax	42	60	59	118	59	118	59	118
Fire point, °C min	80	90	90	110	90	110	90	110
Flock point, °C max	-5	-8	10	25	10	25	10	25
Same for high paraff	-	-	25	42	25	42	25	42
mazout	0.1	0.1	0.12	0.14	0.12	0.14	0.12	0.14
Ash %, max								
Mechanical imp., %	0.1	0.15	0.8	1.5	0.8	1.5	0.8	1.5
max	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5
Moisture, % max	2.0	0.8	0.5	0.5	2.0	2.0	3.5	3.5
Sulphur, % max	41.32	41.32	40.61	40.61	40.40	40.40	39.78	39.78
Calorific val, MJ/kg	9 870	9 870	9 700	9 700	9 650	9 650	9 500	9 500
(kcal/kg)	-	-	41.45	41.62	41.20	41.22	40.95	40.78
Medium calorific val	-	-	9 900	9 940	9 840	9 845	9 780	9 740
MJ/kg								
(kcal/kg)								
Medium content, %								
S, sulphur	2.0	0.8	0.5	0.5	2.0	2.0	3.5	3.5
C, carbon	-	-	84.7	84.7	83.8	83.8	83.0	83.0
H, hydrogen	-	-	11.7	11.7	11.2	11.2	10.4	10.4
O+N, oxygen+nitrogen	-	-	0.6	1.0	0.8	1.0	0.8	1.0
Air (α=1) m^3/kg	10.35	1.38	10.62	10.62	10.45	10.45	10.20	
Combustion gas:								
V_C								
V_{N2}	1.58	1.58	1.58	1.58	1.57	1.57	1.57	
V_{H2O}	8.20	8.17	8.39	8.39	8.25	8.25	8.05	
V_O	1.40	1.40	1.51	1.51	1.45	1.45	1.36	
	11.18	11.15	11.48	11.48	10.28	10.28	10.99	

Table 11. Properties of natural gas (RUS), heavy fuel oil (FIN) and light fuel oil (FIN).

Object	Natural gas (RUS)	Heavy oil (FIN)	Light oil (FIN)
Density kg/m^3 ; 0 °C, 1013 mbar kg/ m^3; 15 °C Kin.viscosity cSt; 20 °C Kin.viscosity cSt; 50 °C	0.731	 950 3.8	 830 200
Fire point, °C min Ash % max	650 0.02	90 0.04	80 0.01
Moisture, % max Sulphur, % max Calorific val, MJ/m^3 gas Calorific val, MJ/kg oil	- - 35.3	0.3 0.5 40.6	0.05 0.5 42.7
Content, % Gas liquid oil CH_4 C C_2H_6 H O_2 S CO_2 O N_2 N	 98.92 0.11 0.05 0.02 0.90	 85.5 11.2 2.4 - 0.8	 85.8 13.2 0.5 0.3 0.2

3.3.2 Boiler plants

Boiler plants are delivered in complete operational units including all necessary components and functions. Boiler plants are gas or oil fired. Solid fuel-fired units are also available. The maximum temperature can be chosen from the range 90–150 °C and the pressure level 1.0–2.5 MPa. A schematic diagram of the boiler plant is presented in Figure 8.

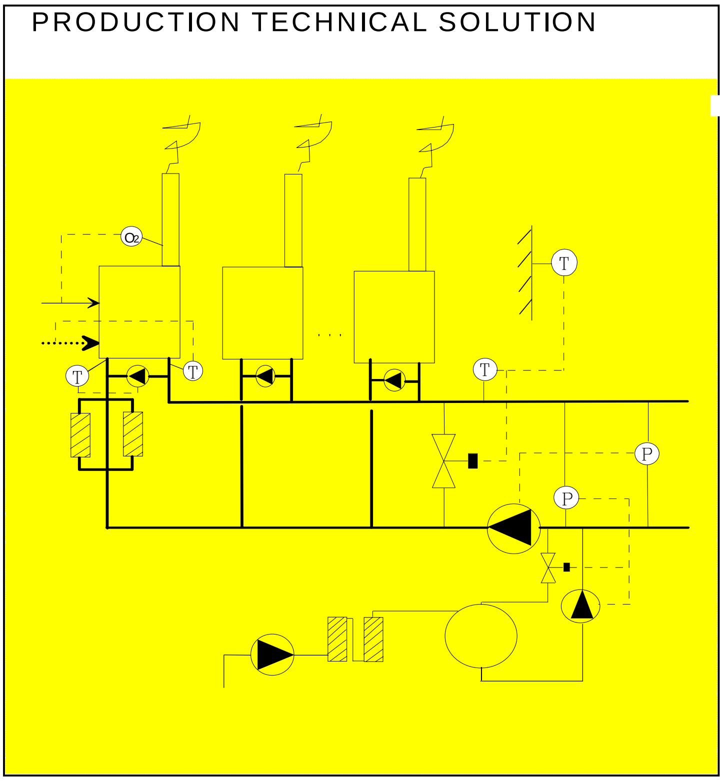

Figure 8. MODiS concept for boiler plant.

Table 12. District heating boilers.

Boiler unit [MW]	Water flow [kg/s]	Pipeline DN
0.05	0.3	25
0.2	1.2	32
0.5	3.0	50
1.0	6.0	80
2.0	12.0	100
3.0	18.0	125
4.0	24.0	150
5.0	30.0	150
6.0	36.0	150
8.0	48.0	200
10.0	62.0	200
12.0	72.0	200
15.0	90.0	200
20.0	120.0	250
40.0	240.0	300
60.0	360.0	400

Three-pass shell boilers are the most used boiler configuration. This reliable and highly regarded technology achieves a thermal efficiency of 90% without economisers. Water treatment and high level control of water quality ensures high availability of boiler plants as well as long service life for pipelines and auxiliaries. The modules of a

MODiS boiler plant and their subproducers are presented in Table 13. The heating output from a supply boiler plant can be 1–200 MW, which can be divided into basic modules as shown in Table 12. A boiler plant of up to 15 MW thermal power will be transported in one modular container. The size of a plant with higher thermal power would require the boiler plant to be divided into more than one modular container for transportation.

Table 13. Components of the district heating boiler plant.

Boiler modules

Component	Connection	Company
• Shell boiler (gas, oil) < 15 MW, one module > 15 MW, 2 or more module units	flange	Sermet Oy Finreila Oy
• Atmospheric boiler (gas) - 50 and 200 kW modules		Finreila Oy
• Burner	flange	
• Fuel system	twisted muffle	
• Stack (insulated)	flange	
• Circulation pumps	flange	Kolmeks Oy
• Pressurisation Pump, overflow valve	flange flange	Kolmeks Oy Naval Oy
• Control and alarm system - DH outgoing water temperature - boiler water temperature - pressure regulation		TAC-Com Oy
• Metering - DH-energy - Fuel consumption - Electricity consumption - Make-up water - Temperature, pressure measurements		
• Water treatment circulation water, additive water	flange	Savcor oy
• Electricity supply	400 VAC / 50 Hz	

3.3.3 Combined Heat and Power production (CHP)

Combined Heat and Power (CHP) is an energy conversion process where electricity and useful heat are produced simultaneously in a single process. Heat produced in CHP plants simultaneously with power generation is called CHP heat. The heat is used for district heating or industrial processes. Accordingly, the electricity generated in the same process is called CHP electricity. CHP is also referred to as cogeneration. CHP production has high overall efficiency, which annually can be as high as 85–90%. This is much higher than the 40–45% efficiency of a condensing power plant, which generates only electricity. CHP production is compared to the equivalent production of a separate boiler and condensing power plant in Figure 9. The separate production plants need about 40% more fuel than the corresponding CHP production.

There are different kinds of CHP plants. Electricity generation is a function of simultaneous heat production. The power to heat ratio describes this connection, which is called the characteristic curve of a CHP plant. The characteristic curve is also a function of the temperature and pressure of the output heat.

If the useful heat supplied by a CHP facility is produced simultaneously with electricity, this amount of heat is considered to be CHP heat.

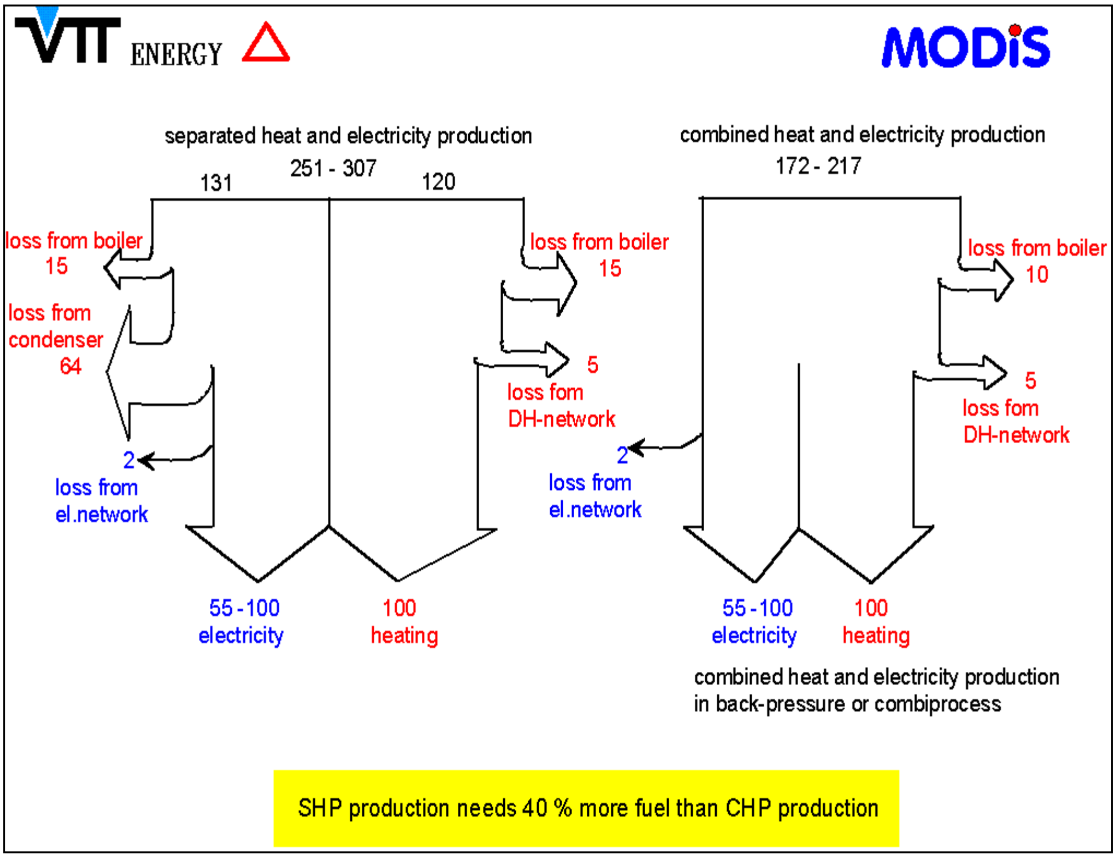

Figure 9. Comparing CHP production to same amount of separated production at boiler plant and condensing power plant.

CHP plant types can be listed as:

- Steam engine power plant with heat recovery system
- Reciprocating engine power plants with heat recovery system
- Conventional backpressure power plants

- Extraction condensing power plants
- Gas turbine plants with heat recovery boiler
- Combined cycle power plants.

The price of a coal-fired back-pressure CHP power plant is 50% lower than the total price of a coal-fired condensing power plant that produces only electricity and an oil-fired boiler plant that produces only heat. Although a gas-fired combined cycle CHP power plant is only 30% cheaper than the equivalent separated production plants, its use would justified, because of its lower running costs and lower emissions.

A 1000 MW gas-fired CHP plant decreases green house gas emissions by about 1 million tons a year when compared to equivalent separated coal-fired conventional production and by about a half of that amount when compared to separated gas-fired production.

As an example, Figure 10 shows a small size CHP power plant, a biopower plant by Sermet Oy, which consists of a biograte boiler and steam engine. Bark, wood chips or sawdust or a mixture of these can be used as fuel. The fuel storage volume is typically 450 m^3. Push bar unloaders (including hydraulics) are installed on the bottom of the fuel storage.

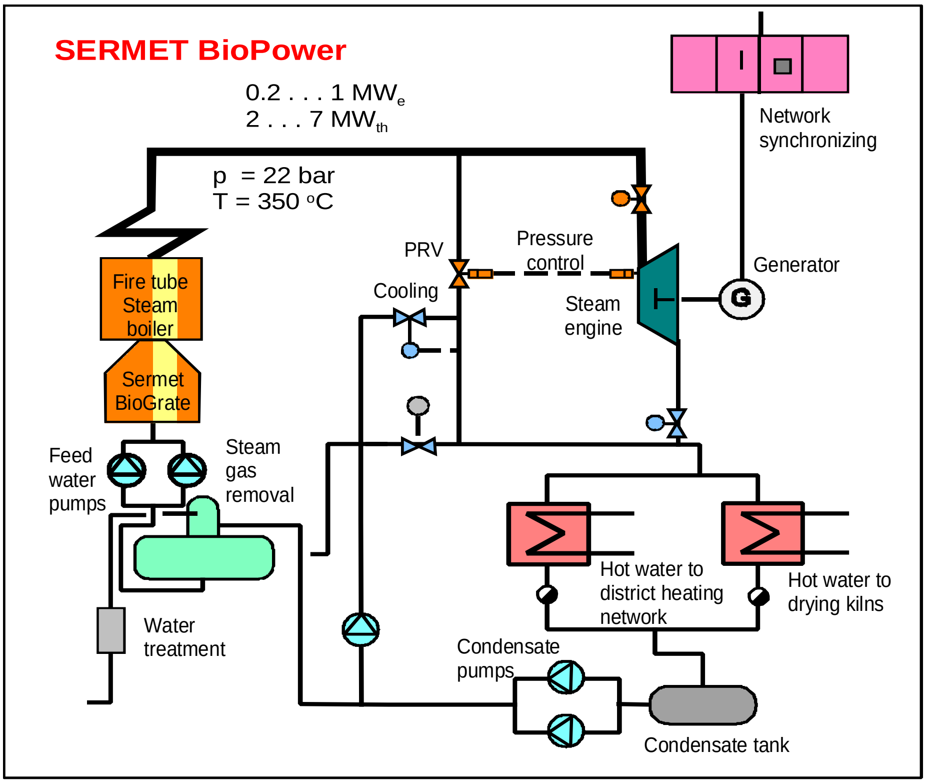

Figure 10. Combined heat and power plant with biofuel boiler and steam engine.

The output of the CHP-plant can be 0.2–1.0 MW_e / 2.0–7.0 MW_{th}. The electricity production can be maximised by using an air-cooled heat condenser mounted parallel to the district heating condenser. The process is designed to be operated unmanned, which is essential for economical long term use of the plant. The emissions of the combustion process fulfil the relevant European emission regulations.

The combustion gases from the primary combustion chamber flow into the secondary combustion chamber in order to ensure enough residence time and good mixing, which are needed for the complete burnout of gas and particles. The superheated steam is generated in a fire-tube steam boiler, which is specially designed for low heat value flue gas application. The fire-tube and evaporator tubes are followed by the superheaters, which superheat the steam flow for the steam engine. The saturated steam storage is an integrated part of the boiler. After that the steam boiler gases flow into the fire-tube tube economiser, which is positioned horizontally below the boiler. The economiser is needed in order to maximise efficiency.

Electricity production is carried out using a steam engine and a 3-phase synchronous alternator. The steam inlet properties for the engine are 22 bar and 350 ^{o}C. The back-pressure ranges from near 0 bar to 1 bar, which covers the entire temperature range needed, for example, for the sawmill dryer and the district heating network. The heat is transferred from the output steam to the dryer water and the district heating water in a condenser type heat exchanger. The steam engine is supplied with an oscillating antivibration foundation, steam flow regulation equipment, switchboard panel and an automatic monitoring, warning and shut down system. The generator produces electricity at 400 V / 50 Hz. The electrical requirements for the boiler process are also based on 400 V. A stepup transformer is used for transforming the voltage up to the 20 kV network. The district heating network is equipped with two speed controlled circulation pumps with an inverter. A pressure maintenance system is included.

The process information is saved to a PC hard disk. The PC information includes several process schemata, control, trend and alarm displays. The basic reports prepared from the data include daily, monthly and annual reports. The reports use the Excel-program format.

The most natural locations for small energy plants are industries like sawmills, where biomass is produced as a by-product. Using wood waste from an own sawmill or other mechanical forest industry plant one can save the costs of purchased energy, oil or electricity, and even earn extra income by selling heat and/or electricity to another local consumer (e.g. the district heating network or another industrial plant). In any case the own production of electricity saves the electricity transfer costs that would be incurred in the public network.

Economic feasibility is greatly dependent on the local fuel costs and on the price of replacement, bought and sold electricity. These values still vary a lot around Europe in spite of recent liberalisation in the energy sector. When electricity production is combined with heat production the preliminary calculations indicate 7 to 15 years for the payoff time.

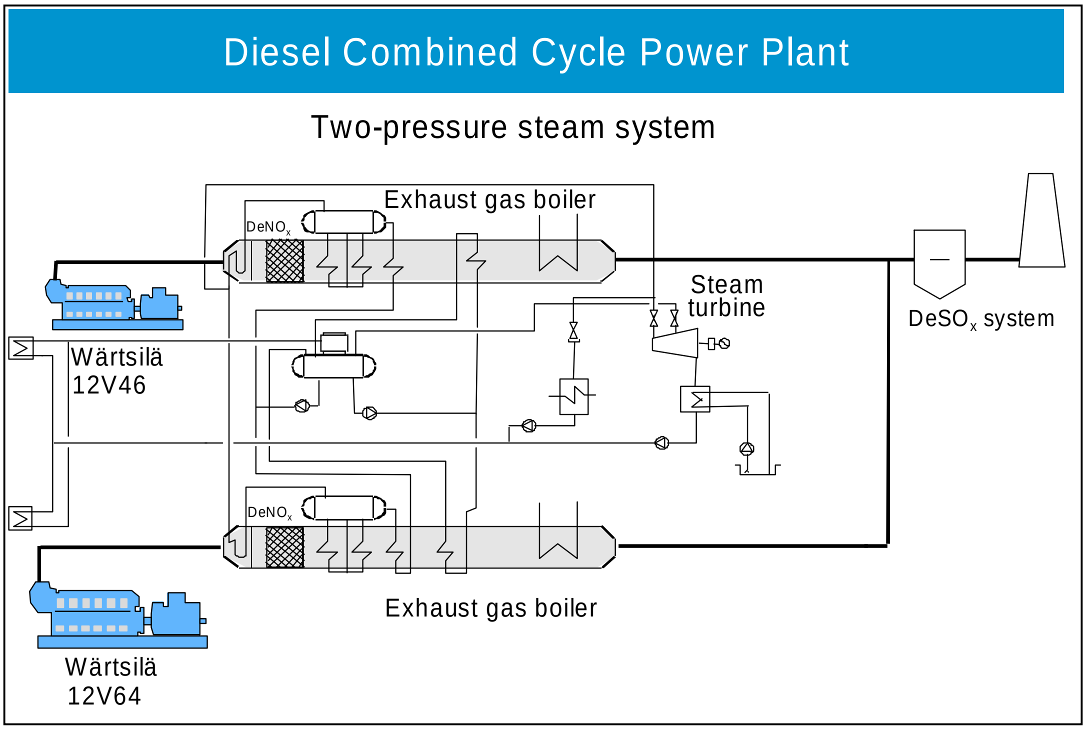

Figure 11. Diesel Combined Cycle Power Plant (38 MW) at Vaasa.

An other example presents the diesel combined cycle power plant by Wärtsilä Diesel as shown in Figure 11. The CHP power plant based on one Wärtsilä 12V46 and one Wärtsilä 12V64 engine connected to a steam turbine through two exhaust gas boilers gives a net total power output of 38 MW_e and a total heat output of 32 MW_{th} as hot water, which is supplied to the DH-network of the town nearby. The net output from the seawater-cooled condensing steam turbine generator is 5 MW_e. District heat is produced from the engine cooling circuits and the economiser on the exhaust gas side, which is placed after the combined cycle steam boiler system. The entire steam output can also be used for district heat production, in which case the steam turbine is either by-passed or disconnected. There exist two steam pressure levels: 20 bar on the HP side and 3.8 bar on the LP side. The high-pressure steam is superheated in the superheater. The temperature of the superheated steam will be close to the exhaust gas temperature and will vary with the load of the engine. The low-pressure evaporators are connected to the feedwater tank, which works as a steam drum on the low-pressure side. The plant will be run on heavy fuel oil and is designed to meet very strict environmental regulations, not only on the exhaust gas side but also with respect to noise.

3.3.4 Make-up water and water treatment

The water quality in the district heating systems should be good. Water treatment has at least two tasks: The formation of scale should be prevented and corrosion should be minimised.

3.3.4.1 Formation of scale

One problem in district heating equipment is scaling. Some substances produce layers that inhibit good heat conduction. The formation of scale depends on the level of the substances that cause hardness of the water, calcium and magnesium. If the water being used has organic impurities, iron may produce layers in the boilers. Silicate combined with calcium- and magnesium salts, and aluminium compounds can also produce layers that are hard to remove.

3.3.4.2 Corrosion in the district heating systems

The most used material in the water systems is steel, and its corrosion rate depends on the content of oxygen in the water. In closed systems, where the oxygen content is constant, the corrosion rate increases as a direct function of temperature. When oxygen reacts with steel, an oxide layer forms on the surface of the steel. If the oxide layer is tight, it can be protective. If the oxide layer is porous, it is not protective. Corrosion can perpetuate in the pores and the local effect can be severe, because the anodic area versus cathodic area is small. Chlorides also have deleterious effects. They can diffuse through the passivation layer causing pitting and crevice corrosion. Solid particles in the water can cause erosion corrosion by abrasive wear of the surfaces. Erosion corrosion is said to be at a maximum at a temperature of approximately 150 ^{o}C.

3.3.4.3 Water treatment

In order to enhance the performance and longevity of a district heating system, the aim of water treatment is to prevent the formation of scales and corrosion damage, both in boiler plants and in district heating networks. The treatments for the make-up water are, when necessary, to soften the water and to remove salt by an ion-exchanger before the water enters the network. It is intended that oxygen be removed from both the additive water and the water in the network in a side circulation, either chemically or thermally, or by means of a new technology. The pH-level should also be raised to between 9 and 10, where the corrosion due to oxygen is at a minimum, and the content of solid particles in the water should be lowered. The procedures outlined above cover the entire water treatment, and should be sufficient to ensure compliance with the criteria mentioned in Table 14 below.

The starting-point for water treatment is a continuous monitoring of the circulating water, and controlling the water treatments in such a way that the water quality remains continuously at the desired level.

Table 14. Quality criteria for Finnish district heating water.

Plant size / Property	> 100 MW		10–100MW		< 10 MW	
	Connection of the plant		Connection of the plant		Connection of the plant	
	Indirect	Direct	Indirect	Direct	Indirect	Direct
PH-value (pH25)	9–10	9–10	9–10	9–10	9–10	9–10
Hardness mmol(Ca+Mg)/kg	< 0.143	< 0.018	< 0.143	< 0.018	< 0.143	< 0.089
DH°	< 0.8	< 0.1	< 0.8	< 0.1	< 0.8	< 0.5
Oxygen O_2 mg/kg	< 0.02	< 0.02	< 0.02	< 0.02	< 0.001	< 0.001
Oxygen binding chem.mg/kg Hydrazine N_2H_4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ammonium NH_3 mg/kg	< 5	< 5	< 5	< 5	< 5	< 5
Iron Fe mg/kg	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Copper Cu mg/kg	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Oil content mg/kg	< 1	< 1	< 1	< 1	< 1	< 1
Conductivity µS/cm Chlorine Cl mg/kg	< 50	< 50	< 50	< 50	< 50	< 50
Hydrocarb .HCO_3^- mg/kg	< 60	< 60	< 60	< 60	< 60	< 60
Solids content mg/kg Particle size < 0,45 µm	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5

3.4 Transfer network

Heat is transported and distributed to the consumer through a district heating network. The network is mostly located under the ground, but is sometimes, for special reasons, mounted in the air. The pipeline of the network can have 1–4 pipes, but in Europe, a two-pipe system is used the most. The heat is delivered to the consumer by hot water pumped in pipelines. The water is a convenient medium, because it is cheap, easily handled, and neither corrosive nor toxic. In district heated countries in winter the supply temperature of the outgoing water varies from 115 to 150 °C and is cooled 40–50 °C by consumers.

3.4.1 Pipelines

A pipeline usually consists of two pipes; a supply pipe and a return pipe. A pipeline with one pipe has only an outgoing pipe, in a three-pipe system there are two supply and one return pipes, and in a four-pipe system there are two supply and two return pipes.

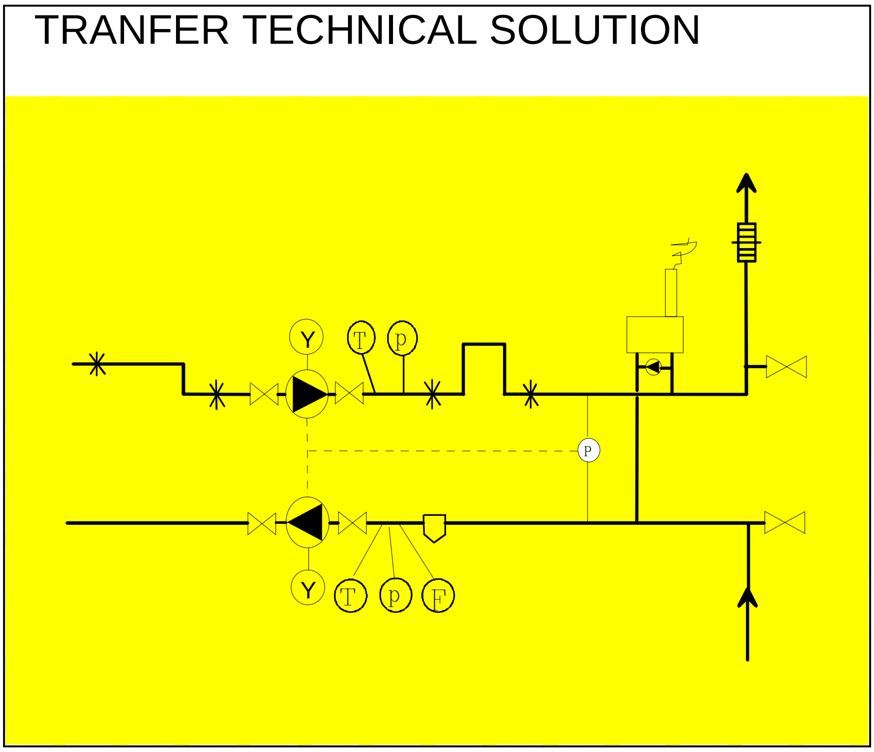

Figure 12. Components of the district heating pipeline.

Table 15. Components of the district heating pipeline.

Component	Connection	Company
• Pipes		
DN 20 – DN 25 in 6 m lengths	welded	KWH-Tech
DN 32 – DN 600 in 12 m lengths	welded	KWH-Tech
• Bend elements 30°,45°,60°,90°	welded	KWH-Tech
• Branch elements		
T-branch, bend-up T-branch,	welded	
branch parallel with main pipe,	welded	KWH-Tech
• Anchor point element		
Straight and bend	welded	KWH-Tech
• Bellow expansion joints	welded	KWH-Tech
• Overlaps	welded	KWH-Tech
• End pieces	welded	KWH-Tech
• Insulated ball valves + actuator stop, emptying valves, air escape	welded	Naval
• Measurement points		
• Wells		KWH-Tech
• Leakage alarm system		KWH-Tech
• Electricity supply 400 VAC / 50 Hz		
• Remote control system		

Pipes with steel walls are covered by fixed rigid foam insulation. The pipes are made in 6 and 12 metre lengths and they are classified in three heat loss groups based on the thickness of the foam insulation. A plastic duct covers the pipeline. Pipelines between branches and fixed points form pipeline modules. Pump stations also form a module in the network. The components of the pipeline modules are presented in Figure 12 and listed in Table 15.

3.4.2 DH pumps at boiler plants and network pump (booster) station

3.4.2.1 Pressure conditions in the network

The necessary water flow in a district heating network is achieved by the pressure difference generated by circulation pumps installed at the heating plant. In addition booster pump stations installed along the network can be used. Pumping work is needed for compensating the pressure losses caused by flow resistance in the pipelines and in consumer equipment. When pumps are in operation there is a pressure difference between the flow and return pipes at a consumer substation. The remaining part of this pressure difference, after flow resistances in consumer equipment, is lost in the regulation valve. The minimum pressure difference guaranteed for a consumer is, in general, 0.5 bar. The pressure conditions in a DH-system are presented in Figure 13.

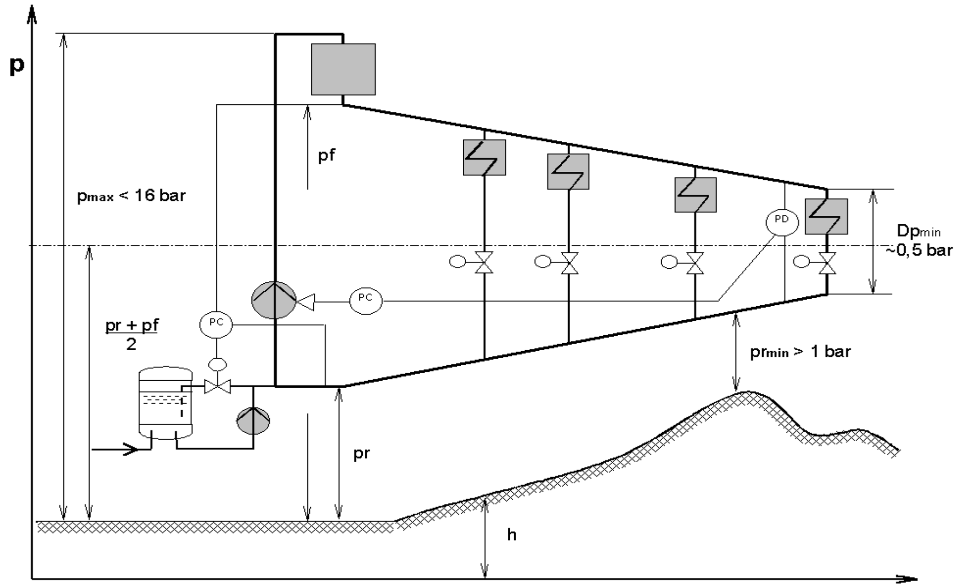

Figure 13. Pressure conditions in a DH-system.

The objective of pressure regulation in a district heating system is to keep within the minimum and maximum pressure levels and to maintain a sufficient pressure difference. The most used pressure level in DH-systems is 1.6 MPa, but the pressure level can vary from1.0 MPa up to 2.5 MPa in different countries. The minimum pressure is normally kept higher than the saturation pressure corresponding to the supply temperature, plus a suitable safety margin. In addition, in order to secure the undisturbed circulation of the water, the static pressure of the network has to be kept at an adequately high level. Static pressure means the pressure in the pipelines when the circulation of water is stopped. If the pressure level is too low, there is a danger that water will evaporate. The most critical places are the intake openings of circulation pumps and heat exchangers located on high ground. Known critical points in the DH-system are used to regulate the pressure and to keep the pressure difference at those critical points above the accepted level. Speed regulated pumps are used for pressure regulation.

Common practice for the regulation of static pressure is to regulate the middle pressure of a network. The purpose is to keep the average of the flow and return pressures at the heating plant on a certain level.

Water flow through consumer equipment is regulated after the heat demand so that the network flow fluctuates according to variations in heat demand. In the course of network water fluctuations, pressure losses change relatively more often, because the pressure loss in a pipe is directly proportional to the square of the water flow rate. If the pumps are operated under constant speed, pressure differences at the consumer substations are higher under part load conditions than under full load conditions and correspondingly, the greater part of this pressure difference must be dissipated in regulating valves. When the rotation speeds of the pumps after the heat load are regulated, the need for uneconomical throttle regulation is decreased and the electrical energy used for pumping is saved.

The network design pressure and the maximum pressure difference at consumers define the upper limit of the pressure in the booster pump. The network design pressure is in general 16 bar. The pressure difference at consumers is limited by the risk of cavitation in the regulation valves. The risk for cavitation grows, if the pressure difference to be dissipated in the regulation valve becomes too high in respect to the inlet pressure before the valve. In order to avoid cavitation the pressure difference over the valve should not be higher than half the inlet pressure.

3.4.2.2 Use of booster pumps

A part of the necessary pressure increase for water circulation in a large district heating network can be performed by booster pump stations situated along the network. The objective of booster pump stations is to save pumping energy, decrease pressure levels and level out pressure differences in different parts of the network. The principle function of a booster pump is illustrated in Figure 14.

The construction of booster pump stations often occurs when the network expands and its transport capacity proves to be insufficient because of limits in the pressure level and the necessary pressure differences. An increase in network transport capacity may be more economically achieved by using booster pump stations, rather than new transport pipelines.

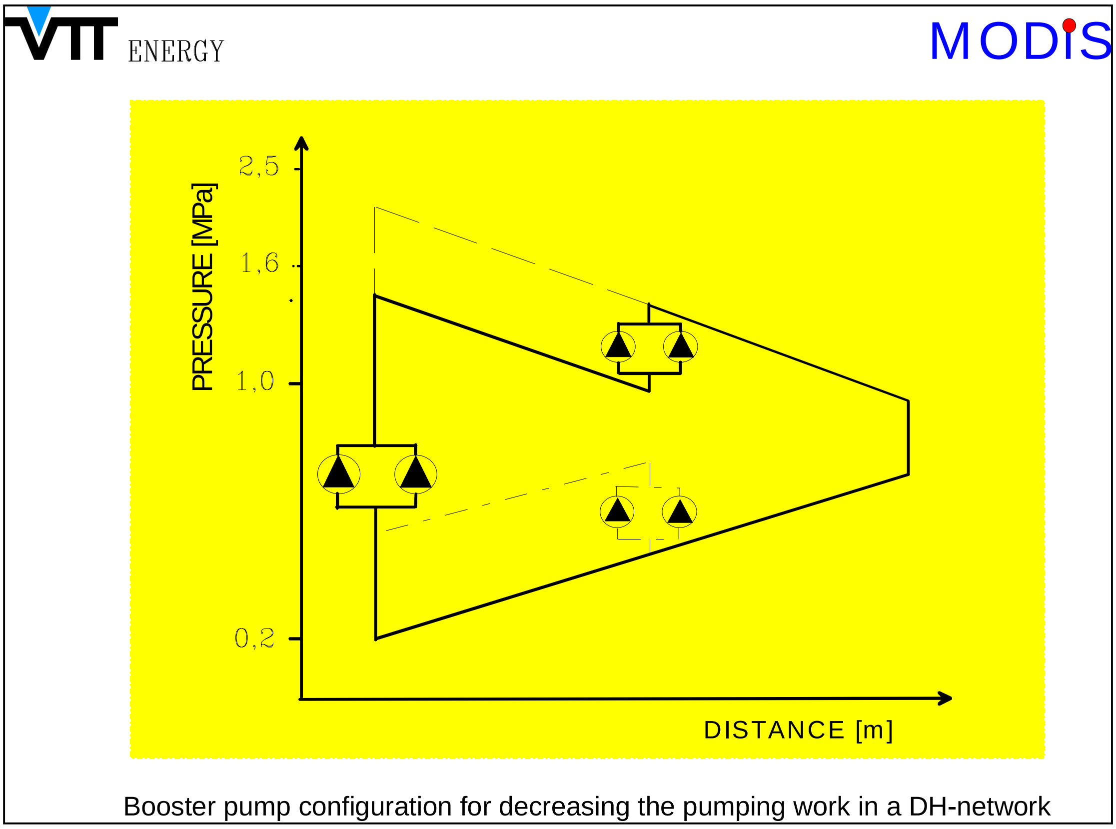

Figure 14. Booster pumps in a DH-network system.

By installing a booster pump station, the required pumping energy may be less than if the whole pressure difference were to be generated at the heating plant. This is possible when the pump station is placed so that the water flow to be transported due the consumption between the heating plant and the pump station, is smaller than at the heating plant. The profitably of installing booster pump stations depends on the network configuration and on the distribution of consumption. Sometimes it may be profitable to install a pump into a separate small delivery pipeline branch, if by this measure the need for an overall network pressure difference can be diminished.

To ensure the undisturbed water circulation in a network, the pressure in every point must be kept high enough. On the other hand, it must be controlled carefully, so that the design pressure is not exceeded. The regulation of the network pressure level is strongly influenced by height differences in the terrain.

In cases where a part of the network is situated exceptionally high, the pressure level regulation can be achieved by using booster pump stations. By utilising a booster pump station installed in the flow pipeline, the nearby network pressure level can be raised higher than in other network sections. The higher level of pressure can even be achieved by installing a throttle valve in the return pipeline.

3.4.2.3 Pump connections

In heating plants, the simplest and most practical solution is to install two pumps in the return pipeline, with both of them designed for the maximum water flow rate and delivery lift. Both pumps should be furnished with their own frequency converter unit. Only one pump is in operation at a time, with the other standing by. The utilisation of the pumps can be alternated and in this way their operation times will be balanced.

It may be recommendable to install a third pump, or pair of pumps, in series with the two other pumps in cases where the load on the driving motor of the pump designed for the maximum delivery lift is higher than 500 kW, the water flow rate is more than 500 l/s and the required delivery lift is 50–80 m wc. At a peak load heating plant, one series-connected pump is sufficient, whose delivery lift is 30% of the maximum value and which is operated during transitory peak demand periods. At a base load heating plant, sufficiently high reliability is achieved when there are two series-connected pumps and their design values are similar to the specifications of the first pair of pumps. Series-connected pumps are often installed in flow pipelines outgoing from heating plants.

The connection schemes used at booster pump stations are quite similar to pump installations at heating plants. In many cases it is managed by using only one-sided pumping. In this case a pump or pair of pumps is installed either in the flow or the return pipeline depending on terrain heights. The need for reserve pumps is determined by whether or not it is possible to maintain the necessary pressure difference in the network by pumps at other facilities, during pump failures.

In cases where the required pressure difference supplied by the booster pump station is to be divided between the flow pipeline and the return pipeline, it is most recommendable to install double pumps to both sides. In practice, there exist cases where there is a connection of three pumps, one of which is in reserve and can replace both the flow or return line pump. The disadvantages of this connection scheme are complicated and bulky piping, numerous valves, awkward operation and leaks between the flow and return lines originating from untight valves.

3.4.2.4 Speed regulation of pumps

There are several methods for the speed regulation of pumps. The most common methods in district heating technology are as follows: the frequency converting of the squirrel cage induction motor, the hydraulic switch between the squirrel cage induction motor and the pump, and the thyristor drive of the direct current motor. The latter two methods are losing ground because of the strong development in the frequency converting technique.

In choosing the speed control method, not only the delivery cost, but also reliability, operational and maintenance cost must be taken into account. Operational costs consist of power losses in the control device and driving motor, whose volume is dependent on the speed of the pump and the control method used.

The difference in efficiency between the frequency converter and the direct current drive is relatively small when the speed is varying. Both methods have an efficiency higher than 80% in the speed range of 50–100% of full speed. The efficiency of the hydraulic switch is clearly poorer, because it is directly proportional to the speed relation between the switch's secondary and primary axles. However, the power losses in the switch can be transferred to the circulation water, and therefore loss costs per energy unit are lower.

Based on investment and operational costs, the frequency converter drive is today, in many cases, the most advantageous solution, even when the effective operating range exceeds 1 000 kW. When the design requirement exceeds 500 kW and the pump is planned for a base-load heating plant where the need for speed regulation is insignificant, hydraulic switching may be more advantageous. The direct current drive is the most expensive alternative in respect to its investment costs. The disadvantage of the direct current motor over the squirrel cage induction motor, is its higher need for monitoring and maintenance.

3.4.2.5 Control of pumps

The control of pumps includes the starting and stopping of pumps, and the regulation of pump rotation speeds. The objective is to achieve operational economy, reliability and pump safety.

By the regulation of pump rotation speeds, the necessary pressure difference in the network is maintained under all loads. The regulation is governed by the pressure difference measured in the optimal working range of the pump station that best represents the pressure difference of consumers in the most difficult locations.

Pumps are equipped with pressure protection, which prevents the supply pressure exceeding the design pressure of the network and which, on the suction side, prevents the pressure from dropping below the evaporation pressure of water. It is recommended to use the restrictive regulation method. When the pressure reaches the allowed limit, the pump is not suddenly stopped, but continues to rotate at a constant speed. After a certain delay, the regulator starts to decrease the rotation speed of the pump.

In general, the control of pumps is implemented by means of programmed logics. It is also possible to manage all the activities by separate regulator units.

3.4.2.6 Corrosion phenomena

Electrochemical corrosion as a phenomenum, can be characterised as a closed circuit. In a corrosion cell there are two electrodes, the anode and the cathode, in a conducting material i.e. electrolyte, and they are somehow electrically connected.

In district heating systems, the electrolyte might, for example, be water, soil or concrete, depending on whether the corrosion is internal or external. A corrosion cell is formed in the joint between two dissimilar metals. The potential difference that is needed to form an anode and a cathode, can also develop due to the unhomogeneity of a metal, or the unequal division of some component, for example oxygen in the electrolyte.

In practice, the metal corrodes so that the metal on the anodic surface dissolves into the electrolyte. On the cathodic surface there is no corrosion as such, but different kinds of reduction reactions occur, depending on the circumstances. The corrosion current goes from the anodic sites to the electrolyte and from the electrolyte to the cathodic sites.

3.4.2.7 Corrosion monitoring

Corrosion can be monitored with sensors that are installed at different locations on the target object, for example a pipeline system. The sensors monitor the corrosion rate, temperature, potential and redox-potential. The monitored data is transferred to the main computer.

In a district heating system, there are several parameters that affect the corrosion. With optimal governing of the key control parameters, it is possible to decrease the corrosion rate significantly. A remarkable decrease in the corrosion rate means an increased lifetime, which brings huge savings in maintenance costs.

3.4.2.8 Corrosion protection

"Switching off" the closed corrosion circuit can stop corrosion. If the anode or cathode is insulated, the electrical contact is effectively broken and there can therefore be no corrosion. By using electrochemical protection, i.e. cathodic protection, the functioning of the circuit will cease and the corrosion rate will become close to zero.

Electrochemical protection can be carried out by using an external power unit. For cathodic protection, a current that opposes the corrosion current is supplied. The potential of the surface to be protected is made cathodic by the supplied current, that is, the protected surface is turned into a cathode. Trouble free cathodic protection requires regular control, because the corrosion in the target area is directly proportional to the changes in the potential level of the target.

When a corrosion protection system is installed, further corrosion stops proceeding. It must be noted, however, that the situation before the installation remains unchanged. The target structure does not become stronger, only the corrosion will be stopped and further damages can be prevented, which results in significant savings in maintenance costs.

3.5 Consumer substation

3.5.1 Substation and modules

The purpose of a substation is to transfer heat from the district heating system to the consumer system in a building. The system in the building consists of a space heating system and a domestic hot water heating system. The space heat can be distributed by water, in a radiator heating system or by air in an air heating system. The main requirements of the substation are easy and common use, reliable, efficient and economical operation while guaranteeing the required thermal effect and temperature for consumers. In the MODiS system, the consumer is connected indirectly by a heat exchanger to the district heating system. The tap water system is also recommended to be connected indirectly to the DH-system, because oxygen inhibitors can then be used to ensure a good transfer function in the district heating pipeline system. If these recommendations are followed, there exists a clear distribution between the primary (DH network) side and secondary (consumer) side of the fluids.

3.5.2 Connection to the consumer's heating system

The basic connection configuration of a consumer substation is presented in Figure 15. It is a so-called two-stage coupling substation. The primary side is divided into two parallel water flows in the first stage, one for the space heating side and the other for the domestic hot water side. In the first stage, the primary flow is cooled separately and then united prior to entering the tap water preheater in the second stage before returning to the district heating return pipe line. The space heat exchanger is connected to the second stage of the tap water exchanger.

The connection of the substation is somewhat simpler for small consumers, e.g. one family houses. The basic concept is then called parallel coupling (a so-called one-stage substation). The substation can also be coupled in three stages. The heat exchangers in the two-stage coupling (one stage substation) are connected in series, with the space heating exchanger located in the second stage between the hot tap water exchangers in the first and third stage. The disadvantage of this coupling method is the high temperature of the domestic hot water in the first heat exchanger. In addition, if the incoming water is rich in calcium, this will cause the problem of scaling inside the heat exchanger and a consequent reduction in effectiveness.

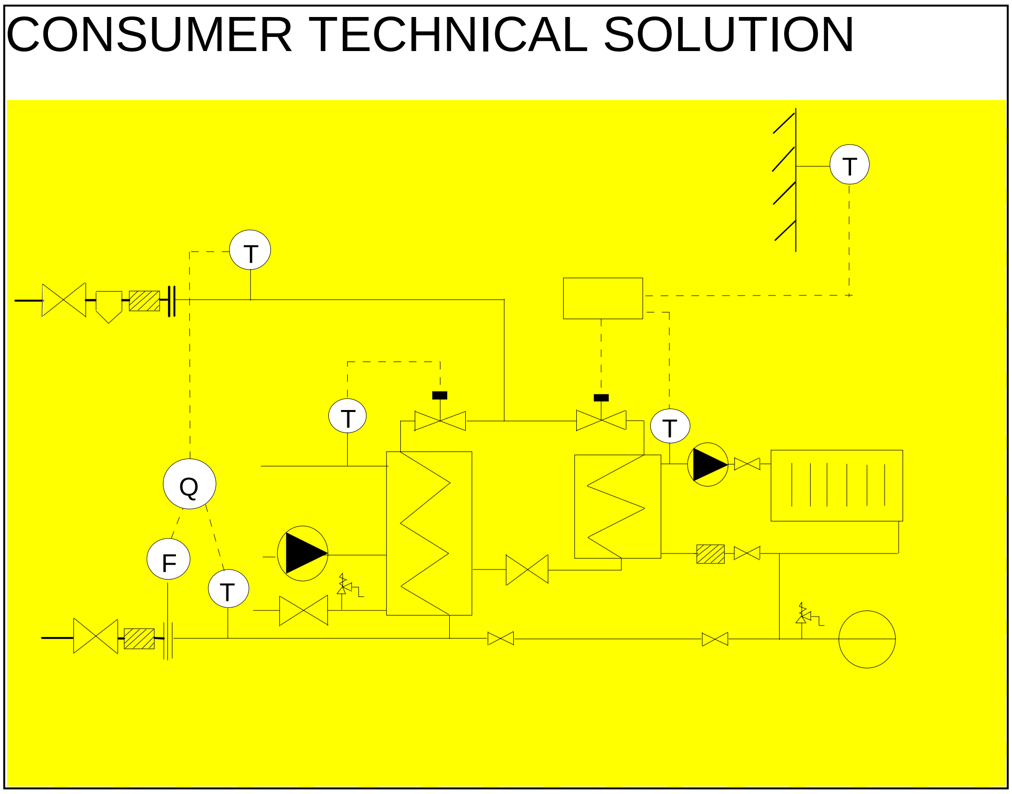

Figure 15. Connection configuration of a substation in the basic MODiS system.

3.5.3 Modules of the substation

The substation modules are presented in Figure 6, i.e. the substation, energy measurement, expansion and operation centre modules.

3.5.3.1 Substation modules

Components of the substation module are presented in Table 16.

Table 16. Components of the MODiS substation.

Component	Connection	Company
• Heat exchanger for space heat		Cetetherm
primary side	welded	
secondary side	inside twist ≤ DN 50	
or	welded	
• Heat exchanger for tap water	welded	Cetetherm
primary side	welded	
secondary side	inside twist ≤ DN 50	
or	flange > DN 65	
• Pumps		
radiator water (circulation)	flange	Kolmeks
tap water (circulation)	flange	Kolmeks
(pressure increase in prim. side)	flange	Kolmeks
(feed water into radiator system)	flange	Kolmeks
• Regulation valves and measuring instruments	flange	TAC
• Operation unit		TAC
• Stop valves	welded	Naval
• Emptying valves	welded	Naval
• Strainers	flange	
• Temperature and pressure instruments		
• Safety valves	welded	
• Electricity supply	400 VAC / 50 Hz	

3.5.3.2 Energy measurement

The components of the energy measurement module are presented in Table 17.

Table 17. Components of the energy measurement module.

Component	Connection	Company
• Flow meter	flange	
• Temperature sensor	welded pocket	
• Calculator		

3.5.3.3 Expansion module

The expansion module components are presented in Table 18.

Table 18. Components of the house expansion module.

Component	Connection	Company
• Expansion tank	flange	
• Safety valve	welded	
• Pressure sensor		

3.5.3.4 Operation centre module

The operation centre module, if not included with the substation, is included with the building automation system, which consists of a measurement, control and regulation system, as well as an alarm control. Measurement instrumentation for the substation is presented in Figure 16.

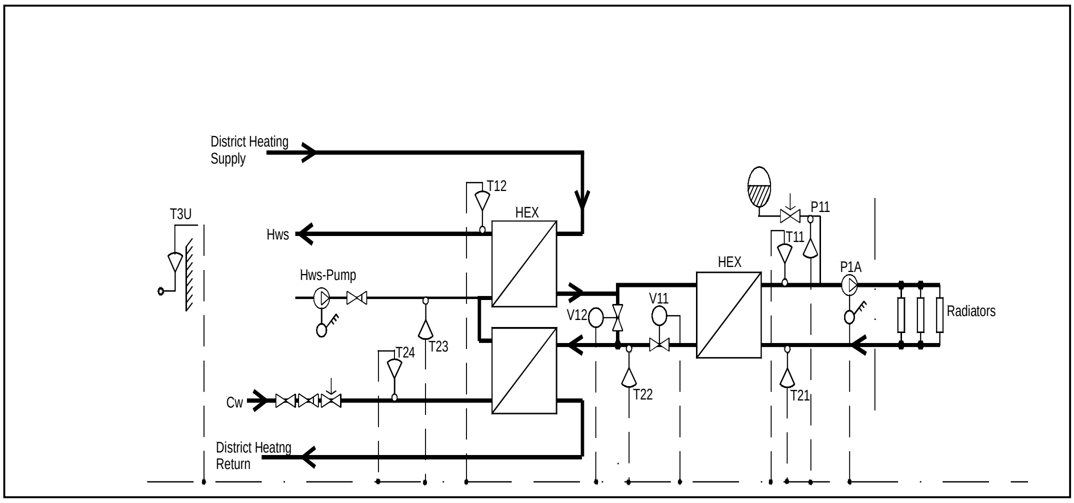

Figure 16. Instrumentation of the substation.

LonWorks® technology, which is used for data transfer, allows direct communication between the intelligent devices and related products of various manufacturers. The open environment of LonWorks® provides a free hand for integrating devices and configuring data exchange both horizontally and vertically. The system is flexible, so that it can be adapted for future needs. The advanced measurement and control system generally requires a digital communication system, however, the system can also be built based on an analogue communication system, but with some loss of features.

Control

The operation centre module, OCM (e.g. TAC Xenta 3000), consists of a series of preprogrammed controllers for the radiator heating circuit (RHC) and the hot water circuit (HWC) of the building. A number of controllers can form a local network and interchange data. The OCM can also be connected to a central system. The OCM holds full heating funtionality, including control loops, curves, time control, alarm handling etc. For local use, the operator (OP) panel can be connected to the OCM. The operator can read point status, read measured values, alter set points, etc. from an OP- panel. The functions are selected from menus. Start-up and commissioning are simplified by the use of a preprogrammed well proven application technique and factory settings.

The control curve for the supply temperature is based on four reference points, defined by four outside temperature points, of which one is adjustable. The curve, as a whole, can be shifted up or down. The supply temperature can be kept within minimum and maximum limits. Two control curves can be calculated, one based on the real outside temperature and one based on a damped outside temperature. The use of the real or damped control curve is selected from the OP-panel.

The OCM has two types of night setback, variable setback or fixed setback. The type of night setback is selected from the OP-panel. To ensure that the heating system is able to restore the indoor temperature after the night setback when the outside temperature is low, the controller would use a variable night setback (if this was selected). The magnitude of the setback is a function of the damped outside temperature, according to a curve that is configured at three adjustable outside temperatures. Each reference point is adjustable. The supply temperature setpoint or the room reference setpoint is lowered by a value independent of the outside temperature. The magnitude of the setback is set at the OP-panel.

The OCM calculates the time for changeover to daytime operation automatically. This means that the controller starts the heating earlier to obtain the correct temperature by the beginning of occupancy. The calculation is a function of a damped outside temperature curve, set by the OP-panel. The supply temperature is increased during the morning boost. The level of increase is a function of a damped outside temperature curve, set by the OP-panel. Each dimension point and each outside temperature point is adjustable. The OCM has a built-in ramp function, which prevents the rapid increase of the supply radiator temperature. The rate of increase of the supply setpoint is set by the OP-panel in °C/min. This function eliminates temperature related flick sounds in the pipes during the morning boost.

The final supply temperature setpoint is calculated from the:

- Outside reset control curve
- Parallel translation of control curve
- Night setback temperature
- Morning boost temperature.

The calculated setpoint is then kept within a minimum and maximum limit. The supply temperature is moved towards the final setpoint by a PI-regulator with adjustable P-band and I-time. The return temperature sensor is used to limit the maximum value of the return temperature. This limitation prevents the return temperature from rising above the set limit, by reducing the radiator supply temperature setpoint. The limitation setting follows a curve that is a damped function of the outside temperature. The return limitation curve is set by means of two reference points, one at outside temperature -10 °C and one at 10 °C

A pump alarm is tripped if the run indication from the pump in operation fails. The alarm time delay is 15 sec. The alarm is automatically reset when the faulty pump restarts. The run time alarm is also tripped if the accumulated run time for each pump exceeds a set (alarm) limit. The alarm time-delay is then 5 sec. The alarm is automatically reset when the logged run time is reset to zero from the OP-panel. If the alarm limit = 0, then the run time alarm is blocked. If a faulty reading from the outside temperature sensor occurs, then the latest "correct" value is saved and used instead of the measured value, to prevent the control loop from "running away".

The numbers and names of the terminal inputs as well as their descriptions are presented in Table 19 and Figure 17.

Table 19. Numbers and names of the terminal inputs and their descriptions.

Inputs:		
Term. no	*Term. name*	*Description*
1	C1	LonWorksTP/FT-10
2	C2	” ”
3	U1	Hws sensor
4	M	Measurement neutral
5	U2	Hws circ sensor
6	U3	Cold water sensor
7	M	Measurement neutral
8	U4	Pressure switch
9	B1	Rad supply sensor
10	M	Measurement neutral
11	B2	Outside sensor
12	B3	Rad return sensor
13	M	Measurement neutral
14	B4	Hex return sensor
15	X1	Run indication P1A
16	M	Measurement neutral
17	X2	Run indication P1B
18	X3	Pulse counter m³
19	M	Measurement neutral
20	X4	Pulse counter MWh

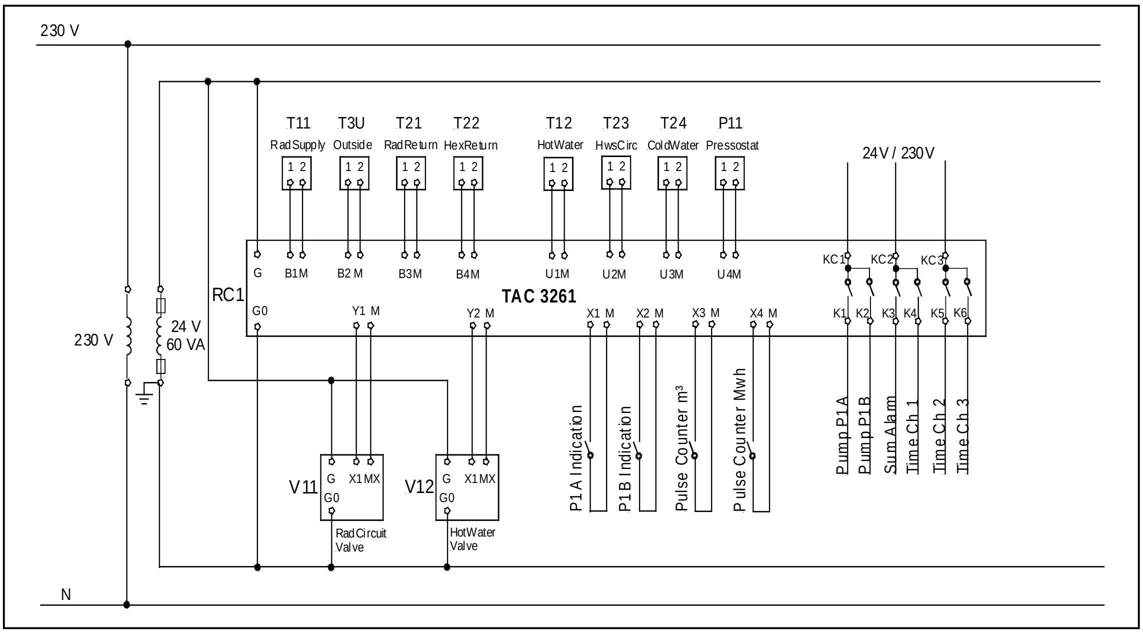

Figure 17. Input wiring diagram of the operation center.

3.6 Measurement and control systems

3.6.1 Local network communication system

The local network communication system (LNCS) is used for the measured data transmission in the MODiS DH-system. The remote control system is used for monitoring and controlling a plant, DH-network and different types of buildings. The operator can see what is happening to, for example, the heating, ventilation and climate, and as well, he can influence the operation directly, and change the set points if necessary. The operation unit consists of a personal computer (PC) with monitor, keyboard, mouse and printer. With colour graphics, the operator can control, regulate and monitor the entire system. Dynamic objects change during operation, reflecting either changes in the plant itself, or as a result of operator action at the operation unit. Changes in dynamic objects may take the form of changes in shape or colour, flashing, display of actual values or text that appears when changes happen.

The basic functions (e.g. TAC Vista®) include these modules:

- Colour graphics
- Alarm handling
- Access control
- Time control
- System documentation.

These additional elements are available (e.g. TAC Vista ®):

- Networks
- Communication:
  - Direct
  - Dialled
  - SNVT (Standard Network Variable Types) Direct
  - SNVT Dialled
- Trend logging
- Energy management
- Presentation generator
- Report generator
- Colour graphic editor
- Database generator
- Historical logging.

The basic functions provide the basic functionality needed to monitor and control a plant. It is a simple matter for the operator to monitor the plant and get information about values and alarms, in order to influence and control the plant directly. The basic functions are colour graphics, alarm handling, authorisation checking and time control.

The supplementary modules are tools for programming the system and for logging and displaying data from a plant. A network module of up to 16 operator units (with a maximum of 6 operator units communicating with process units) can be connected together in a network. The operator units communicate through the network module to the operator units within the same network. Process units are mostly directly connected to the operator unit (PC), sometimes operator or process units might be connected with a dial-up connection via modem. SNVT (Standard Network Variable Types) is used for units connected to a LonWorks network or via DDE-communication to/from external DDE-servers. The system can perform the download/upload of parameters and applications to/from several process units at the same time. (A number of operations, e.g. a cold start, can be performed using the same method.)

A trend logging module aquires and stores data over a selectable interval for later processing and trend display. Energy monitoring is used for monitoring energy consumption etc. There is also an analysis and budgeting tool. This program includes functions such as energy signatures, which generate an alarm when consumption deviates from the budgeted level of consumption.

A presentation module displays two- and three-dimensional diagrams of collected readings in the trend-logging module. Acquired data is presented dynamically as curves. A report generator is used to create reports, surveys and diagrams from readings taken from a plant. The colour graphics can be linked together to form a series of images of a plant. The database generator is an aid to the programming of all plant data, and includes features for re-using existing data. The colour graphics of a plant should be structured hierarchically, which is accomplished by using link areas to link one graphic to another. Starting from an overall view, the operator can use link areas to view plans of buildings and proceed from there to floors, rooms, air handling units or other equipment.

Alarm handling covers events in the system that trigger alarms, as well as operator actions. A change of status may also initiate a message to the operator. Alarms can be generated from digital or analogue signals. The operator defines alarm objects, which are then linked to signals in the system. Digital signals trigger an alarm when their states change. The values of analogue signals are compared with specified limits for high and low values and an alarm is tripped if the limits are violated. By pressing a function key or clicking a toolbar button the user can display an alarm survey. For every alarm object the operator can get statistical information in the form of the date/time of the last alarm and the number of alarms since the previous reset. The alarm statistics are also useful for preventive maintenance. Prioritised alarms can also be relayed to a printer and/or a cellular phone.

The remote communication system creates system documentation for testing, as well as the final documentation for a plant. The lists are displayed on the screen. They can be printed out and also stored as files. The following lists can be created:

- System configuration, where there is a schematic list describing how the plant is physically connected.
- List describing the processing units and their associated objects, with variables.
- List of objects (logical, physical or tables) with associated attributes. By selection the operator can choose one or more object, the desired object type and attributes for the objects.
- List of physical inputs and outputs for the units in the plant.
- Lists for testing the inputs and outputs of units in the plant.
- Display of forced variables for the units in the plant.

The principal schema of a local and remote control and measurements system is presented in Figure 18. The principal features of the local and remote control system are:

- Data transfer from the computer system for monitoring the parameters of the DH-system, using a DDE-link.
- Data transfer from all of the heat meters via LonWorks routers from the meter-bus as well as from serial ports RS-232C and RS-485.
- Export of selected system parameters to the numerical hybrid map and hydraulic calculation system.
- Transfer of selected data from the system to different users, using intranet, www and e-mai.l
- The system is to be open for any further integration.
- Data transfer to remote users via ISDN.

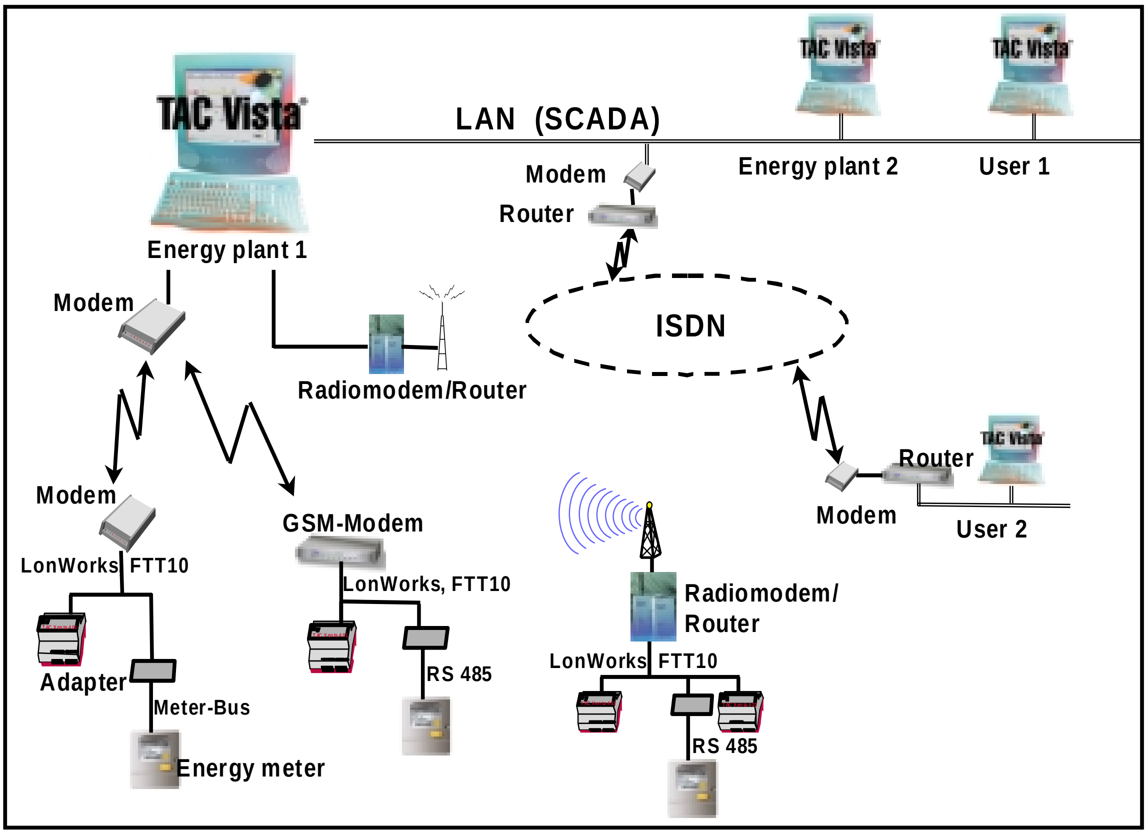

Figure 18. Control and measurement system of MODiS DH -system.

3.6.2 Remote network communication system

A remote network communication system (RNCS, e.g. TAC Vista system) consisting of several operator units is a so called peer-to-peer network, where all the operator units are equal and communication between them is initiated when needed, as shown in Figure 18. The database is decentralised and can be reached from all the nodes in the network. RNCS supports the following types of networks:

- LAN (Local Area Network), where the operation units for a plant are connected to a network.

- WAN (Wide Area Network). A WAN includes operator units from two or more local area networks (LAN).

The operator units can be connected to all local printers or to printers shared across the local network of which they are a part.

RNCS also supports wide area networks using ISDN communication (Integrated Services Digital Network). Through so-called ISDN routers, several local networks can be connected into a wide area network. Communication using ISDN has short connection times and high communication speed. Using for example the TAC Vista system, up to 16 operation units can be connected to the system, where a maximum of 6 operation units can communicate with the units in a plant. The TCP/IP network protocol is used for communication between operator units. Data from the units in the plant is stored in the operator units to which the units are connected, but can be reached from every operation unit in the network. Each operator unit (PC) in a local area network must have the network module installed. A network adapter board and the TCP/IP network protocol must also be installed on each of the operation units.

When using a wide area network (WAN) and ISDN service, an ISDN router are needed for each of the local area networks (which contain the operator units that are to be included in the wide area network). The ISDN routers are programmed to communicate with each other in order to connect the local area networks into a wide area network. The operator units and the ISDN router should have specified IP addresses in the local area networks. An ISDN service that complies with the EURO ISDN standard should be used. The service should have at least 2 B channels (B=bearer) for the communication of data. A wide area network can also be achieved using modem connections between the operator units. An operator unit can also be remotely connected to a system via modem. The connection is established by means of special software, enabling the user to take control of an operator unit on the network.

3.7 Renovation of a target area DH-system

The most important task in renovation is to make the DH-network watertight and reduce heat loss by fitting better insulation. The outgoing temperature in the pipeline should be limited to 100–120 °C because of heat losses in pipelines. Then a temperature of 80–90 °C for the radiator system and 55–60 °C for hot tap water in the buildings can be guaranteed. Heat losses are a function of outdoor, supply and return pipeline temperature. A temperature reduction of 10 °C in the supply pipeline can save several ten percents of the annual heat losses in a DH-network.

The pressure level of pipelines should be limited to 1,6 MPa or less. In that way the DH-network can be constructed more lightly, and the investments will be lower. In long pipelines, booster pumps are used to lower maximum pressure level. The pumps should be speed controlled because of short-term variations in the district heating load. Long-term control is achieved by temperature control in the boiler plants. The hydraulic stability of the network is also better controlled, if the pumps are operated by remote control from the central operation centre.

The other task is to separate consumers from the network by using a heat exchanger. In that way oxygen diffusion from consumer equipment and pressure variation problems can be avoided. The DH water should also be treated, with the addition of oxygen inhibitor to prevent corrosion, and toner to detect water leakage. If the warm water is to be produced in the buildings, it must be ensured that the capacity and condition of the cold water pipelines are adequate. The substation can usually be situated in the ejector room and from there, connected to the building system. An expansion tank has to be connected to the heating system of the buildings. In general, buildings will also require basic renovation (windows, doors, more insulation into the walls and roof, machine driven air conditioning with a recuperator, new water fittings, etc) for lowering heat demand.

There might be some problems in areas where the DH-water flow is regulated and where there exists a mixture of both indirect and direct connection to the consumer. If the pressure difference over the ejector to the consumer is too low, the ejector will not work. Such a problem would have to be solved in some way, for example by intalling flow limiting devices before consumers that have a modern substation or by installing a booster pump driving with constant pressure difference before the consumer group using ejectors.

Large district heating systems should be divided into renovation areas that are separated from the mother DH-system by a heat exchanger. The local area pipeline systems will be renovated as a closed-loop system with MODiS components and modules. The water will be taken from the mother DH-system and fed through a water handling unit into the local pipeline system. A gas- or oil-fired peak boiler could be built into the local area system for extra reserve and peak hours capacity. The renovation work should be started from the top of the network branches and then progress to the body pipelines, the base load boiler plants and the combined heat and power plants. The peak boilers, water handling units and heat exchanges, which are housed in containers, can be moved on following the renovation, when they are no longer needed.

4. Information and management

4.1 Information systems

The district heating system and the entire energy system need a lot of measurements and control signals, and therefore need instruments to handle those data flows and to make decisions based on that information. The media for controlling the data transmission between different points in the system is presented in chapter 3.

The data transmission requirements in the MODiS software group have been defined. The data banks and software packages for DH-network calculations are presented in Figure 19.

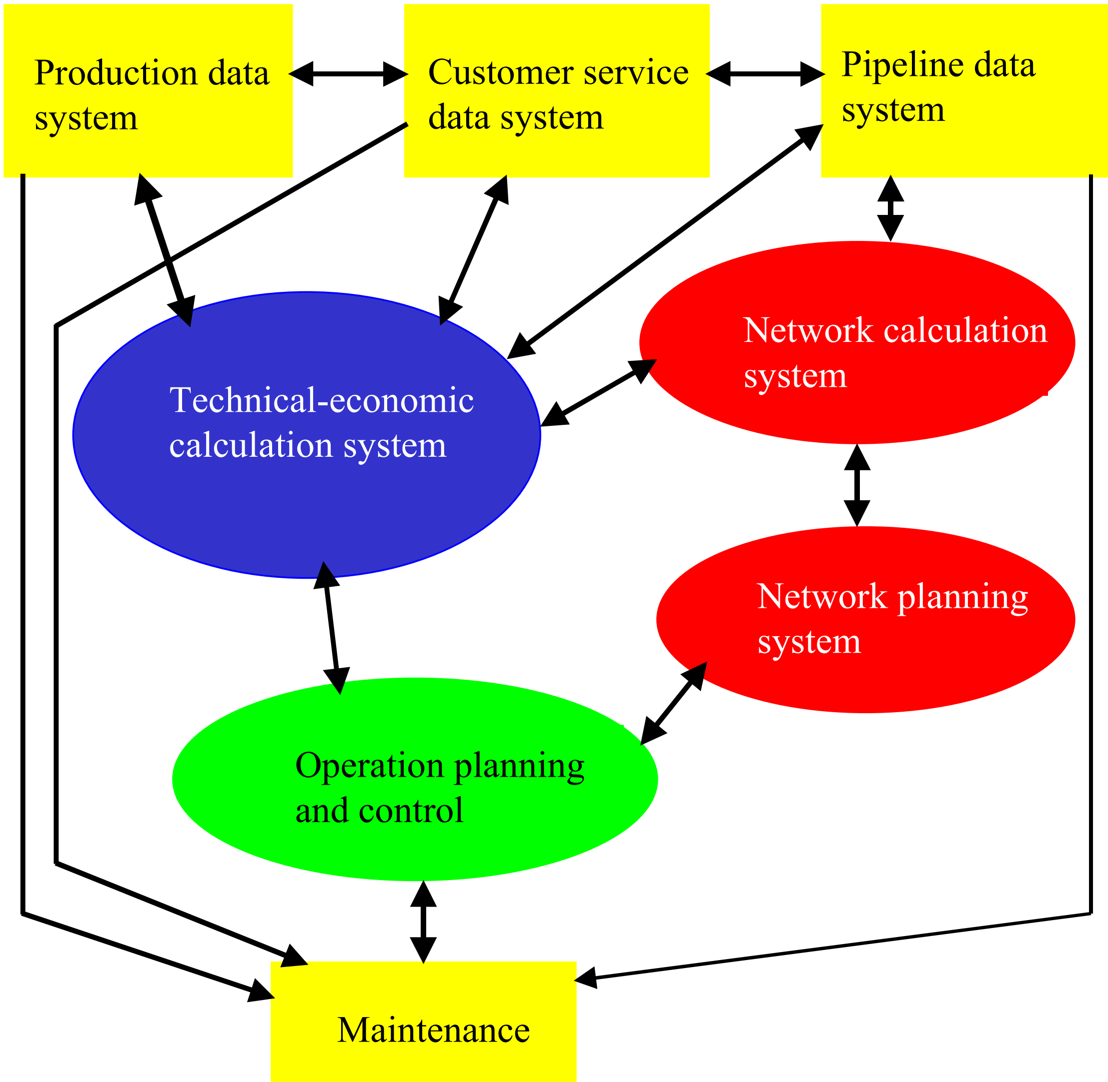

Figure 19. Data banks and software packages for DH-network calculations.

The following information is needed for the input and output of data for the DH-network calculations. Communication between software programs is presented in Figure 20. Descriptions of the software products are presented in Appendix A.

Network calculations

Input:

- Network data system: network topology, pipe data
- Network planning: structure of the network
- Customer service : thermal output capacity, energy-/effect line, cooling
- Maintenance: equipment data
- Producer: specifications of the pipe-elements.

Output:

- Network data system: dimensions of pipelines
- Economic tools: calculated output, lengths and dimensions of pipelines.

Network planning

Input:

- Network calculation: designed thermal output
- Producer: characteristc data of pipe-elements
- Customer service: customer data, thermal input data of customers
- Measuring dep.: new pipeline measuring in the field (central pipeline in the field), old pipeline measuring in the field (control of the central pipeline in the field).

Output:

- Network data system: network topology, pipe data
- Map information network topology, pipe data
- Network calculation: network topology, pipe data
- Storage/work control: specifications and number of pipe-elements, earth-moving mass
- Contractor: field data (data for marking out the pipelines in the field)
- Maintenance: equipment data.

Network database

Input:

- Network planning network data
- Customer service: customer data
- Maintenance: service points and timetable.

Output:

- Map information: network topology, pipeline data
- Network calculation: network topology, pipe data
- Maintenance: service points.

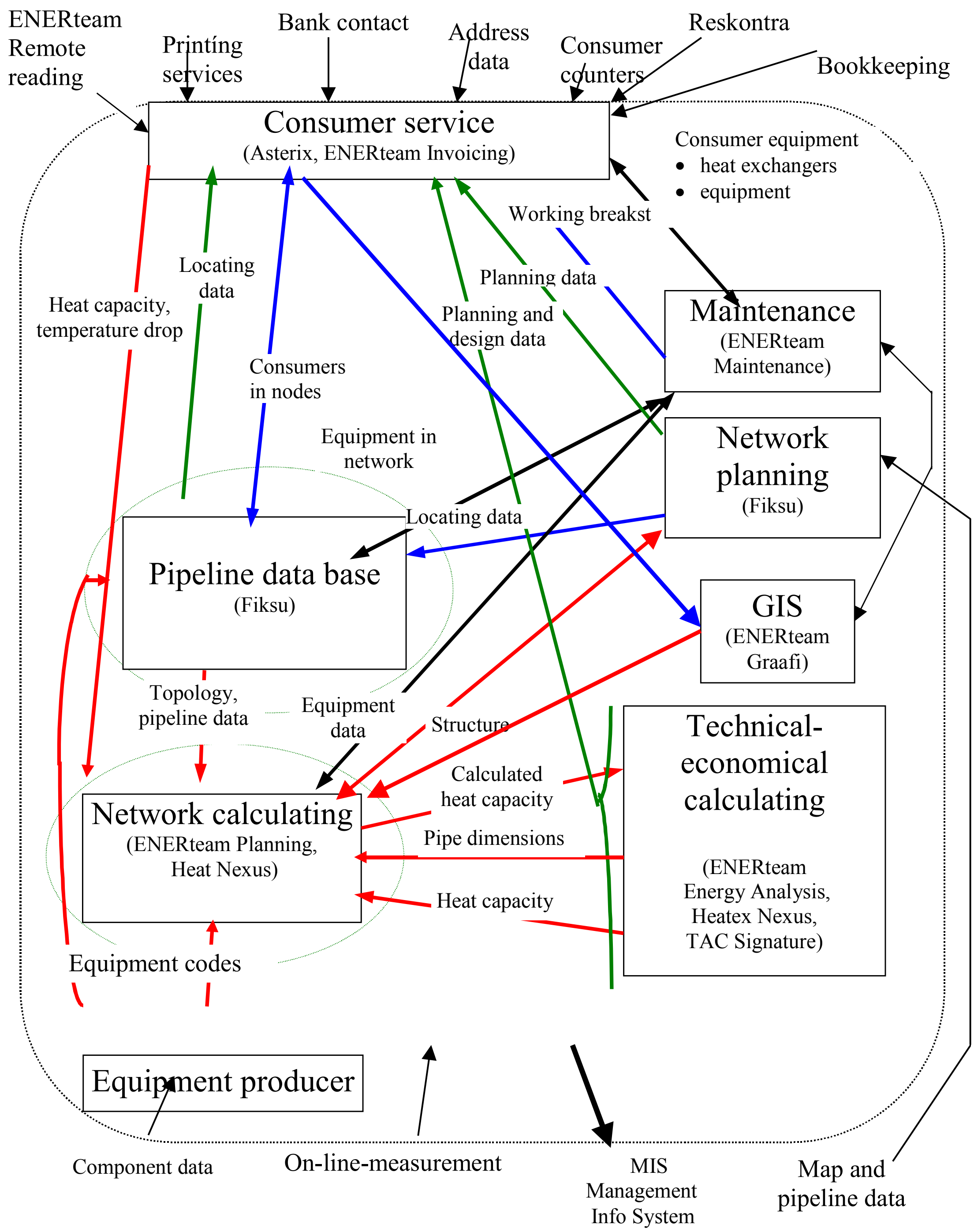

Figure 20. Communication between software programs.

Maintenance

Input:

• Network data base	equipment in the network
• Customer service:	customer equipment, seasonal breaks from working
• Cost	maintenance cost for accounting
• Equipment data:	data from planning and producers' data base, codes for equipment.

Output:

• Cost:	maintenance cost of plants and equipment, cost monitoring.

Customer service

Input:

• Maintenance:	customer equipment, interruption in use
• Consuming:	data from consumer energy counter.

Output:

• Consumer data:	network planning, energy analysis, maintenance
• Consumer equipment:	maintenance
• Consumer:	effect, energy, water flow and cooling (ΔT) for network calculations and energy analysis
• Measurement data	maintenance
• Counter:	reskontra, accounting, direct payment and output service programs
• Consumer data:	hand terminal, remote reading
• Printed lists:	readable lists.

4.2 Management system

The management system consists of, in addition to general management within the field of district heating, comprehensive coverage of strategic and operational planning, operation in practice, maintenance, training, project planning and management, customer management, as well as economic and financial issues. The DH-systems should be designed according to customer needs. The MODiS management package can provide diverse benefits based on wide professional knowledge and broad based practical experience.

MODiS is designed to improve the operational, financial and technical performance of district heating organisations. The following list gives the points covered by MODiS. Service benefits are as follows:

Benefits of the services

- Strategic benefits
  - Satisfied customers
  - Profitability
  - High efficiency
  - Overall reliability
  - Clean environment.

- Operational benefits
  - Improved organisational and personal knowledge
  - Improved organisational and personal skills and readiness
  - Access to new solutions
  - Improved exchange of experience and information
  - Improved motivation.

Target customer groups of MODiS are listed below.

Customers of the services

- Energy and specialist companies
- Municipalities
- Ministries and authorities
- Educational institutions
- Energy associations
- Consultants.

A training and development matrix is presented below. The target groups are divided into different levels and training packages are presented for each level.

Training and development matrix

Levels	Strategies	Organisation	Economy	Customer	DH.network	Production	Operation	Environment	Target Groups
Top Level	Str	Org	Econ	Cust	Net	Prod	Oper	Env	Top Management
Specific level			Econ	Cust	Net	Prod	Oper	Env	Managers and Specialists
Practical				Cust	Net	Prod			Mid/lower Management
level					Net	Prod			Supervision

The target groups and goals for each level are as follows:

Levels, target groups and goals

- ♦ Top level
  - Target group: Top management
  - Goal: Improved knowledge and skills in strategic, business and technology management

- ♦ Specific level
  - Target group: Managers and specialists
  - Goal: Improved specific and general knowledge and skills in operational and special tasks and duties

- ♦ Practical level
  - Target group 1: Mid / lower management
  - Goal: Improved practical and general knowledge and skills in daily tasks and duties
  - Target group 2: Supervision
  - Goal: Improved practical knowledge and skills in daily tasks and duties.

The content of training packages is presented in the following list:

Main issues

- ♦ Strategies
  - Strategic planning
  - Implementation of strategies
  - Management
  - Management tools

- ♦ Organisation
  - Ownership
  - Corporate development
  - Organisational structures
  - Administration

- ♦ Economy
  - Financial administration
  - Financial planning
  - Operation
  - Tariff planning and pricing

- The customer
    - Marketing and customer relations
    - Processes and services
    - Metering and billing
    - Customer equipment
    - Tariff policies
    - Energy saving

- DH Network
    - Planning
    - Structures
    - Construction systems
    - Maintenance

- Production
    - CHP combined heat and power production
    - Boiler plants
    - Optimisation and efficiency
    - Maintenance

- Operation
    - Production and distribution control
    - Automation and control systems
    - Automation maintenance

- The environment
    - Technologies
    - Monitoring
    - Legislation
    - International agreements.

The management packages can be tailored to the customer's needs and implemented step by step with the aim of optimising the whole administrative operation.

5. Environmental aspects of district heating

A number of factors must be weighed when determining whether or not a district heating (DH) or district heating and cooling (DHC) system should be constructed in a particular community. These factors include local economic and climatic conditions, the viability of competing alternative energy supply systems, local energy production and utilisation efficiency considerations, environmental benefits, and differing producer and user perspectives on the significance of the benefits of district heating systems.

The following themes are discussed in this section:

- Environmental impacts that are associated with human life on this planet
- Specific aspects of district heating systems associated with environmental effects
- Environmental benefits related to the use of district heating systems

5.1 Introduction to environmental issues

5.1.1 Air pollution

5.1.1.1 Types of air pollution

Air pollution [7] occurs when the concentrations of certain substances become high enough to contaminate the atmospheric environment. Air pollutants can be gaseous, liquid or solid in form, and can come from natural as well as human sources. Examples of natural sources of air pollution include forest fires, pollen, volcanic emissions, and dust. Human sources of air pollutants include emissions from industry, agriculture, forestry, transportation, power generation, and space heating. In general, two types of air pollutants, primary and secondary, have been recognized.

Primary pollutants

Primary pollutants consist of materials (gases, liquids, dust and other solids) that enter the atmosphere through natural and human-made events. The main primary pollutants influencing our atmosphere in order of emission (by weight) are carbon monoxide, sulphur oxides, nitrogen oxides, volatile organic compounds, and particulate matter.

Volatile organic compounds are organic molecules that are mainly composed of carbon and hydrogen atoms (hydrocarbons). The most common volatile organic compound released into the atmosphere is methane. Methane poses no direct danger to human health, however, it does contribute to global warming through the greenhouse effect. Industrial activity and transportation are the major sources of this type of air pollution.

Particulate matter includes common irritants like smoke, pollen, and dust, which can affect the human respiratory system. In cities, particulate matter may also include particles composed of iron, copper, nickel and lead. These particles influence the respiratory system immediately, and make breathing difficult for people with chronic respiratory disorders. Airborne lead, formed by the burning of leaded petrol, can accumulate in the tissues and bones of humans and other living organisms.

Secondary pollutants

Secondary pollutants consist of primary pollutants that have reacted with each other or with the basic components of the atmosphere to form new toxic substances. In cities, the emissions from cars and industries combine with the help of light energy from the sun to produce photochemical smog. Photochemical smog is toxic to animal and plant life, and damages paint, rubber, and plastics.

5.1.1.2 Photochemical smog

The industrial revolution has been the central cause for the increase in pollutants in the atmosphere over the last three centuries. Before 1950, the majority of this pollution was created from the burning of coal for energy generation, space heating, cooking, and transportation. Under the right conditions, the smoke and sulphur dioxide produced from the burning of coal can combine with fog to create industrial smog. In high concentrations, industrial smog can be extremely toxic to humans and other living organisms. Today, the use of other fossil fuels, nuclear power, and hydroelectricity instead of coal has greatly reduced the occurrence of industrial smog. However, as has been mentioned, the burning of fossil fuels like gasoline can create another atmospheric pollution problem known as photochemical smog.

Photochemical smog is a condition that develops when primary pollutants (oxides of nitrogen and volatile organic compounds created from fossil fuel combustion) interact under the influence of sunlight to produce a mixture of hundreds of different and hazardous chemicals known as secondary pollutants. Table 20 describes the major toxic constituents of photochemical smog and their effects on the environment.

Table 20. Major chemical pollutants in photochemical smog: Sources and environmental effects.

Toxic Chemical	Sources	Environmental Effects	Additional Notes
Nitrogen Oxides (NO and NO_2)	- combustion of oil, coal, gas in both automobiles and industry - bacterial action in soil - forest fires - volcanic action - lightning	- decreased visibility due to yellowish color of NO_2 - NO_2 contributes to heart and lung problems - NO_2 can suppress plantgrowth - decreased resistance to infection - may encourage the spread of cancer	- all combustion processes account for only 5% of the NO_2 in the atmosphere, most is formed from reactions involving NO -concentrations likely to rise in the future
Volatile Organic Compounds (VOCs)	- evaporation of solvents - evaporation of fuels - incomplete combustion of fossil fuels - naturally occurring compounds like terpenes from trees	- eye irritation - respiratory irritation - some are carcinogenic - decreased visibility due to blue-brown haze	- the effects of VOCs are dependent on the type of chemical - samples show over 600 different VOCs in atmosphere - concentrations likely to continue to rise in the future
Ozone (O_3)	- formed from photolysis of NO_2 - sometimes results from stratospheric ozone intrusions	- bronchial constriction - coughing, wheezing - respiratory irritation - eye irritation - decreased crop yields - retards plant growth - damages plastics - breaks down rubber - harsh odour	- concentrations of 0.1 parts per million can reduce photosynthesis by 50% - people with asthma and respiratory problems are influenced the most - can only be formed during daylight hours
Peroxyacetyl Nitrates (PAN)	- formed by the reaction of NO_2 with VOCs (can be formed naturally in some environments)	- eye irritation - high toxicity to plants - respiratory irritation - damaging to proteins	- was not recognized until detected in smog - higher toxicity to plants than ozone

To begin the chemical process of photochemical smog development the following conditions must occur:

- Sunlight
- The production of the oxides of nitrogen (NOx)
- The production of volatile organic compounds (VOCs)
- Temperatures greater than 18 degrees Celsius.

5.1.1.3 Acid deposition

Acidic pollutants can be deposited from the atmosphere to the Earth's surface in wet and dry forms. The common term to describe this process is acid deposition. The term acid precipitation is used to specifically describe wet forms of acid pollution that can be found in rain, sleet, snow, fog, and cloud vapour. An acid can be defined as any substance that when dissolved in water dissociates to yield corrosive hydrogen ions. The acidity of substances dissolved in water is commonly measured in terms of pH (defined as the negative logarithm of the concentration of hydrogen ions). Precipitation is considered to be acidic when its pH falls below 5.6 (which is 25 times more acidic than pure water).

Acid deposition can form as a result of two processes. In some cases, hydrochloric acid can be expelled directly into the atmosphere. More commonly it is due to secondary pollutants that form from the oxidation of nitrogen oxides (NOx) or sulphur dioxide (SO_2) gases that are released into the atmosphere. The process of altering these gases into their acid counterparts can take several days, and during this time these pollutants can be transferred hundreds of kilometers from their original source. Acid precipitation formation can also take place at the Earth's surface when nitrogen oxides and sulphur dioxide settle on the landscape and interact with dew or frost.

Several processes can result in the formation of acid deposition. Nitrogen oxides (NO_x) and sulphur dioxide (SO_2) released into the atmosphere from a variety of sources can fall to the ground simply as dry deposition. This dry deposition can then be converted into acids when these deposited chemicals meet water. Most wet acid deposition forms when nitrogen oxides (NO_x) and sulphur dioxide (SO_2) are converted to nitric acid (HNO_3) and sulphuric acid (H_2SO_4) through oxidation and dissolution. Wet deposition can also form when ammonia gas (NH_3) from natural sources is converted into ammonium (NH_4).

More than 90% of the sulphur in the atmosphere is of human origin. One of the main sources of sulphur is coal burning. Coal typically contains 2–3% sulphur, and when it is burned a certain amount of sulphur dioxide is liberated depending on the purification technology.

Some 95% of the elevated levels of nitrogen oxides in the atmosphere are the result of human activities. The remaining 5% comes from several natural processes. One source of nitrogen oxides is the combustion of fuels e.g. oil, coal and gas.

Acid deposition affects the environment in several different ways. Acid deposition can influence aquatic ecosystems by lowering their pH. However, not all aquatic systems are affected equally. Streams, ponds or lakes that exist on bedrock or sediments rich in calcium and/or magnesium are naturally buffered from the effects of acid deposition. Aquatic systems on neutral or acidic bedrock are normally very sensitive to acid deposition because they lack the basic compounds that buffer acidification. In less buffered soils, vegetation is affected by acid deposition because, for example:

- Increasing acidity results in the leaching of several important plant nutrients, including calcium, potassium, and magnesium. Reductions in the availability of these nutrients causes a decline in plant growth rates.

- The heavy metal aluminium becomes more mobile in acidified soils. Aluminium can damage roots and interfere with the plant uptake of other nutrients such as magnesium and potassium.

- Reductions in soil pH can cause germination of seeds and the growth of young seedlings to be inhibited.

- Many important soil organisms cannot survive in soils below a pH of about 6.0. The death of these organisms can inhibit decomposition and nutrient cycling.

- High concentrations of nitric acid can increase the availability of nitrogen and reduce the availability of other nutrients necessary for plant growth. As a result, the plants become over-fertilized by nitrogen (a condition known as nitrogen saturation).

Acid deposition also affects a number of inanimate features of human construction. Buildings and head stones that are constructed from limestone are easily attacked by acids, as are structures that are constructed of iron or steel. The paint on cars can react with acid deposition. Many of the churches and cathedrals in Europe are under attack from the effects of acidic deposition.

5.1.1.4 Global climate change

The overall climate system, despite the variations, is generally in a state of equilibrium. That is, the rate of solar energy input from the sun is balanced by an equal amount of energy released (as infrared radiation) back to space. As long as the factors that maintain this equilibrium remain constant, global temperatures are expected to, on average, remain relatively constant. The observed global warming trend is therefore thought to be caused by a shifting of the equilibrium conditions of the past, as a result of the build-up of certain gases in the atmosphere (some naturally occurring, others not). Such gases inhibit the release of infrared radiation, causing the "greenhouse effect". These "greenhouse gases" include carbon dioxide (CO_2), methane (CH_4), nitrous oxide

(N_2O), ozone (O_3) and chloroflurocarbons (CFCs). Their presence in increasing or decreasing concentrations changes the equilibrium point and impacts our environment.

Considerable debate does exist within the scientific community as to the significance or overall impact this warming trend will have on our environment. Some believe that, as a result of global warming conditions, the earth's average temperature could increase anywhere from l.5°C to 4.5°C in less than fifty years. Such an increase could cause ocean levels to rise considerably causing flooding of coastal inhabited areas; lake levels could drop creating a shortage of fresh water and a degradation of water quality; storms, floods, erosion, droughts could all be more severe and frequent; and plant and wildlife inability to adapt to these relatively sudden changes to their habitat, and possibly major climate changes, may imperil many species. Nowadays, most agree that intensifying conservation efforts and reducing emissions to the atmosphere are necessary means to reduce environmental threats.

5.2 Heat production and the environment district heating and CHP technology review

5.2.1 Energy production units

The heat production units in a district heating system can be a combination of heating-only plants, combined heat and power production plants, waste heat recovery plants, or auxiliary heating units (for peak use and standby purposes). [8]

5.2.2 Heating-only units

For small district heating systems, usually called block or group central heating systems, that serve a small number of adjacent buildings, the most common heating unit is a packaged boiler consisting of a hot water boiler with its burner and feed system, primary boiler circuit, distribution pump, pressurizing system, cold water controls and associated electric circuits. Such boilers tend to range in size from 1 MW to 20 (50) MW but could be larger, and can be fired by oil, gas, coal, wood, peat or refuse, or can function as waste heat recovery boilers coupled with gas turbines or refuse incineration. In addition, they can be utilised as transportable boilers for use in the initial stages of a district heating development or as stand-by and peak boilers. Overall efficiency can be as high as 90% at the station, but in poor conditions can fall below 70 per cent.

5.2.3 Electricity-only units

For modern coal-fired power stations of 200–600 MW using seawater as coolant, the maximum conversion efficiencies obtainable will be no better than about 45% in conventional plants, but can be 50% in modern power plants. These levels can only be realised at steam pressures as high as 240 bar, temperatures of 560°C, and with a single reheat of steam.

The use of natural gas in a combined cycle power plant makes it possible to increase the maximum efficiency to approximately 54% due to the higher temperature of the working medium. In a combined cycle plant a gas turbine is placed before a boiler producing steam to operate a steam turbine. The higher the temperature of the working medium (gas or steam) and the lower the temperature of the coolant in producing mechanical energy in a turbine or combustion engine, the higher the output of mechanical energy or electricity. These are important factors when considering combined heat and power (CHP) systems, in which case the coolant is the district heating water.

5.2.4 Combined heat and power production units

Energy production from a combined heat and power plant is usually based on steam turbines, open cycle combustion turbines, combined cycle turbines, and diesel engines. These systems are appropriate for residential, commercial, and industrial applications. The steam turbine system has been the dominant design for combined heat and power plants. They have a relatively high overall efficiency, are very reliable and can use a variety of fuels. The units are generally in the size range of 200 MWe to 300 MWe, but can be below 10 MWe and even as low as 1 MW. Two types of steam turbines are used, extraction and back-pressure turbines.

The **extraction CHP** is characterized by a variable ratio of power to heat generation. The DH water is indirectly heated by steam extracted from the turbine. The rest of the steam is condensed in the condenser, and when more hot DH water is produced, less heat energy is lost in the condenser. The steam turbine systems are generally coal- or gas-fired. In a **back-pressure CHP**, the heat of steam from the turbines is utilized by heating the supply water of a DH system. In the back-pressure plant the ratio of electricity to heat production is fixed. This is a disadvantage that can be somewhat alleviated by using heat accumulators. Efficiency can be as high as 88% in a back-pressure operation. In **combined cycle CHP plants,** the hot flue gas from the gas turbine is utilised in the boiler to produce steam for the steam turbine. It is necessary to use either natural gas or fuel oil for the gas turbine, whereas it is possible to use either gas or coal as supplementary fuels for the steam boiler. **Small-scale CHP plants** can be placed close to the heat consumers. The costs of the transmission pipe system will thus be relatively low compared to the case of large plants. As examples, combustion engines are now available in sizes from about 15 MW down to a few kW. Electrical efficiencies range from about 30% for the smallest and 35–40% for ignition lean-burn gas engines. For large diesel engines the electrical efficiencies can be as high as 50%. Due to the utilisation of heat it is possible to attain a total efficiency above 85% and an el/heat-ratio ranging from 0.85 to 1.0. In a CHP plant based on a gas-fired gas turbine, gas turbines range in size from 200 kW to 220 MW. Their electrical efficiencies are about 20% for the smallest units to 40% for the largest. At a medium-size local CHP plant equipped with a waste heat recovery boiler, total efficiencies above 85% are possible and el/heat-ratios are in the range of approx. 0.5–0.6. Biomass or coal-fired CHP plants use wood chips, straw, waste or coal to fuel a steam boiler supplying a back-pressure steam turbine or steam engine.

Industrial combined (on-site) production facilities are generally dimensioned on the basis of process heat (usually steam) requirements, and/or the heating and cooling needs in buildings. Excess power can be distributed to the nearest utility grid or can be purchased from the grid if required. The technology is the same as that used for combined DH-heat and power production units.

5.3 Environmental benefits associated with DH systems district heating and CHP technology review

In this section, the potential environmental benefits of DH systems, compared to conventional or non-district systems, are identified. These benefits are derived, partly due to the difference between district and conventional systems and, partly due to the stand-alone features of DH systems. IEA, General Description of District Heating and Combined Heat and Power Systems [6].

5.3.1 Structural benefits

Partial Load Efficiency

In general, DHC plants operate at higher efficiencies under partial thermal load conditions, compared to conventional systems. This is because conventional systems typically employ only one boiler unit. While such units must be rated for peak seasonal and hourly loads, they actually operate most of the time at much lower partial loads. Operation at these lower loads can result in much lower operating efficiencies. District systems with multiple units can optimize overall plant efficiency by selectively operating fewer units at or near maximum efficiency during partial load conditions.

Improved efficiency means less fuel use for the same amount of energy produced, which in turn results in the conservation of fossil fuels, reduced emissions, and improved air quality.

DH integration with power generation

District heating systems are well suited for combination with electric power in co-generation plants. The mixture of these two energy production/utilisation schemes results in a substantial improvement in overall energy conversion efficiency. Conservation of fossil fuels and a reduction of combustion-related emissions are the resultant benefits of such a DH system.

Biomass combustion

Biomass combustion is considered to be a means of zero net production of CO_2.

Limited number of emission sources

The centralized nature of DH energy production plants results in a reduced number of emissions sources in a community. This introduces the potential for several direct benefits. Firstly, large facilities are much more suitable for the incorporation of sophisticated pollution control technologies than individual buildings. Secondly, the exhaust stacks, characteristic of large energy production facilities, are relatively high and therefore the exhaust gases are well mixed with large volumes of the ambient air before deposition of the pollutants.

Superior operating and maintenance

Large, centralized plants, such as DH facilities, typically use better operating and maintenance practices than do small individual building systems. Large facilities have trained staff, as well as computerized monitoring equipment available to continuously monitor system operations, ensuring that performance specifications are being met on a long-term basis.

Technical upgrades

Centralized DH facilities permit the adoption of developing thermal energy production and emission reduction technologies. Examples of such developments include:

- fitting new or retrofitting old boilers with low NO_x burners, flue gas recirculation or selective catalytic reduction techniques to reduce NO_x levels.

- flue gas heat recovery scrubber systems to minimize SO_2 emissions (reduction of up to 90%)

- separating particulate matter (by electrical precipitators up to 99%).

There are also many other indirect environmental benefits of DH related, for example, to noise, fuel storage, transportation and employment.

5.3.2 CHP benefits

In conventional power generation 30–50% of the energy consumed is converted to electricity, the remainder being rejected to the environment as heat, mainly through cooling towers or condensers. The fuel efficiency of a CHP plant can be around 80–88%. Figure 21 compares the energy flows in separated production with the CHP production case. In both cases the same amount of district heat (56) and electricity (29) is generated. The demand for fuel in the former case is 152 compared with 100 in the CHP case. Correspondingly, the fuel efficiency is 56% for separated production and 85% for CHP production.

The increased fuel efficiency of CHP gives it a potentially useful role in helping to resist global warming, through reduction of the emission of carbon dioxide (CO_2). Depending on the fuel being displaced by CHP, the reduction in CO_2 emissions is 13 to 57%. According to a rule of thumb the average CO_2 reduction is around 500 kg/MWh. The value is higher in coal based production and lower in gas based production. Figure 22 (Lehtilä 1997) shows a comparison of CO_2 emissions per unit of produced energy between condensing power plants and CHP plants, and between separated power and heat generation and CHP generation. CO_2 emissions have been allocated to power and heat with weights 2:1 at the CHP plant. The reduction is greatest (quantitatively and proportionally) in the case of coal fuel when a CHP plant displaces a condensing plant. The right hand side of the figure shows that the emissions reduction achieved by CHP generation is nearly 30%.

In another study [9] are shown different cases, where gas-fired CHP displaces separate generation (Table 21). Depending on the type of power station and the type of fuel the CO_2 reduction can range from 13 to 57%.

Increased fuel utilisation efficiency and reduced emissions from CHP plants can also help to reduce acid rain by cutting emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x). CHP also lowers emissions of particulate matter and heavy metals. In a study related to the improvement of the Polish energy system by the Netherlands government two old coal-fired heating boilers were replaced with a small-scale gas-fired co-generation plant (UN, Framework Convention on Climate Change (UNFCCC), Reduction of Atmospheric Pollution through Modernisation of the Energy Supply System in the Town of BycZyna [10]). Annual heat demand is 17 TWh, and thermal power is 2.5 MW. By fuel switching and by CHP production enormous emission reductions can be achieved. CO_2 emission is reduced by 34% from 4 800 kg/a to 3 200 kg/a, N_2O emission is reduced from 7 100 kg/a to 1 100 kg/a by 85%, SO_2 emission reduces by 25 000 kg/a to zero, and dust lowers from 9 900 kg/a to zero, too.

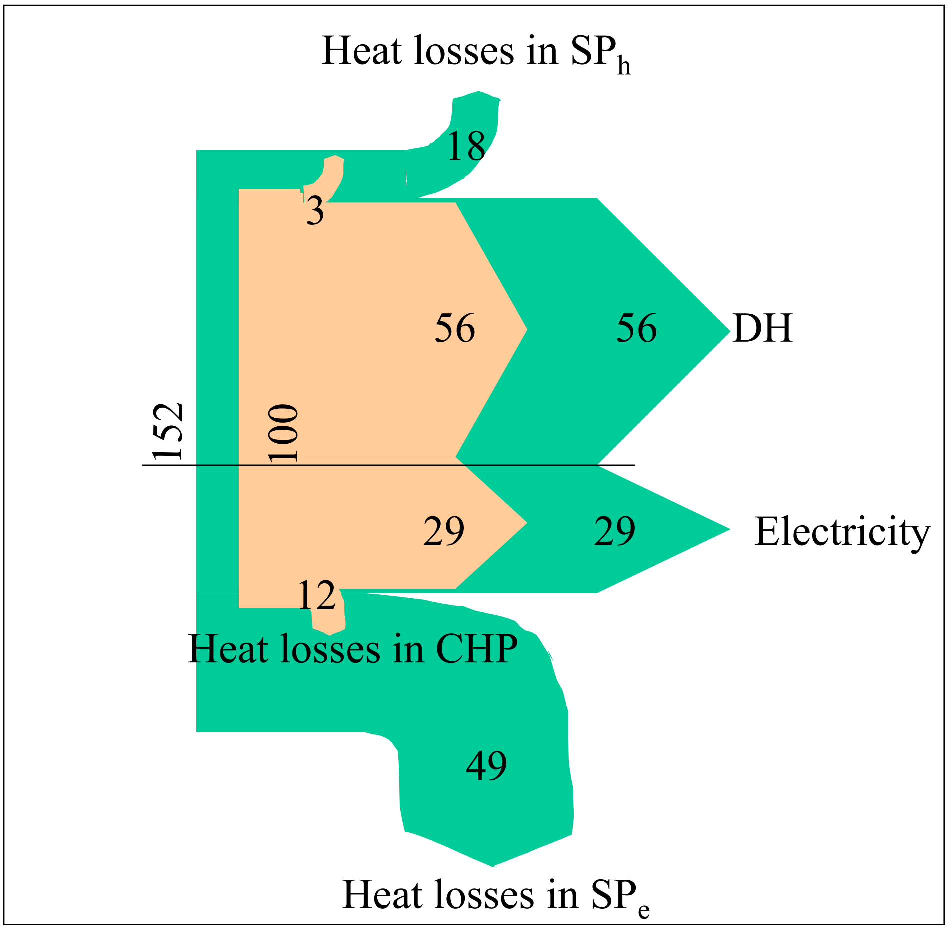

Figure 21. Energy flows in separated production and in combined heat and power production. SP_h =separated heat production, SPe = separated electricity production, DH = district heat production, CHP = combined heat and power production.

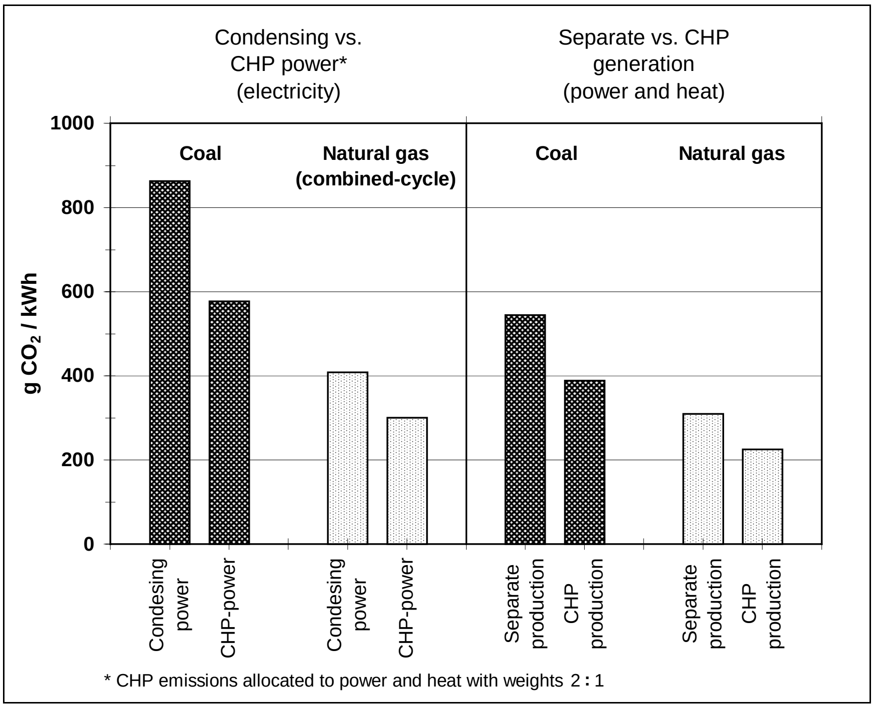

Figure 22. Comparison of CO_2 emissions per produced energy between condensing power plants and CHP plants, and between separate power and heat generation and CHP generation.

Table 21. Impact of gas-fired CHP on CO_2 emissions.

Displaced power station fuel	Coal	Coal	Gas	Gas
Displaced boiler fuel	Coal	Gas	Coal	Gas
CO_2 emission reduction, tC/MWe/a	2833	1622	1486	315
Percentage CO_2 reduction	57	44	41	13
Assumptions	Heat/Power ratio 3:1 Load factor 90% CHP efficiency 81% Displaced boiler efficiency 80%(coal), 86% (gas) Displaced public electricity supply generaton efficiency 34% (coal), 50% (gas) Electricity transmission/distribution loss 8%			

6. Results of MODiS research work

6.1 General

The MODiS project contains a lot of individual research and development work on both the MODiS modules and on the products, made by the partner companies, that are included in the modules. General research and development work, which served all the MODiS partners, was performed by VTT Energy and TUT (Tampere University of Technology). The partner companies gave their knowledge to the common table and in turn received information about how their products would perform in the MODiS DH-system. In this chapter some MODiS common results of work performed by VTT are given.

6.2 MODiS concept model

6.2.1 Concept model description

Planning of the district heating system is not very complicated, if there are only branches and not loops in the network. A lot of equipment data is also required for planning a simple DH-network comprising only branches. A calculating tool for rough planning of a MODiS district heating system, called MODiS-Concept tool (version 2.0), has been developed by VTT Energy. The tool can also be used for DH-systems with loops by cutting the loops open so they can be analysed as branches. The MODiS-Concept tool can be saved to the harddisk of a portable PC so that anyone can sit down with the customer, fill in the system questionnaire table in the PC and evaluate the construction and budget price of the new or renovated DH-system.

The model is made by Excel table calculation. The user fills the required input data in the left side table on the main level and the model will calculate the results on the right side table as shown in Figure 1. More detailed tables are presented later in this chapter with the MODiS Case Study calculation. The basic data of the model is located in the SUB-level. The basic data can also be displayed as tables and figures for hand calculation in the blank output table. The nodes of the DH-network and the names of pipe-elements are not required, but would be useful later on, when discussing the details of the pipeline network with the customer.

As a result, the MODiS Concept model can produce the budget for the DH-system divided into boiler plant, district heating network and consumer equipment. Size, type and the quantity of pipes and equipment are calculated as well. At the end of the calculation the annual investment and running cost of the system as well as the cash flow with the decided district heating tariff are evaluated.

Consumer

The consumers are connected indirectly via a heat exchanger to the DH-system. The inside heating system of the house can work at a different pressure level to the DH-delivering system. Russian radiators are planned to work at a temperature of 90 °C. The surface area of the radiators are large enough to also perform adequately at the desired temperature of 80 °C with a lower flow of water. Thermostatic valves are recommended for better temperature distribution inside the house. Hot tap water will be produced from water coming from the cold water pipeline. The capacity of the cold water pipeline must therefore be ensured and, if required, renovated. The heating system in the buildings must be provided with an expansion tank. The technical planning of the consumer substation is made with the Cetemit 5.0 planning tool of Cetetherm Ltd. The packages for the substation are presented in Table 22.

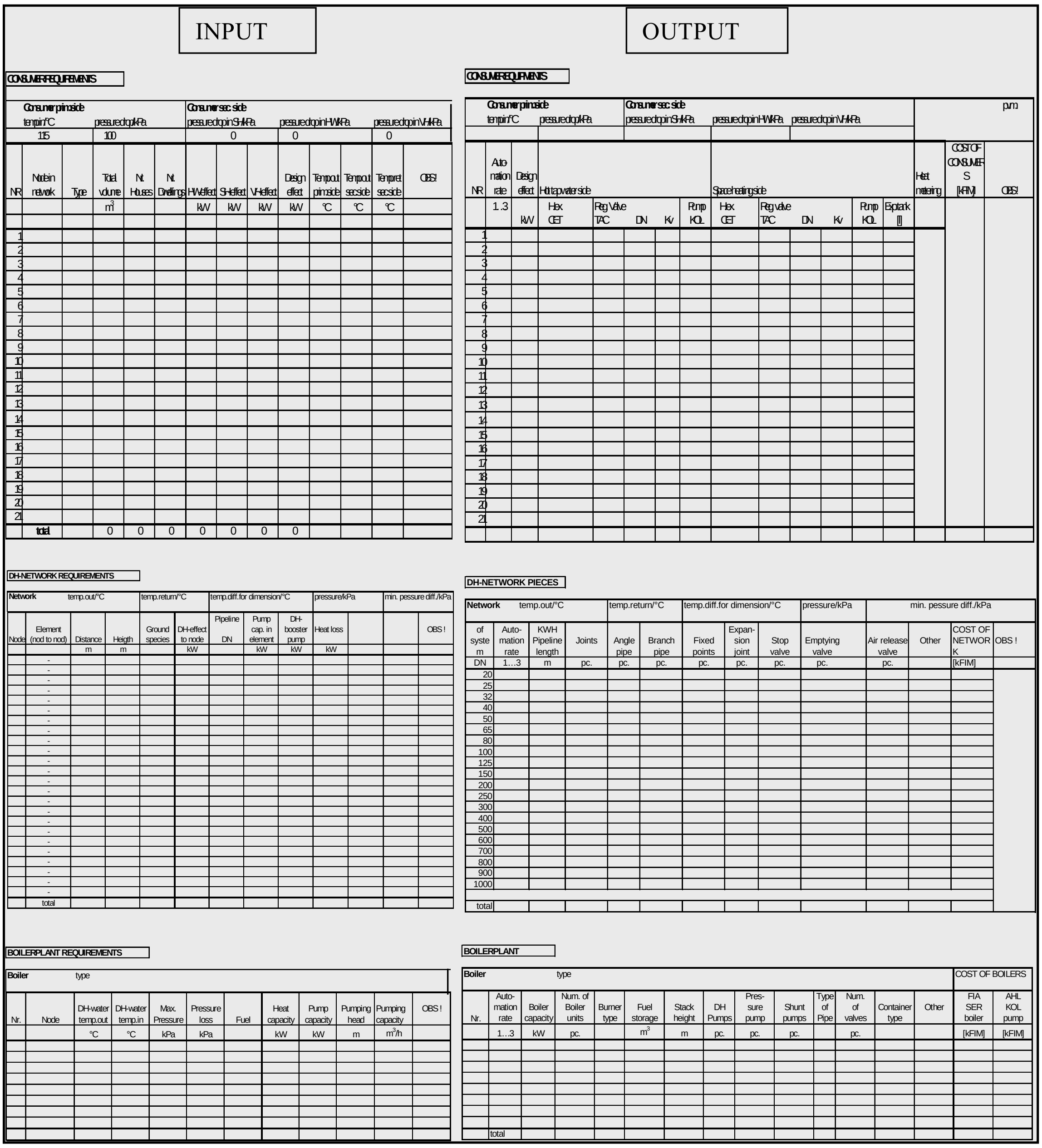

Figure 23. Input and ouput tables of the MODiS Concept Model.

Table 22. DH-consumer substation package.

		TEMPERATURES 70 - 25 / 5 - 60 °C				PRESSURE LOSS 20/30 kPa					
Hot tap water kW		105	167	225	290	450	640		**Space heating**		
Exchanger model		410-60-2v	410-100-2v	410-150-2v	422-64-2v	422-100-2v	422-150-2v		**exchanger**		
Control valve DN/k--value		15/2,5	15/4,0	25/6,3	25/8,0	40/12,5	25/6,3&40/1			Control valve	
Thermal Effect [kW]								surf.area	exchanger model	DN/k-value	
120								1,5 m2	410-60	15/3,2	TEMPE-
170								2,5 m2	410-100	25/5,0	RATURE
195								4,0 m2	422-40	25/5,0	130-75 /
325								7,0 m2	422-70	25/8,0	70-90 °C
450								10 m2	422-100	40/12,5	
600								15 m2	422-150	40/16,0	PRESS
1100								14 m2	500-50	50/31,0	LOSS
2200								28 m2	500-100	65/49,0	5/20 kPa

District heating network

Heat is transported and distributed to the consumer through district heating pipelines. The network is located underground. The heat is delivered by pumping hot water through a 2-pipeline system (i.e. outgoing and return pipes). The supply temperature of the outgoing water varies from 90 to 130 °C (in the target area) and is cooled a maximum of 40 °C by consumers.

The steel pipes are covered by fixed rigid foam insulation. A plastic duct protects the pipeline. Pipelines between branches and fixed points form the pipeline modules. A pump station located in either the boiler plant or the network also forms a module. The pipeline with all necessary accessories can be supplied by the MODiS partners. Pipes classified by diameter are presented in Table 23.

Table 23. District heat pipes with steel wall and foam insulation.

District heating pipelines												
KWH-Tech Oy				120/60 °C								
EN253	SKY L1/94			Water speed	Water flow	Transfer capacity Q [MW]			Pump capacity	Heat loss q/Q [*10^-3] ;ins.class 1		
DN	D_u [mm]	s [mm]	D_s [mm]	[m/s]	[m³/s]	Cooling [°C]			[kW/km]	Cooling [°C]		
		tol +-10%				40	50	60		40	50	60
20	26,9	2,3	22,3	0,42	0,00016	0,026	0,033	0,040	0,019	0,83397	0,66717	0,55598
25	33,7	2,6	28,5	0,50	0,00032	0,051	0,064	0,077	0,038	0,54147	0,43317	0,36098
32	42,4	2,6	37,2	0,61	0,00066	0,106	0,132	0,159	0,077	0,26595	0,21276	0,17730
40	48,3	2,6	43,1	0,67	0,00098	0,158	0,197	0,237	0,115	0,20566	0,16452	0,13710
50	60,3	2,9	54,5	0,79	0,00185	0,298	0,373	0,447	0,218	0,12496	0,09997	0,08331
65	76,1	2,9	70,3	0,95	0,00370	0,595	0,744	0,892	0,435	0,07296	0,05837	0,04864
80	88,9	3,2	82,5	1,07	0,00571	0,919	1,148	1,378	0,672	0,04833	0,03866	0,03222
100	114,3	3,6	107,1	1,29	0,01160	1,865	2,332	2,798	1,365	0,02517	0,02014	0,01678
125	139,7	3,6	132,5	1,50	0,02068	3,324	4,155	4,986	2,432	0,01669	0,01335	0,01113
150	168,3	4,0	160,3	1,72	0,03467	5,574	6,967	8,361	4,078	0,01179	0,00944	0,00786
200	219,1	4,5	210,1	2,08	0,07226	11,616	14,520	17,424	8,499	0,00619	0,00495	0,00413
250	273,0	5,0	263,0	2,45	0,13292	21,369	26,711	32,054	15,635	0,00324	0,00260	0,00216
300	323,9	5,6	312,7	2,77	0,21264	34,184	42,730	51,276	25,011	0,00234	0,00187	0,00156
400	406,4	6,3	393,8	3,26	0,39762	63,923	79,904	95,885	46,771	0,00129	0,00103	0,00086
500	508,0	6,3	495,4	3,85	0,74137	119,185	148,981	178,777	87,204	0,00101	0,00081	0,00067
600	610,0	8,0	594,0	4,38	1,21340	195,070	243,837	292,605	142,728	0,00000	0,00000	0,00000
700	711,2	8,8	693,6	4,89	1,84815	297,114	371,393	445,672	217,393			
800	812,8	8,8	795,2	5,39	2,67842	430,590	538,238	645,886	315,056			
900	914,4	10,0	894,4	5,87	3,68518	592,440	740,550	888,659	433,479			
1000	1016,0	11,0	994,0	6,32	4,90819	789,055	986,319	1183,582	577,341			

Heating boiler plant

Boiler plants are delivered in complete operational units including all necessary components and functions. Boiler plants (1–200 MW thermal output) are gas or oil fired. Solid fuel fired units are also available. A maximum temperature of between 90 and 150 °C, and a pressure level of between 1.0 and 2.5 MPa can be chosen.

A boiler plant of up to 15 MW thermal power is transported in one modular container. The boiler plant and the stock are then mounted on a concrete foundation that has been earlier built at the site. A plant size of higher thermal power would require the boiler plant to be divided into more than one modular container for transportation. The separate components of the boiler would then be connected together on site. The various sizes of MODiS boiler plants are presented in Tables 24 and 25.

Table 24. Boiler plants from Finreila Oy.

Single boiler container (1B), two boiler container (2B) with different fuels, DF= dual fuel							
Design temperature 115 °C, Wessex boiler 90 °C, pressure 10 bar							
Built on ready foundation							
Thermal Power	Boiler type and fuel						
MW	Wessex,Gas	1B, Gas	2B, Gas	1B, Oil	2B, Oil	1B, DF	2B, DF
0,5	2x0,2+0,1	1x0,5	2x0,25	1x0,5	2x0,25	1x0,5	2x0,25
1,0	2x0,2+0,2	1x1,0	2x0,5	1x1,0	2x0,5	1x1,0	2x0,5
2,0	10x,2	1x2,0	2x1,0	1x2,0	2x1,0	1x2,0	2x1,0
3,0	14x0,2+0,2	1x3,0	2x1,5	1x3,0	2x1,5	1x3,0	2x1,5
4,0	20x0,2	1,4,0	2x2,0	1,4,0	2x2,0	1,4,0	2x2,0
5,0		1x5,0	2x2,5	1x5,0	2x2,5	1x5,0	2x2,5
6,0		1x6,0	2x3,0	1x6,0	2x3,0	1x6,0	2x3,0
8,0			2x4,0		2x4,0		2x4,0
10,0			2x5,0		2x5,0		2x5,0
12,0			2x6,0		2x6,0		2x6,0

Table 25. Boiler plants from Sermet Oy.

Boiler range						
Fire tube / water tube boiler			0,5 - 15,0	MW		
Water tube boiler			20 - 40	MW		
Builded on ready foundation						
DH-effect	Boiler modules					
MW	1B	2B	1B+1B	3B	4B	OBS.
0,5	0,5					
1	1	2x0,5				located on the roof:
1,5	1,5		0,5+1,0	3x0,5		max 0,5 MW units
2	2	2x1,0				
3	3	2x1,5	1,0+2,0			ridge roof train model
4	4	2x2,0				
5	5		2,0+3,0	1,0+2x2,0		
6	6	2x3,0	2,0+4,0	3x2,0		
8	8	2x4,0	3,0+5,0		4x2,0	
9	9			3x3,0		
10	10	2x5,0	4,0+6,0			
12	12	2x6,0	4,0+8,0	3x4,0	4x3,0	
15	15		5+10	3x5,0		
16		2x8,0	6+10		4x4,0	
18			6+12	3x6,0		
20	20	2x10			4x5,0	train model: max 5,0 MW units
22			10+12			
24		2x12			4x6,0	
27			12+15			
30	30	2x15				
35			15+20			
40	40	2x20				
45			15+30	3x15		block model: max 15 MW units
50			20+30			
60	60	2x30		3x20		
70			30+40			
80		2x40				
90				3x30		
100						
110						
120		2x60		3x40		
160					4x40	assembled on site

6.2.2 MODiS case study

The case study involves a small part of a Russian town. The object of the study is to plan a new MODiS district heating system for that area. Later in this report the operation of the planned DH-system is studied with the APROS-dynamic simulation model. The area, which has about 100 000 inhabitants, consists of 42 buildings from the 1950s and 60s. Maximum heating power is 20 MW and hot tap water power 2 MW.

The DH-system is an open 2-pipe system to which the radiator heating system in the buildings is connected with an ejector. The hot tap water is the same as in the DH-pipeline and is taken directly from the DH-system. The temperature in the DH-system is 150/70 °C, but in practice the outgoing temperature is 130 °C for the greater part of the year. The cooling of DH-water by consumers is typically 30 °C. The highest building is 35 m. Pipe diameter varies 50–300 mm and the pressure level is 2,5 MPa. The total length of the network is 4 600 metres. The pipelines are mostly insulated with concrete foam and covered with a bitumen coat. There is also a small amount of mineral wool and polyurethane foam insulation. The water flow can not be varied and regulation of the thermal power is based solely on temperature variation. The pipelines are located both underground and in the air. Subsurface draining and air conditioning in the pipeline canal do not work and there are serious corrosion problems both inside and outside the pipelines. The amount of additive water is high. There is no measurement of energy at the consumers. The heat supply is an old gas-fired boiler, although heavy oil (mazout) is used as well. There is no water treatment in the boiler plant.

The plan of the DH-area is presented in Figure 24.

Renovation of the consumer equipment

There are 41 renovated buildings in the area. The connected power and temperature of the buildings are presented in Table 26. The ejectors are replaced by substations with heat exchangers for heating and hot tap water. The hot water heat exchangers are connected in parallel to the space heat exchangers. Each building has a heat meter and an expansion tank for the radiator system. The numbering and nodes of each consumer are presented in Figure 24.

The results of the MODiS Concept Model planning for each consumer are presented in Table 27. There are heat exchangers for space heating, air conditioning and hot tap water. Control valve types, i.e. DN size and K_v-numbers, and the pump types for the consumer substation are also given. The heat meters are Finnish magnetic water flow meters, each with two Pt-100 temperature transducers and an electronic calculator.

The condition of the cold water pipeline must also be evaluated and renovated if necessary. The radiator pipelines should be balanced with line valves and thermostatic radiator valves to compensate temparature deviation between rooms.

The budgeted value for consumer equipment is 3.14 million FIM (580 000 USD), which is 18.2% of the whole budget.

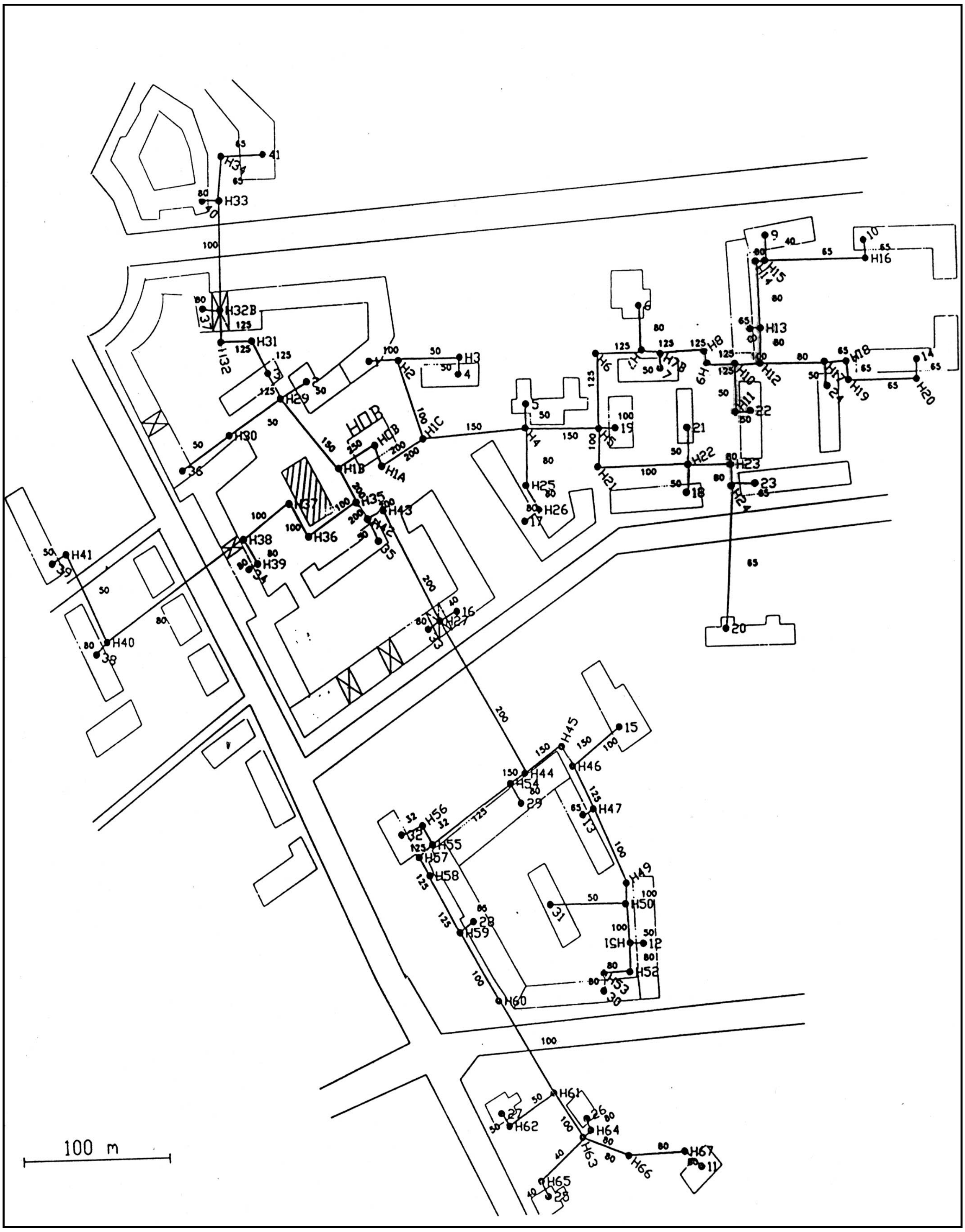

Figure 24. Map of the renovated Russian town area.

Table 26. Numbering of connections as well as the thermal effect of consumers.

QUESTIONNAIRE STUDY FOR THE TARGET DISTRICT HEATING AREA											Date:	25.10.1999	
Russian town											Draftman:	K.Sipilä	
CONSUMER REQUIREMENTS													
	Consumer prim.side					Consumer sec. side							
	temp.in/°C		pressure drop/kPa			pressure drop in SH/kPa			pressure drop in HW/kPa			pressure drop in VH/kPa	
	115		100				20		50			20	
NR	Node in network	Type	Total volume	Nr. Houses	Nr. Dwellings	HW-effect	SH-effect	VH-effect	Design effect	Temp.out prim.side	Temp.out sec.side	Temp.ret sec.side	OBS !
			m³			kW	kW	kW	kW	°C	°C	°C	
1	1	stock		6		425	767		1192	50	80	60	Tap water out
2	2	hospital		1		39	194		233	50	80	60	60 °C
3	5	office		3		67	170	35	272	50	80	60	
4	6	one family		10		56	503		559	50	80	60	
5	9	office		2		25	125		150	50	80	60	
6	11	church		1		388	390		778	50	80	60	
7	15					103	1419	164	1686	50	80	60	
8	16					59	49		108	50	80	60	
9	17					227	620		847	50	80	60	
10	21					55	263		318	50	80	60	
11	22					48	230		278	50	80	60	
12	25					3	52	39	94	50	80	60	
13	26					16	84	453	553	50	80	60	
14	27					9	64	186	259	50	80	60	
15	3						402		402	50	80	60	
16	4						245		245	50	80	60	
17	7						224		224	50	80	60	
18	8						342		342	50	80	60	
19	10						443		443	50	80	60	
20	12						315		315	50	80	60	
21	13						501		501	50	80	60	
22	14						469		469	50	80	60	
23	18						253		253	50	80	60	
24	19						84		84	50	80	60	
25	20						331		331	50	80	60	
26	23						435	90	525	50	80	60	
27	24						259		259	50	80	60	
28	28						350		350	50	80	60	
29	29						977		977	50	80	60	
30	30						977		977	50	80	60	
31	31						239		239	50	80	60	
32	32						63		63	50	80	60	
33	33						929		929	50	80	60	
34	34						933		933	50	80	60	
35	35						200		200	50	80	60	
36	36						200		200	50	80	60	
37	37						853		853	50	80	60	
38	38						556		556	50	80	60	
39	39						258		258	50	80	60	
40	40						700	230	930	50	80	60	
41	41						310	220	530	50	80	60	
total			0	23	0	1520	16778	1417	19715				

Table 27. Substations, expansion tanks and heat meters for consumers.

QUESTIONNAIRE STUDY FOR THE TARGET DISTRICT HEATING AREA															Date:	25.10.199
Russian town															Draftman:	K.Sipilä
CONSUMER EQUIPMENTS																
						SH=space heating			HW=hot water		VH=ventilation heating					
	Consumer prim.side					Consumer sec. side										
	temp.in/°C		pressure drop/kPa			pressure drop in SH/kPa			pressure drop in HW/kPa			pressure drop in VH/kPa			Give currency	
	115			100			20			50			20			
NR	Auto-mation rate	Design effect	Hot tap water side						Space heating side							Heat metering
	1...3	kW	H.ex.		Reg. Valve			Pump	H.ex.		Reg. valve			Pump	Exp.tank	
			CET		TAC	DN	Kv	KOL	CET		TAC	DN	Kv	KOL	[l]	
1	1	1192	CP 410-60-2v		V294	40	12,5	AP-25/4	CP-422-150		V294+V294	25+20	10+6,3	AL 1065/4	1000	40
2	1	233	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-410-60		V294	15	2,5	AE 20/4	200	15
3	1	272	CP 410-100-2v		V294	15	4	AP-15/4	CP-410-60		V294	15	2,5	AE 20/4	200	15
4	1	559	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-422-100		V298	32	16	AL 1065/4	640	32
5	1	150	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-410-60		V294	15	2,5	AE 20/4	200	15
6	1	778	CP 422-80-2v		V294	40	12,5	AP-25/4	CP-422-80		V294	25	10	AL 1054/4	525	40
7	1	1686	CP 410-100-2v		V294	15	4	AP-15/4	2xCP-422-150		V295+V294	40+25	25+10	AL 1102/4	1800	15
8	1	108	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-410-30		V294	15	1,6	AE 20/4	80	15
9	1	847	CP 410-150-2v		V294	25	6,3	AP-15/4	CP-422-150		V294+V294	25+20	10+6,3	AL 1065/4	1000	25
10	1	318	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-422-30		V294	20	6,3	AE 32/4	320	20
11	1	278	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-410-60		V294	15	2,5	AE 20/4	200	15
12	1	94	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-410-30		V294	15	1,6	AE 20/4	80	15
13	1	553	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-422-100		V298	32	16	AL 1065/4	640	32
14	1	259	CP 410-60-2v		V294	15	1,6	AP-15/4	CP-422-30		V294	20	6,3	AE 32/4	320	20
15	1	402							CP-422-80		V294	25	10	AL 1054/4	525	25
16	1	245							CP-422-30		V294	20	6,3	AE 32/4	320	20
17	1	224							CP-410-60		V294	15	2,5	AE 20/4	200	15
18	1	342							CP-422-30		V294	20	6,3	AE 32/4	320	20
19	1	443							CP-422-80		V294	25	10	AL 1054/4	525	25
20	1	315							CP-422-30		V294	20	6,3	AE 32/4	320	20
21	1	501							CP-422-100		V298	32	16	AL 1065/4	640	32
22	1	469							CP-422-80		V294	25	10	AL 1054/4	525	25
23	1	253							CP-422-30		V294	20	6,3	AE 32/4	320	20
24	1	84							CP-410-30		V294	15	1,6	AE 20/4	80	15
25	1	331							CP-422-30		V294	20	6,3	AE 32/4	320	20
26	1	525							CP-422-100		V298	32	16	AL 1065/4	640	32
27	1	259							CP-422-30		V294	20	6,3	AE 32/4	320	20
28	1	350							CP-422-30		V294	20	6,3	AE 32/4	320	20
29	1	977				32			2xCP-422-100		V298+V294	32+25	16+10	AL 1081/4	1800	32
30	1	977				32			2xCP-422-100		V298+V294	32+25	16+10	AL 1081/4	1800	32
31	1	239							CP-410-60		V294	15	2,5	AE 20/4	200	15
32	1	63							CP-410-30		V294	15	1,6	AE 20/4	80	15
33	1	929				32			2xCP-422-100		V298+V294	32+25	16+10	AL 1081/4	1800	32
34	1	933				32			2xCP-422-100		V298+V294	32+25	16+10	AL 1081/4	1800	32
35	1	200							CP-410-60		V294	15	2,5	AE 20/4	200	15
36	1	200							CP-410-60		V294	15	2,5	AE 20/4	200	15
37	1	853				16			2xCP-422-100		V298+V294	32+25	16+10	AL 1081/4	1800	16
38	1	556							CP-422-100		V298	32	16	AL 1065/4	640	32
39	1	258							CP-422-30		V294	20	6,3	AE 32/4	320	20
40	1	930				32			2xCP-422-100		V298+V294	32+25	16+10	AL 1081/4	1800	32
41	1	530							CP-422-100		V298	32	16	AL 1065/4	640	32
total		19715														

Renovation of the district heating network

A new district heating network will be constructed. Pipelines will consist of welded steel pipes with fixed rigid polyurethane foam insulation and plastic ducts. The outgoing temperature is specified as 120/50 °C and the pressure will be 1.6 MPa. The temperature drop due to the consumers will be 40 °C. The cooling could be made as high as 50 °C by renovating the system on the consumer side. The numbering and nodes of the new pipelines are presented in Figure 24. The pipelines are evaluated with the MODiS-Concept tool 2.0. The network is also computed by the steady state models "WinFloura" of Elektrowatt-Ekono Oy and "Heat Nexus" of Process Vision Oy. All three calculation systems give the same dimensions for the pipeline elements. The total length of the pipeline is 2 x 3074 meter (outgoing+return). The numbering of nodes and elements, including the length of the elements and the input thermal power at the nodes, are presented in Table 28. The diameter of the pipe elements including pumping power and heat loss, are also included. At present, the MODiS-Concept tool evaluates bend, branch, anchor point elements and valves based on the length of the pipelines. The pipes, categorised by nominal diameter (DN), are presented in Table 29.

As an installation method pre-heating is preferred, where the pipeline elements are set into the ground and pre-heated before burying. If we assume a maximum operating temperature of 120 °C in the pipeline and an outdoor temperature of 15 °C at the moment of burying, we can choose a pre-heating temperature of 70 °C inside the pipeline when burying it. In such a case, the stresses of movement will be about half of those that would be incurred if using cold installed pipes. We have ensured a short installation time for the pipelines by good organisation of the work plan.

It is also worth noting that a 100 metre pipeline will be built between nodes 15 and 21 to ensure the availability of district heat through one circular line to both main and remote areas of the DH-system.

The budget price of the network is 4.3 million FIM (780 000 USD), which is 26.3% of total budget. A detailed budget should be calculated before rebuilding the network.

Table 28. Nodes and element numbering of the DH-network including pressure and heat loss.

QUESTIONNAIRE STUDY FOR THE TARGET DISTRICT HEATING AREA									Date:	25.10.1999
Russian town									Draftman:	K.Sipilä
DH-NETWORK REQUIREMENTS										
Network		temp.out/°C		temp.return/°C		temp.diff.for dimension/°C			pressure/kPa	
		115		50		40			1600	
Node	Element (nod to nod)	Distance	Heigth	Ground species	DH-effect to node	Pipeline DN	Pump cap. in element	DH-booster pump	Heat loss	
		m	m		kW		kW	kW	kW	
H16	H16-10	11,2			443	50	0,005		0,930	
H15	H15-H16	68,1			443	50	0,030		5,655	
	H15-9	15,9			150	40	0,004		0,736	
H14	H14-H15	6,8			593	65	0,006		0,441	
H13	H13-H14	41,7			593	65	0,036		2,706	
	H13-8	8,5			342	50	0,004		0,545	
H20	H20-14	11,2			469	50	0,005		0,985	
H19	H19-H20	46,9			469	50	0,020		4,123	
H18	H18-H19	12,8			469	50	0,006		1,125	
H17	H17-H18	16,0			469	50	0,007		1,407	
	H17-24	14,4			259	50	0,006		0,699	
H12	H12_H13	21,3			935	80	0,029		1,444	
	H12-H17	43,7			728	65	0,038		3,482	
H11	H11-22	10,1			278	50	0,004		0,526	
H10	H10-H12	17,0			278	50	0,007		0,886	
	H10-H11	28,7			1663	80	0,039		3,460	
H9	H9-H10	19,2			1941	100	0,052		1,407	
H8	H8-H9	9,0			1941	100	0,025		0,660	
H7B	H7B-H8	30,9			1941	100	0,084		2,264	
H7	H7-H7B	12,8			2165	100	0,035		1,046	
	H7-6	28,7			559	65	0,025		1,756	
H6	H6-H7	29,3			2724	100	0,080		3,013	
H24	H24-23	15,8			525	65	0,014		0,908	
	H24-20	89,4			331	50	0,039		5,547	
H23	H23-H24	13,4			856	80	0,018		0,831	
H22	H22-H23	29,2			856	80	0,039		1,812	
	H22-18	16,6			253	50	0,007		0,787	
	H22-21	22,9			318	50	0,010		1,365	
H21	H21-H22	60,1			1427	80	0,081		6,217	
H5	H5-H6	46,3			2724	100	0,126		4,762	
	H5-H21	23,4			1427	80	0,031		2,421	
	H5-19	12,3			84	40	0,003		0,319	
H26	H26-17	11,8			847	80	0,016		0,725	
H25	H25-H26	17,0			847	80	0,023		1,044	
H4	H4-H5	49,5			4235	125	0,241		5,249	
	H4-H25	35,1			847	80	0,047		2,155	
	H4-5	14,4			272	50	0,006		0,734	
H3	H3-4	10,1			245	50	0,004		0,464	
H2	H2-1	19,2			1192	80	0,026		1,659	
	H2-H3	42,1			245	50	0,018		1,933	
H1C	H1C-H2	51,2			1437	80	0,069		5,333	
	H1C-H4	68,2			5354	125	0,332		9,143	
H1A	H1A-H1C	33,6			6791	150	0,274		4,037	
H34	H34-41	27,7			530	65	0,024		1,607	
H33	H33-H34	27,3			530	65	0,024		1,583	
	H33-40	12,3			930	80	0,017		0,829	
H32B	H32B-H33	67,6			1460	80	0,091		7,154	
	H32B-37	12,3			853	80	0,017		0,761	
H32	H32-H32B	19,7			2313	100	0,054		1,720	
H31	H31-H32	20,2			2313	100	0,055		1,764	
H30	H30-36	38,3			200	50	0,017		1,436	
H29	H29-H30	42,3			200	50	0,018		1,586	
	H29-3-H31	40,3			2715	100	0,110		4,131	
	H29-2	20,9			233	50	0,009		0,913	
H41	H41-39	11,0			258	50	0,005		0,532	
H40	H40-H41	61,2			258	50	0,027		2,960	
	H40-38	10,2			556	65	0,009		0,621	
H39	H39-34	7,8			993	80	0,010		0,561	
H38	H38-H40	113,9			814	65	0,099		10,147	
	H38-H39	18,3			993	80	0,025		1,317	
H37	H37-H38	38,3			1807	100	0,105		2,613	
H36	H36-H37	24,2			1807	100	0,066		1,651	
H53	H53-30	9,6			977	80	0,013		0,680	
H52	H52-H53	17,4			977	80	0,023		1,232	

H51	H51-H52	18,1			977	80	0,024		1,282	
	H51-12	9,6			315	50	0,004		0,567	
H50	H50-H51	24,2			1292	80	0,033		2,266	
	H50-31	50,5			239	50	0,022		2,262	
H49	H49-H50	13,1			1531	80	0,018		1,454	
H47	H47-H49	49,7			1531	80	0,067		5,516	
	H47-13	7,5			501	65	0,007		0,411	
H46	H46-H47	30,7			2032	100	0,084		2,355	
	H46-15	39,4			1686	80	0,053		4,815	
H45	H45-H46	15,9			3718	125	0,077		1,480	
H67	H67-11	14,1			778	65	0,012		1,201	
H66	H66-H67	39,1			778	65	0,034		3,329	
H65	H65-25	11,3			94	40	0,003		0,328	
H64	H64-26	8,6			553	65	0,007		0,520	
H63	H63-H65	38,8			94	40	0,009		1,125	
	H63-H66	32,6			778	65	0,028		2,776	
	H63-H64	7,1			553	65	0,006		0,430	
H62	H62-27	9,6			259	50	0,004		0,466	
H61	H61-H62	36,0			259	50	0,016		1,748	
	H61-H63	34,0			1425	80	0,046		3,512	
H60	H60-H61	68,5			1684	80	0,092		8,362	
H59	H59-H60	49,0			1684	80	0,066		5,982	
	H59-28	11,9			350	50	0,005		0,781	
H58	H58-H59	40,9			2034	100	0,112		3,141	
H57	H57-H58	14,3			2034	100	0,039		1,098	
H56	H56-32	14,8			63	40	0,003		0,288	
H55	H55-H56	13,5			63	40	0,003		0,262	
	H55-H57	11,9			2034	100	0,032		0,914	
H54	H54-H55	63,8			2097	100	0,174		5,051	
	H54-29	13,7			977	80	0,018		0,970	
H44	H44-H45	29,4			3718	125	0,143		2,737	
	H44-H54	11,8			3074	100	0,032		1,370	
H27	H27-H44	110,0			6792	150	0,897		13,217	
	H27-16	12,9			108	40	0,003		0,430	
	H27-33	9,6			929	80	0,013		0,646	
H43	H43-H27	79,0			7829	150	0,644		10,942	
H42	H42-H43	11,8			7829	150	0,096		1,634	
	H42-35	14,9			200	50	0,006		0,559	
H35	H35-H36	39,1			1807	100	0,107		2,668	
	H35-H42	13,2			7829	150	0,108		1,828	
H1B	H1B-H29	57,9			3148	100	0,158		6,882	
	H1B-H35	23,4			9636	150	0,191		3,989	
HOB'	HOB-H1A	13,4			6791	150	0,109		1,610	
	HOB-H1B	28,2			12784	200	0,479		3,347	
HOB	HOB				19575	200	0,000		0,000	
	total	3074			19575		6,9		259,1	

Table 29. Pipelines categorised by DN diameter.

QUESTIONNAIRE STUDY FOR THE TARGET DISTRICT HEATING AREA										Date:	25.10.1999	
Russian town										Draftman:	K.Sipilä	
DH-NETWORK PIECES				Pipeline type	MPUK							
Network		temp.out/°C		temp.return/°C		temp.diff.for dimension/°C			pressure/kPa		min. pessure diff./kPa	
		115		50		40			1600		500	
Piece of system	Auto-mation rate	KWH Pipeline length	Joints	Angle pipe	Branch pipe	Fixed points	Expan-sion joint	Stop valve	Emptying valve	Air release valve	Other	OBS !
DN	1…3	m	pc.	pc.	pc.	pc.	pc.	pc.	pc.	pc.		
20	1											2MPUK
25	1											2MPUK
32	1											MPUK
40	1	239,0										MPUK
50	1	1435,8										MPUK
65	1	849,6										MPUK
80	1	1550,0										MPUK
100	1	1121,2										MPUK
125	1	326,0										
150	1	568,8										
200	1	56,4										
250	1											
300	1											
400	1											
500	1											
600	1											
700	1											
800	1											
900	1											
1000	1											
total		6147	0	0	0	0	0	0	0	0	0	

Renovation of the district heating boiler plant

The old boiler will be replaced by a new 20 MW boiler plant, which is prefabricated and will be transported to the site. Foundations for the boiler house and duct will be made ready by the customer. A description of the new boiler plant is presented in Table 30.

Table 30. Specifications of the boiler plant.

QUESTIONNAIRE STUDY FOR THE TARGET DISTRICT HEATING AREA											Date:	25.10.1999	
Russian town											Draftman:	K.Sipilä	
BOILERPLANT REQUIREMENTS													
Boiler		type				G=gas	LO=light oil	M=mazut					
						S=solid	HO=heavy oil	1…4 boilers					
Nr.	Node	DH-water temp.out	DH-water temp.in	Max. Pressure	Pressure loss	Fuel	Heat capacity	Pump capacity	Pump motor	Pumping head	Pumping capacity		OBS !
		°C	°C	kPa	kPa		MW	kW	kW	m	m^3/h		
1	HOB	115	60	1600	100	G+HO2	20	50,0	75,0	40	32,6		
	total						20						

The complete boiler plant set will comprise 2 x 10 MW boilers. The boilers are double-fired by gas and heavy fuel oil. The pumps (2 x circulation pumps and 2 x presssure pumps) will be located in the boiler house. There will also be one shunt pump. The chimney, 20 metres high and with two ducts, will be located on the ready-made foundation. The boiler plant design is presented in Table 31.

Table 31. Specifications of the boiler plant.

QUESTIONNAIRE STUDY FOR THE TARGET DISTRICT HEATING AREA											Date:	########	
Russian town											Draftman:	K.Sipilä	
BOILERPLANT													
Boiler			type										
Nr.	Auto-mation rate	Boiler capacity	Num. of Boiler units	Burner type	7 days Fuel storage	Stack height	DH Pumps	Pres-sure pump	Shunt pumps	Type of Pipe	Num. of valves	Container type	Other
	1…3	MW	pc.		m^3	m	pc.	pc.	pc.		pc.		
1	1	10	2	dual	336	20	2	2	1	MPUK		block	
	Total	10	2		336		2	2	1				

The price budgeted for the boiler plant is 7.3 million FIM (1.33 million USD), which is 42.4% of the total budget.

Total budget and economic evaluation

The total budget of the renovation is 17.2 million FIM (3.1 million USD). Local taxes and transportation costs must be added. The itemised total budget as well as annual investment (10%, 15 a) and driving costs are presented in Table 32. The annual peak heat power time is evaluated to be 2 500 hours. The cost of heat supply is evaluated as well. The annual cost is 6.8 million FIM (1.24 million USD).

Table 32. Annual cost of DH system in Russian town.

QUESTIONNAIRE STUDY FOR THE TARGET DISTRICT HEATING AREA												Date:	06.08.1999
												Draftman:	K.Sipilä
CASE STUDY		**Russian town**			**RESULTS**								
INVESTMENT													
			Inv.cost		ann.cost	life [a]	ann. cof.	**OBS !**	Duty free investment cost, tax and transportation not included				
	Boiler		7290	kFIM	958,4	15	0,13147						
	DH-nerwork		4523	kFIM	594,7	15	0,13147	Look at reference list, what is included					
	Consumer		3135	kFIM	412,2	15	0,13147	Pipelines with accessories are included					
	Other		2242	kFIM	294,8	15	0,13147	Substation with expansion tank and energy measurements are included					
	Other 2		0	kFIM	0,0	15	0,13147	Design works and technical assistance					
		total	17191	kFIM	2260,1								
ANNUAL INVESTMENT COST													
		rate	10	%	2260	kFIM/a	33,4						
ANNUAL DRIVING COST													
DH-	Peak hours		2500	h									
20	MW DH energy		50000	MWh									
259,1	kW DH-n.w.loss		1814	MWh					Annual network loss		3,6	% of annual DH energy	
	DH energy		51814	MWh brutt									
0,9	Fuel		57 571	MWh	3454	kFIM/a			60	FIM/MWh	fuel		
13,7	kW Pumping		34 371	kWh	7	kFIM/a			0,2	FIM/kWh	electricity		
140,6	kW Auxiliaries		351 500	kWh	70	kFIM/a							
boiler+network	Maintenance				149	kFIM/a							
6 pers.	Staff		10 000	FIM/p,mon	720	kFIM/a							
Other fixed cost					100	kFIM/a							
Annuala driving costs					4501	kFIM/a	66,6		Net DH-price for production			**133,04**	FIM/MWh, a
Annual costs total					6761	kFIM/a	100,0		Net DH-price for consumer			**135,22**	FIM/MWh, a

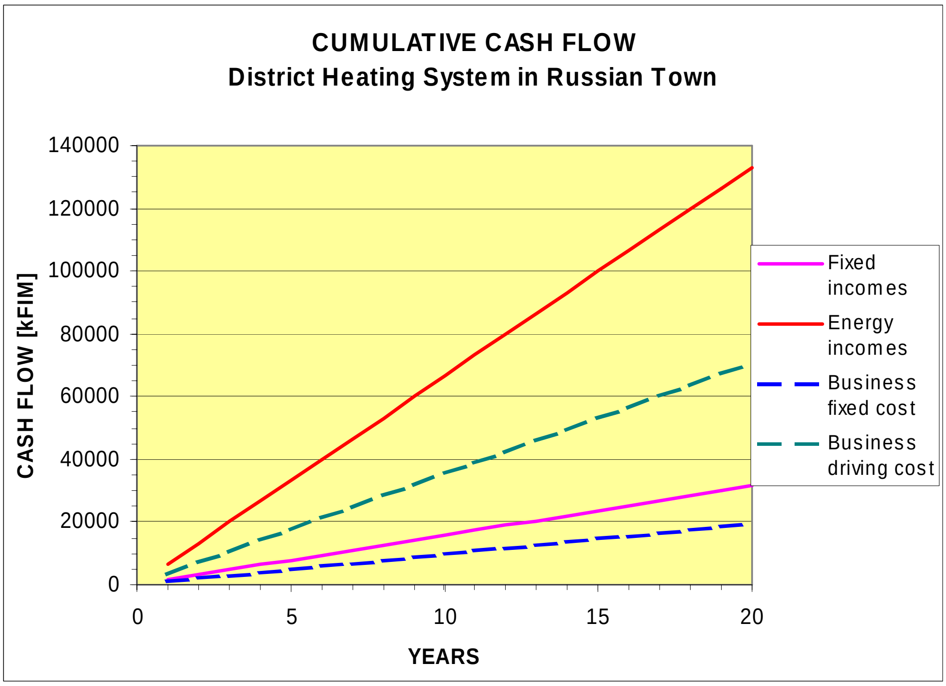

Figure 25. Cumulative cash flow of rebuilt DH-area in Russian town.

A tariff would have to be estimated, for example, in a case where the fixed annual cost is 80 FIM/kW,a and the energy price is 135 FIM/MWh. The estimated income is 8.2 million FIM (1.49 million USD), which is divided into a fixed price income of 19% and an energy price incomes of 81%. The cumulative cash flow is presented in Figure 25. The payback time is estimated to be 6.5 years, which is presented in Figure 26.

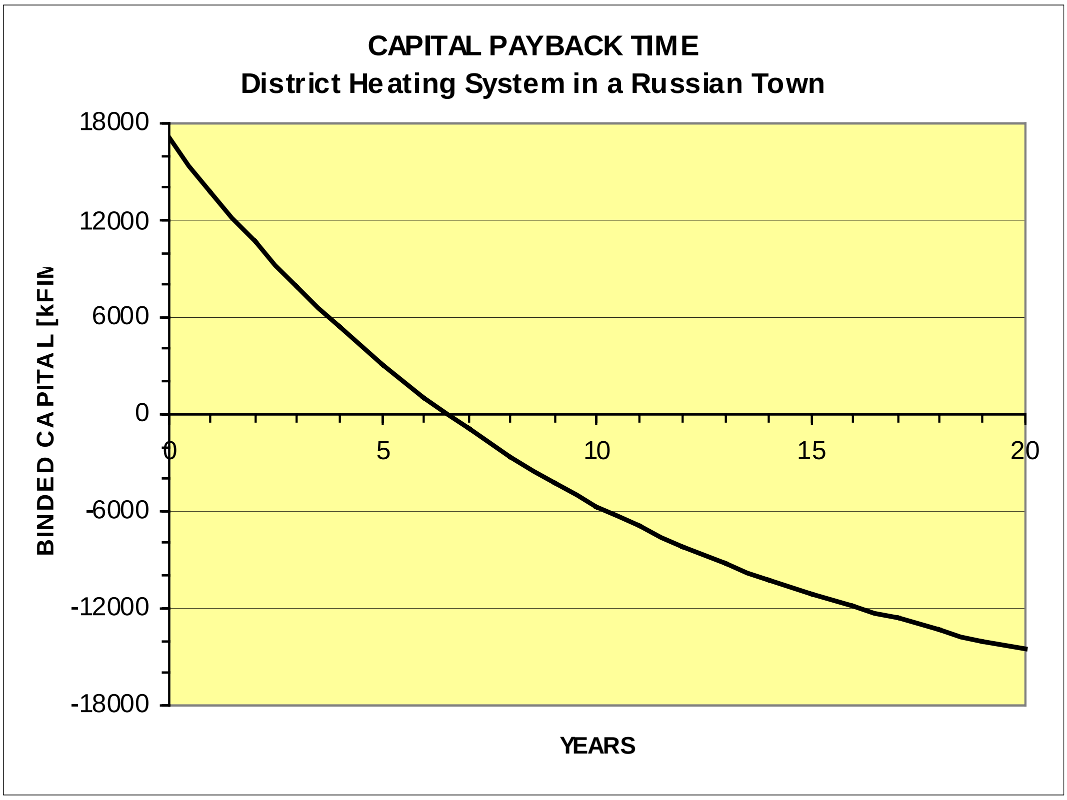

Figure 26. Capital payback time of DH-investment in Russian Town.

6.3 The ejector in district heating systems

6.3.1 Introduction

Ejectors are used in district heating systems for connecting the heat distribution network in a building with the district heating pipelines. This method, known as direct connection, prevails in the district heating systems of the former East bloc countries and China, whereas indirect connection is used in West Europe. At present, indirect connection, which utilises a heat exchanger, is also encroaching on the heating systems of both Central and East European countries.

In this section, the principles relating to the functioning of an ejector in a district heating system are presented. In addition, the APROS simulation program has been used for investigating the ejector connection in an apartment building and for analysing the operation of the ejector in the context of the entire heating system. A more detailed presentation of ejector and heating systems is available in a report prepared in the MODiS-project [11]. The following text outlines the main features and results.

6.3.2 Connection principle

In a district heating system, the supply temperature is designed to exceed 100 °C for part of the year, with a maximum limit of 150 °C in the East European countries. The temperature in the heat distribution network of a building, however, is always below 100 °C. The ejector connection provides the necessary drop in supply temperature. Figure 27 shows that the pressure/flow profile is basically a function of the distance from the power station. The ejector and the distribution network of the building are located between the supply and return pipelines of the DH-network. A valve (v) is needed to compensate the excess pressure difference between the supply and return pipelines. A constant pressure difference of about 2.2–2.5 bar is maintained at the ejector connection.

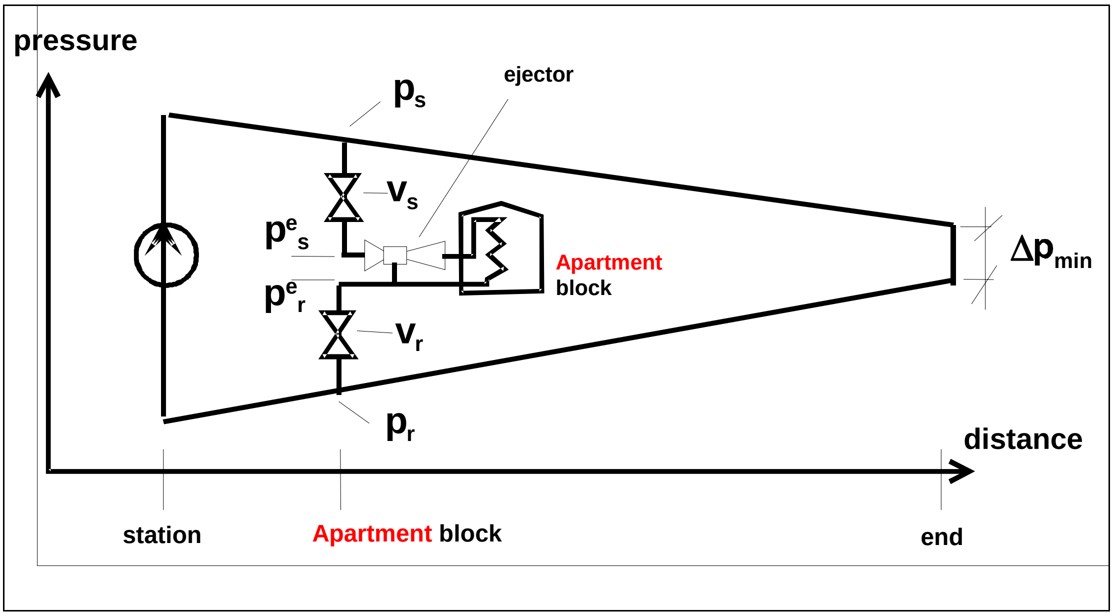

Figure 27. Ejector connection between DH and building networks.

The role of the ejector is outlined in Figure 28. The inlet flow of DH-water to the ejector is a driving flow, and this is mixed with the suction flow from the return pipeline of the heating network. The resulting outlet flow from the ejector forms the supply flow for the heating network in the building. The driving flow is equal to the return flow to the

DH-network, and both of them are smaller than the flow suctioned into the ejector. Thus, the supply temperature is lowered in the ejector to a level suitable for the heating network.

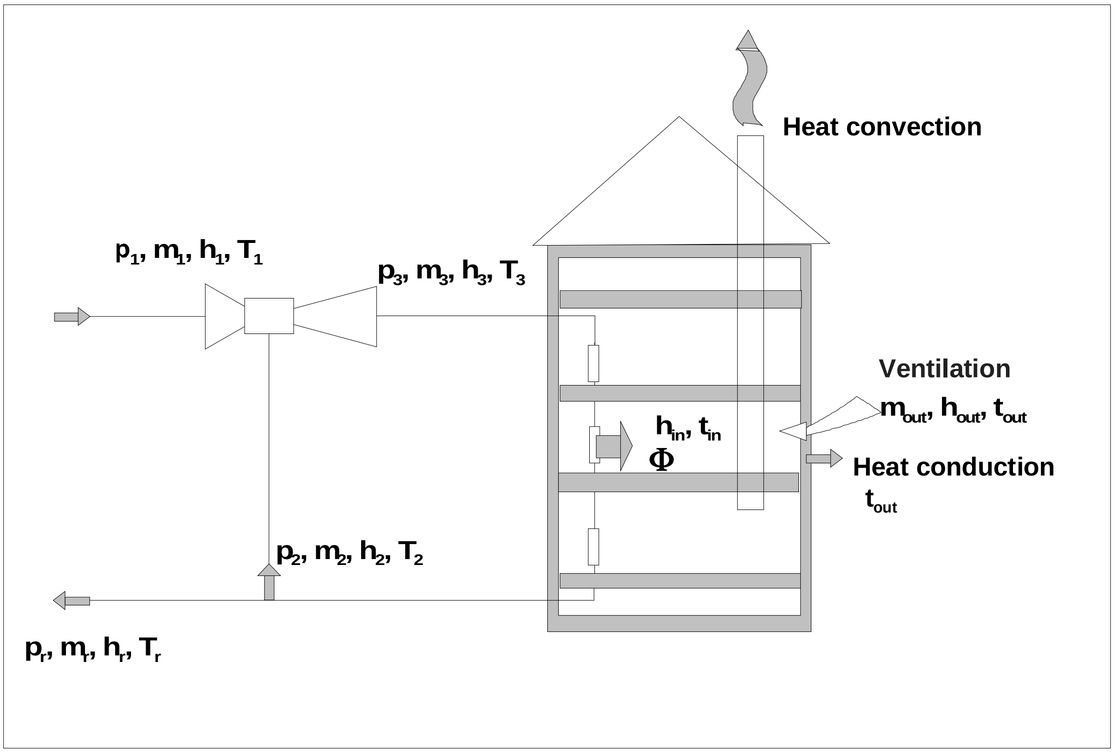

Figure 28. Ejector and heating network of building.

The simple equations below illustrate the role of the ejector in a heating system:

If ω denotes the mixing ratio of the ejector

$$\omega = \frac{\dot{m}_2}{\dot{m}_1} \tag{1}$$

According to the energy conservation law we get

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \tag{2}$$

According to the law of mass flow conservation we get

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3 \tag{3}$$

Solving the mixing ratio by using equations 2 and 3 we obtain

$$\omega = \frac{h_1 - h_3}{h_3 - h_2} \approx \frac{T_1 - T_3}{T_3 - T_2} \tag{4}$$

Thus, the supply temperature of heating network can be written:

$$T_3 \approx \frac{T_1 + \omega T_2}{1 + \omega} \tag{5}$$

The indexes used in equations 1 to 5 are presented in Figure 29, where

T is temperature

and

h is enthalpy.

The mixing ratio, which depends on the dimensions of the ejector, is chosen so that the supply temperature of the heating network is 95 °C in design conditions, i.e. when the supply temperature in the DH network is 150 °C and the return temperature is 70 °C. These temperatures give a value of 2.2 for the mixing ratio.

6.3.3 Heating system simulation

A typical Russian apartment building, with five storeys and external dimensions of 80 m (length), 12.5 m (width) and 14 m (height), was used in the APROS program simulation. The volume of the building is 14 000 m^3. The average heat transfer coefficient for the walls, deck and floor is assumed to be 1.0 W/(m^2, °C). A ventilation rate of 1.0 1/h (times per hour) is assumed in the basic case, but the rates of 0.85 and 0.73 1/h are also simulated (see Figure 29). The maximum supply temperature of the DH network is 150 °C, but it is limited to 130 °C in some cases. The minimum supply temperature is 70 °C, but the value of 60 °C is also simulated.

At the design condition ambient temperature of -28 °C, heating demand is 350–370 kW, consisting of 210 kW for ventilation and 130–160 kW for heat conduction.

The ejector is described in Figure 30. The dimensions of the ejector are calculated according to Russian instructions and equations. The first step is to calculate the diameter d_5 for the mixer:

$$d_5 = 28{,}7 \cdot \sqrt[4]{\frac{\dot{m}_3^{\,2}(1+\omega)^2}{\Delta p_{ds}}} \tag{6}$$

where $\dot{m}_3$ is the inlet mass flow to the heating network (3.2 kg/s), and Δp_{ds} is the pressure drop in the heating network of the building. A value of 15 kPa is used for Δp_{ds}. ω is the flow ratio of the ejector.

If ω is taken to be 2.2, then d_5 must be 26.6. The nearest standard size is 25 mm.

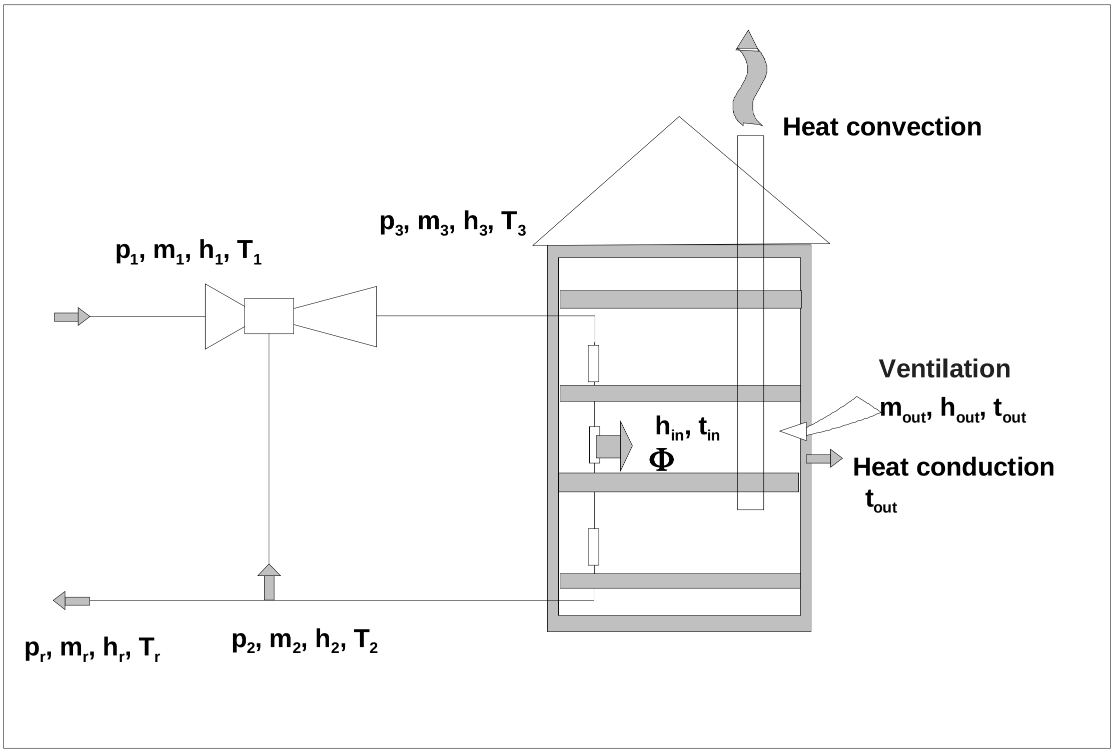

Figure 29. Heating system simulated by APROS.

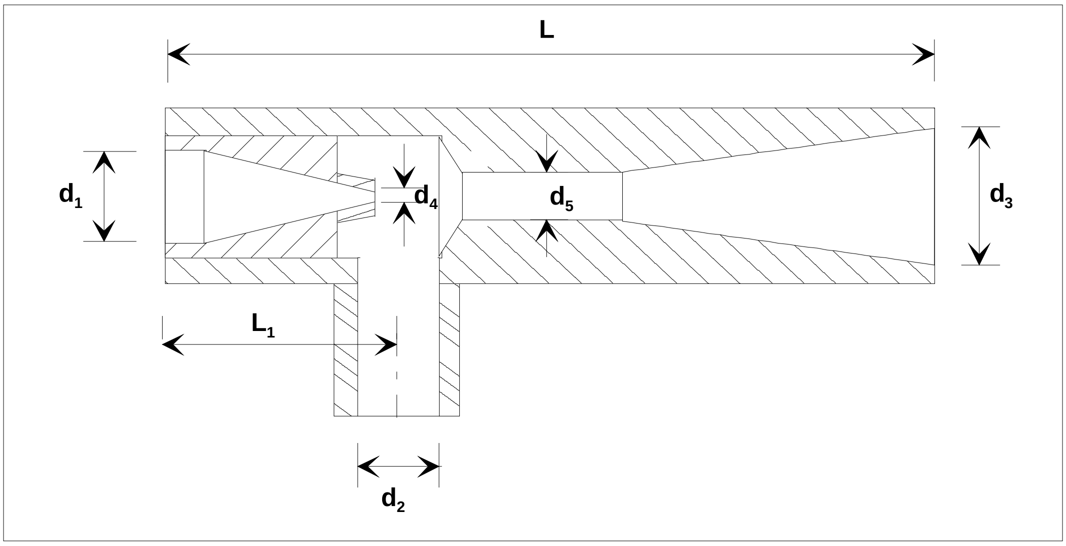

Figure 30. Ejector.

The diameter d_4 of the nozzle is calculated in Eq x according to Russian practice:

$$d_4 = \frac{d_5}{1+\omega} \tag{7}$$

yielding a value of 7.2 mm for d_4.

6.3.4 Simulation results

The main results concerning the performance of the heating system under design conditions are presented in Tables 33 and 34. The ventilation rate is 0.73 1/h in Table 32 and 1 1/h in Table 34.

Table 33. Performance of the heating system under design conditions, when ventilation is 0.73 1/h.

Variable	Symbol	Value	Unit
DH supply temperature	$t_s = t_1$	150	°C
DH flow	m_1	1.058	kg/s
Suction flow	m_2	2.332	kg/s
Distribution flow	m_3	3.390	kg/s
Mixing rate	m_2/m_1	2.20	
Distribution temperature	t_3	95	°C
Return temperature	$t_4 = t_2$	70	°C
Heat loss, conduction	Φ_{wall}	230	kW
Heat loss, ventilation (*	$\Phi_{ventilation}$	128	kW
Heat loss together	Φ	358	kW
Indoor temperature	t_{in}	20	°C

*) ventilation rate 0.73 1/h.

Table 34. Performance of the heating system under design conditions, when the ventilation rate is 1 1/h.

Variable	Symbol	Value	Unit
Distribution temperature	t_3	93.9	°C
Return temperature	$t_4 = t_2$	68.1	°C
Heat loss, conduction	Φ_{wall}	208	kW
Heat loss, ventilation(*	$\Phi_{ventilation}$	161	kW
Heat loss together	Φ	369	kW
Indoor temperature	t_{in}	16.7	°C

*) ventilation rate 1.0 1/h.

Due to the nature of the ejector system, flows are kept constant, thus the heat supply is affected by the ambient temperature, not the indoor temperature. If the ventilation rate in the building alters, heat loss will also change, in turn causing a shift in the indoor temperature. In the cases shown in the tables above, the indoor temperature decreases from 20 °C to 16.7 °C, when the ventilation increases from 0.73 to 1.0 1/h.

Figures 31 to 32 present the performance of the heating system at different outdoor temperatures during the heating period. The heat losses of the building, the supply and return temperatures of the distribution network, and finally the indoor temperature are shown in Figures 31, 32 and 33 respectively. In addition to the basic curves, dashed lines indicate performance when there are restrictions in the DH supply temperature. In winter, the supply temperature is limited to 130 °C instead of 150 °C. This restriction is normal practice in Russian heating systems. In summer, the supply temperature is lowered to 60 °C instead of the usual 70 °C. This change, however, is normally not carried out because of problems related to the hot water service and to corrosion at the boiler stations.

The main result concerns the indoor temperature during the heating period. It does not stay constant, but rises with an increase in outdoor temperature. Indoor temperatures are insufficient and fall below comfortable levels during winter frosts and become uncomfortably high at other times, causing excessive heat losses.

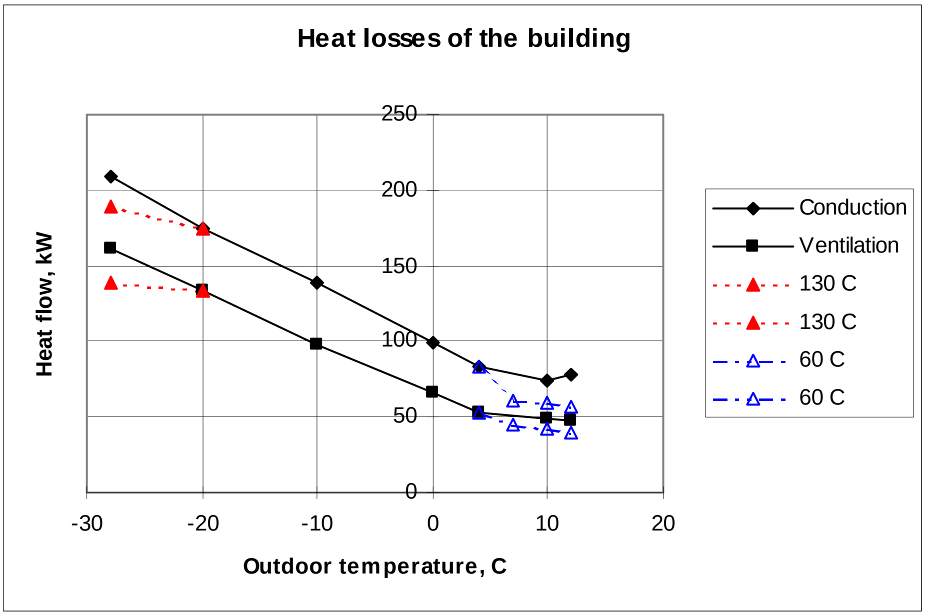

Figure 31. Heat losses through walls and ventilation.

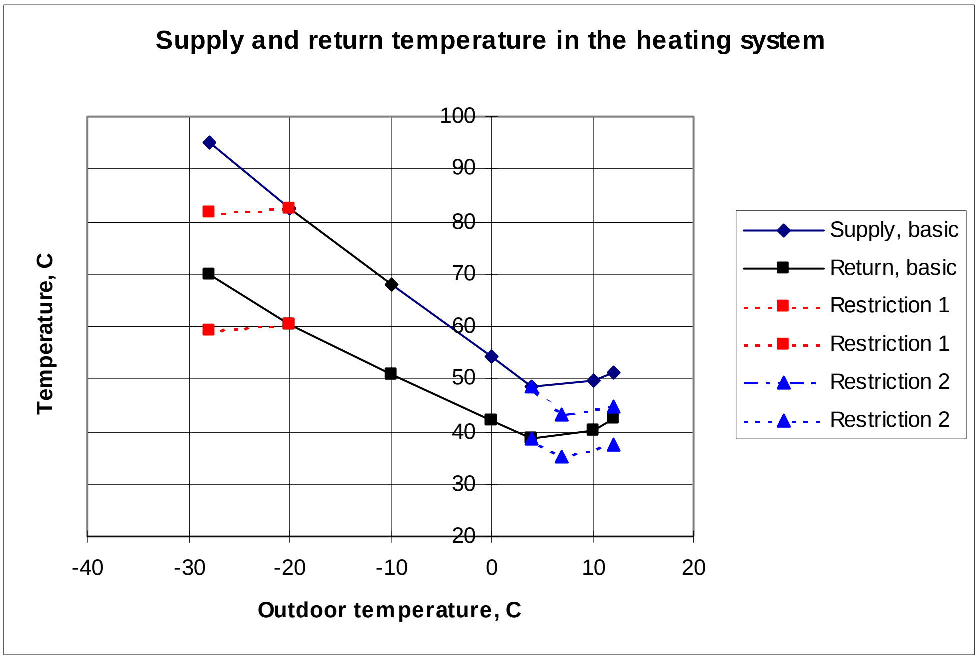

Figure 32. Inlet and outlet temperatures in distribution network.

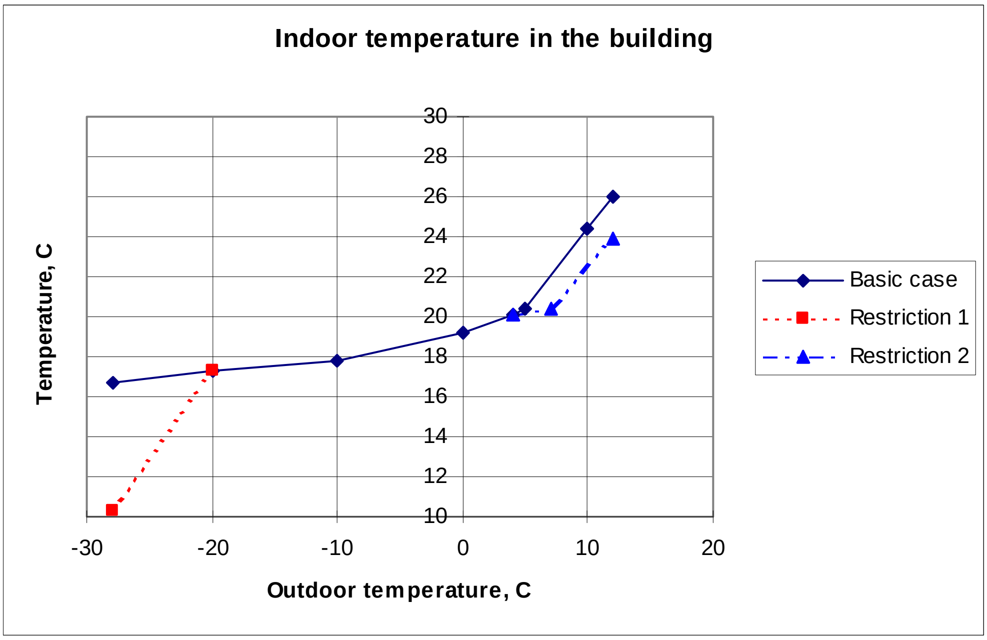

Figure 33. Indoor temperature as a function of outdoor temperature.

6.3.5 Sensitivity studies

Structural and operational alterations in ejector systems result in changes to the indoor temperatures of the building. In this section, the impacts from changes in the ejector's dimensions and the DH pressure difference are studied.

The diameters of the ejector's nozzle and mixer can be chosen in a way other than that indicated in the equations above, and the dimensions can also change under operation due to corrosion or scaling. Figure 34 shows the effect of the nozzle diameter on the indoor temperature when the outdoor temperature is minus 10 °C. The nozzle diameter is 7.2 mm in the basic case, but diameters of 6.8 mm and 7.6 mm are also studied. A change of 0.8 mm in the diameter results in a change of 3.2 °C in indoor temperature. Thus, enlargement of the nozzle gives higher indoor temperatures. Enlarging the diameter of the mixer lowers indoor temperature, as shown in Figure 35, but sensitivity to this change is lower than in the case of the nozzle.

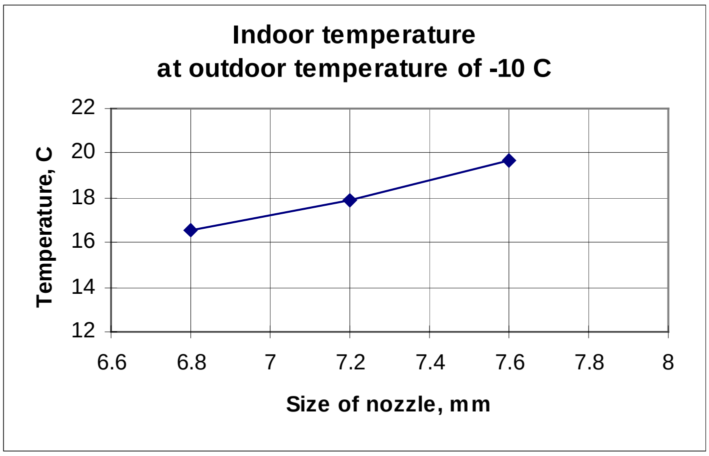

Figure 34. Effect of nozzle size on indoor temperature.

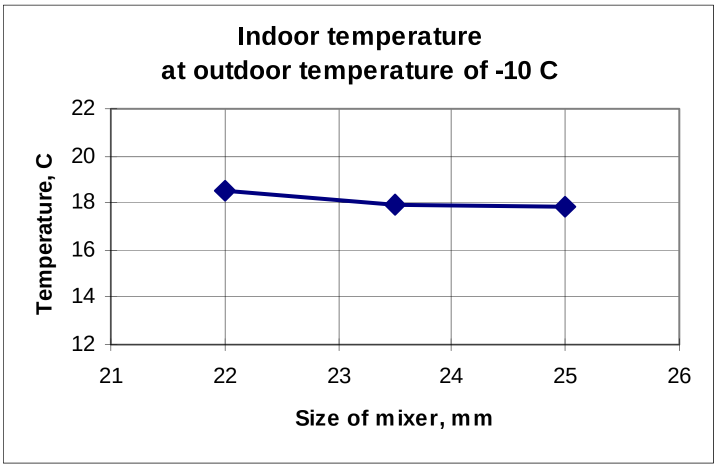

Figure 35. Effect of mixer size on indoor temperature.

The pressure difference between the supply and return pipelines in the DH network (p_s - p_r, in Figure 36) is affected by many operational factors, although in Russian DH systems, the aim is to keep it constant. The impact of a pressure change on indoor temperature is shown in Figure 36. If the outdoor temperature is minus 10 °C, the decrease in indoor temperature is 2.75 °C per decrease in pressure difference of 1 bar.

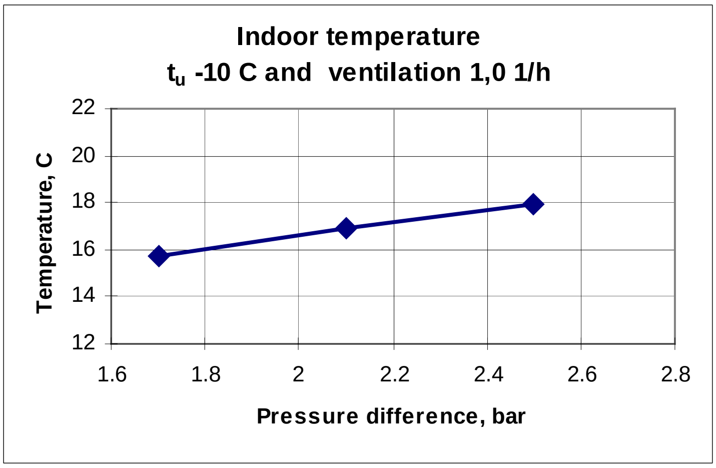

Figure 36. Effect of pressure difference in the DH network on indoor temperature in an ejector-connected system.

6.4 Heat Index

6.4.1 Introduction

Heat index is defined in this context as the ratio of the heat energy consumed in a heat exchanger connected building to the heat energy consumed in an ejector connected building, when the building is district heated and when it is located in the former USSR.

The ejector connection produces an unbalanced indoor temperature in the buildings according to empirical knowledge and according to the study discussed in section 6.3. Indoor temperatures are unacceptably low during winter frosts and uncomfortably high in spring, autumn and summer. Supplementary ventilation such as opening windows has to be utilised during these periods, which causes excessive heat losses. Renovation of the heating network in the building and changing the DH connection from ejector to heat exchanger enables control of the indoor temperature by regulation of the input temperature of the heating network.

In calculating the heat index, it has been assumed that the heating system has been designed to produce a sufficient indoor temperature during the coldest period of the year, and this is certain to result in excessive indoor temperatures at other times of the year. A balanced indoor temperature is assumed to result from using an indirect connection.

6.4.2 Input data in the calculation

Simulations of the heating system for both direct and indirect connections have been carry out by the APROS program. The apartment block simulated by APROS has five storeys and the volume of the building is 14 000 m^3. The average heat conduction for walls, roof and floor is assumed to be 1.0 W/(m^2°C). The rate of ventilation is 1.0 1/h (once an hour). The heating system has design values of 150/70 °C for the DH-network and 95/70 °C for the heating network in the building. The outdoor temperature is -28 °C in the design conditions.

The heating effect of the radiators is 377 kW in the design conditions. Additional heat is produced by people living in the house and by equipment, e.g. lighting and other electrical appliances. This effect is assumed to be 25 kW, which causes a rise of 3 °C in indoor temperature. Figure 37 represents indoor temperature as a function of outdoor temperature for the whole year when using the ejector system.

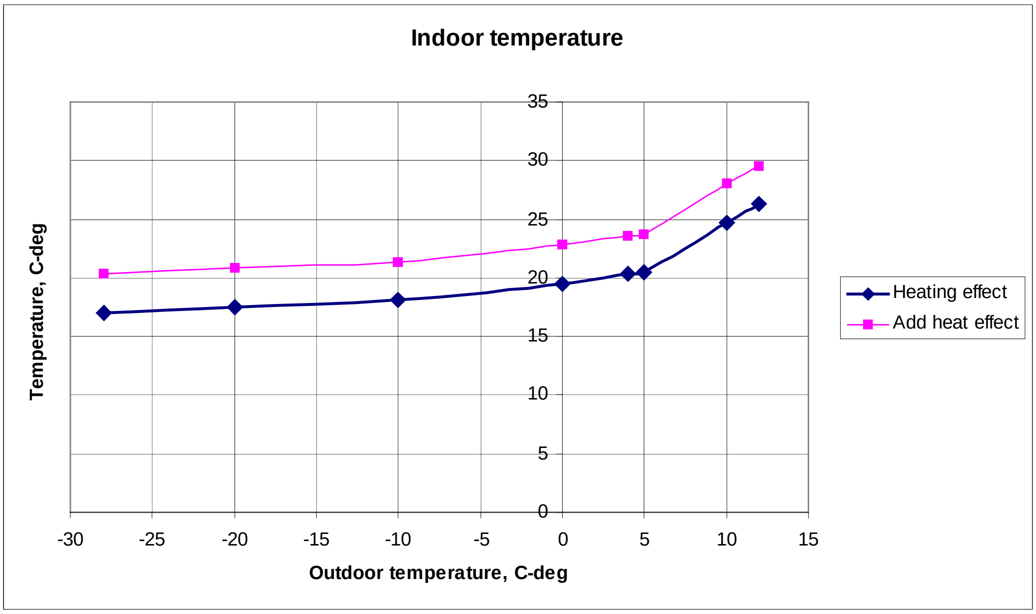

Figure 37. Indoor temperature in ejector heating system.

When calculating heating energy during a whole year, an hourly time series of outdoor temperature is needed, and in this case values measured in Tampere in 1992 were used. The average temperature for the year was 5.3 °C and the lowest temperature was minus 20.5 °C. Space heating is in use when outdoor temperature is plus 12 °C or less. Figure 38 presents the duration of outdoor temperatures during the year.

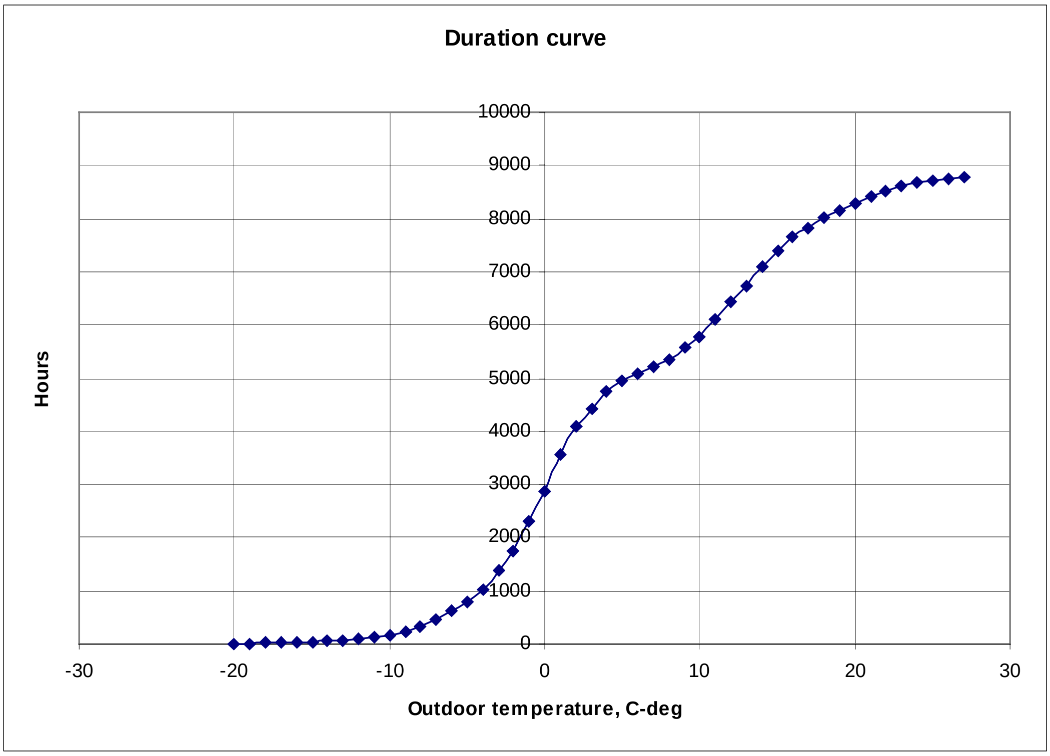

Figure 38. Duration curve of outdoor temperature used in calculation.

In this context, the electricity needed for the circulation pump in the radiator network has also been studied. A pump with a fixed rotation speed has normally been used in the target area, and is compared with a variable speed pump. Figure 39 shows the efficiency curve of the regulable pump. At the design point (4 kg/s and 40 kPa), the total pumping efficiency is 63%, and it lowers with decreasing rotation speed. An efficiency of 60% is assumed for the pump with constant rotation speed.

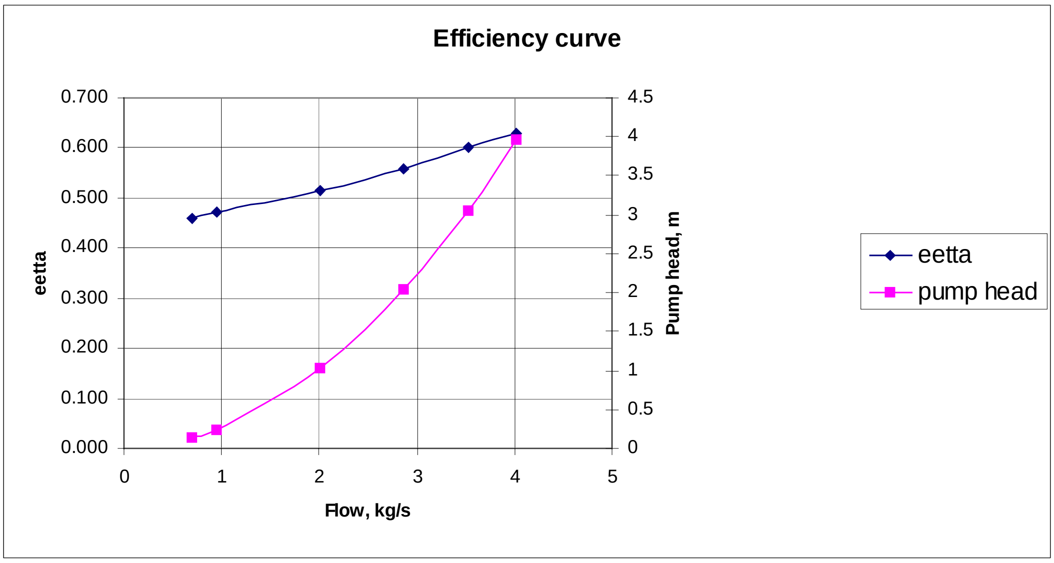

Figure 39. Performance and efficiency curves of regulable pump.

6.4.3 Results - Heat index

Simulation of a heating system using both ejector connection and heat exchanger connection gives the energy consumption at every outdoor temperature, in steps of one degree, from the coldest value up to plus 12 °C degrees as shown in Figure 40. Thus, the energy consumption value contains the time duration of the temperature range and the heat demand at this temperature level. The higher the outdoor temperature, the larger the difference between the two heating systems is.

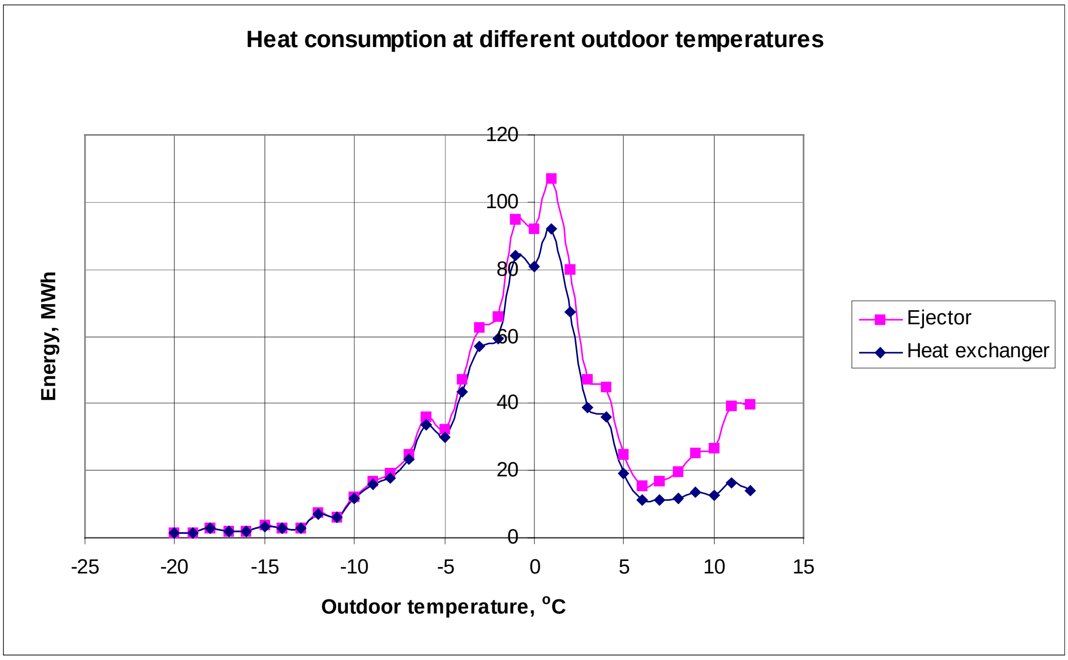

Figure 40. Heat consumption at different outdoor temperatures during a one year period, for both ejector and heat exchanger systems.

The main results can be obtained by summing up heat consumption over the whole year. Heat consumption is:

- using ejector connection 1021 MWh/a
- using heat exchanger 831 MWh/a
- energy saving 189 MWh/a
- percentage saving 19%.

The potential heat saving to be gained by replacing an ejector system with a heat exchanger system is thus 19% according to theoretical calculations. Some practical measurements also indicate the same level of energy saving.

One way to save energy in a heating system is to regulate the speed of the circulation pump in the heating network of the building. This method is normally utilised in western countries, but flow regulation can not be applied to ejector connection. Replacing the ejector with a heat exchanger makes it technically feasible to apply flow regulation, and the resultant electricity saving possibilities are considered more closly in the following text. The basic alternative is constant flow and it is compared with flow regulated by a pump fitted with rotation speed adjustment. The heating network and building simulated by APROS are the same as were used in the calculation of the heat index described above.

The electric power needed for the pumps is presented in Figure 41 for both cases. The power for the constant flow pump is about 270 W over the whole year, whereas the power for the adjustable pump decreases strongly with a rise in outdoor temperature. Electricity saving is shown in Figure 42 for all temperatures, measured in steps of one degree Celsius.

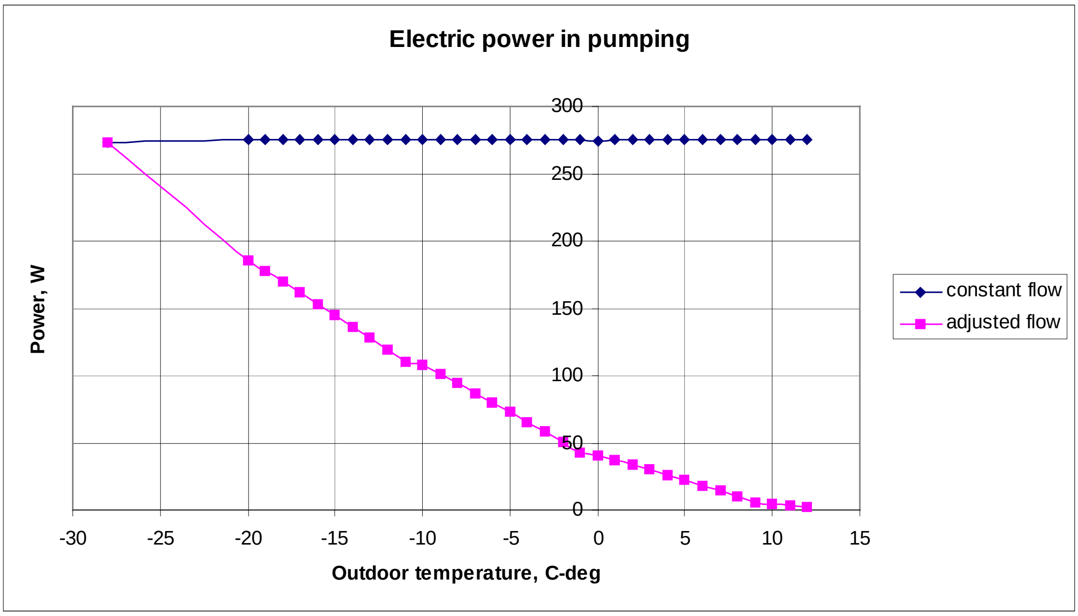

Figure 41. Electric power needed in pumping using the different control techniques.

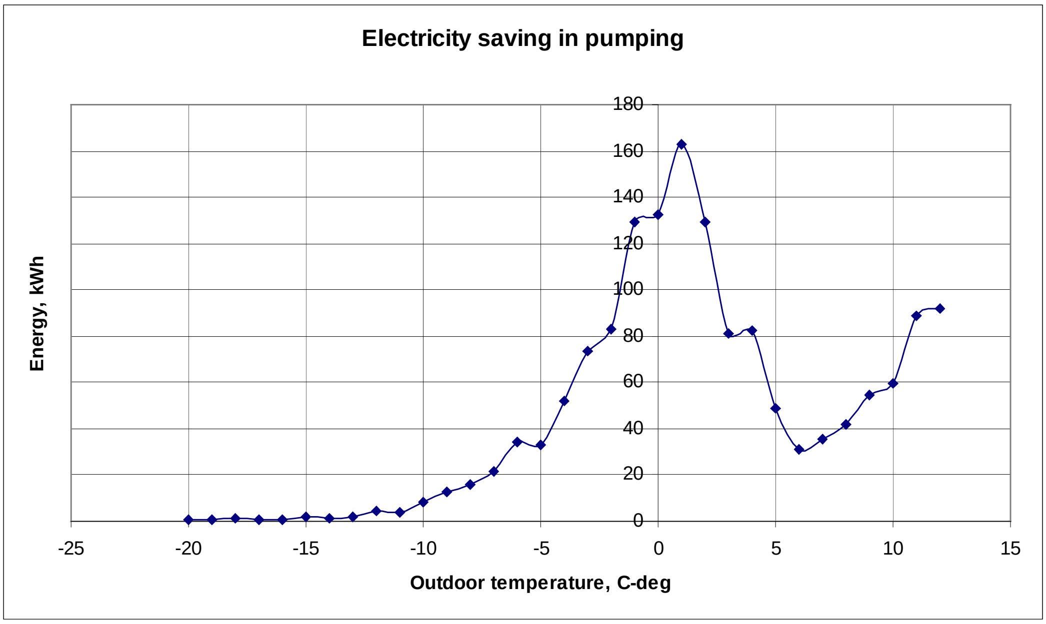

Figure 42. Electricity saved at every temperature range during the year.

Summing up the savings presented in Figure 42 gives the following:

- Electricity consumption using unregulated pump 1772 kWh/a
- Electricity consumption using regulable pump 251 kWh/a
- Electricity saving 1520 kWh/a
- Percentage saving 86%.

Using an adjustable circulation pump in the heating network of buildings achieves a remarkable saving in electricity consumption. However, flow regulation can not be recommended for heating systems in the former USSR countries without thorough renovation of the radiator network. This is because the series connection of the radiators in buildings would cause differing temperatures in the apartments on different floors. The apartments in upper floors would be warm and the apartments in lower floors would be cold if flow regulation is used.

6.5 Dynamic simulation of the MODiS district heating system

The dynamic simulation model of MODiS was created with a real time simulation tool called APROS, a commercially available product from VTT and Fortum. The objective of APROS simulations in the MODiS project was to pilot the real time operation of the entire MODiS district heating (DH) system, including heat production, heat transfer and heat distribution to consumers. APROS was used as a prototype plant analyser to evaluate the operation of the MODiS system in a Russian (or East European) environment.

The APROS simulation tool is well suited for dynamic calculations of district heating (DH) systems. Appropriate library modules exist for modelling boiler houses, district heating networks and different types of consumer substations. Different fuels, such as oil, gas, coal or biomass may be utilised as an energy source. If we consider a full scale MODiS (or other DH) project, APROS is well suited for equipment, automation, and detailed process design. APROS can also be tuned for training or for use as an analysis simulator. An APROS training simulator tool can be built already months before start-up enabling operators to practise process control, emergency situations, start-up and shut-down in a graphical user display environment. By visualising process responses, a comprehensive view of the whole system operation can be created. The control systems may be tuned and tested by APROS real time simulations. This saves time and money during the construction and start-up period. The simulator can be used for studying normal operation, emergency conditions, and process failures.

In APROS, the library modules for boiler house, DH network and consumer substations were tailored, using input data provided by the MODiS partners, to agree with the operation of MODiS components. As an example, the renovated Russian DH system presented above, was modelled with APROS. An alternative DH network with a ring-pipe was also simulated and, finally, a partial renovation of the example DH system was modelled with both ejectors and heat exchanger units in the same network.

Experience has shown that difficulties may occur in partial renovation of the Russian DH network as ejectors are designed for a minimum pressure difference of 0.25 MPa and supply temperatures of 150 °C. The corresponding design temperature and pressure for the MODiS system are 0.1 MPa and 115 °C respectively. Such design values would result in insufficient heat supply to housing with ejector connections resulting in too low indoor temperatures. With indirect consumer connections, indoor temperature is kept constant by regulating DH water flow with a control valve. Instead, the mass flow of DH water through the ejector is dependent on the pressure difference of the network, and the indoor temperature is regulated by means of the DH supply temperature. Due to these different design criteria, the reconstructed part of the network may operate well, while houses with ejectors may suffer from insufficient heating. In practice, to avoid situations like this, DH water flow has been restricted in the heat exchanger units. This results in more equal indoor temperatures (i.e. an equally bad situation) throughout the network. The other solution would be to change the old ejectors or ejector nozzles to bigger ones, if the pipe dimensions of the radiator lines are large enough. Below, 'mixed consumer connections' were simulated with different supply temperatures and network pressure differences to evaluate the different renewal alternatives for step-by-step construction.

6.5.1 Main features of the APROS simulator

APROS (Advanced PROcess Simulator) is developed for the full-scale modelling and dynamic simulation of industrial processes, e.g. [12]:

- Combustion power plants: APROS Combustion
- Nuclear Power plants: APROS Nuclear
- Pulp and paper mills: APROS Pulp & Paper (also known as Apms = Advanced Paper and Pulp Mill Simulation Software).

With each of these simulators, one can model gas/liquid flow networks, automation and electrical systems. The APROS simulation environment consists of a simulation engine and a graphical design user interface called Grades. The simulation engine contains versatile solvers and model libraries. The models used for the components are designed so that in most cases, (for example, pipes, pumps, heat exchangers, valves, controllers, etc.) the necessary input data is available on the basic component data sheets. A very important feature of the design simulator is the speed of simulation, which should be clearly faster than real time while still maintaining the necessary accuracy level.

The APROS database structure supports a hierarchical model description. The user normally operates on the component level using predefined process components. These elementary components form ‘a dual network structure’, which is made up of thermal hydraulic and composition networks. The thermal hydraulic package of an APROS solution includes mass, momentum and energy conservation equations. Pressures, densities, and other scalar variables are solved in their own nodes and mass flows in the junctions (branches) lying between the nodes. As pressures are solved through iteration of linearized mass and momentum equations, loops in the network are also allowed.

6.5.2 The APROS model for MODiS

Heat production was modelled for the combustion of coal, biomass, oil and natural gas. In APROS, combustion reactions take place in a calculation node, into which fuel and combustion air are fed. In the design phase, pipes were used to model the ducts, which in turn determine the furnace air/flue gas volume and the dimensions of the furnace. Heat transfer from the air/flue gas to the water or steam was represented as a series of heat exchangers having flue gas on one side and water or steam on the other. In the MODiS model, the supply temperature of the DH water was set by the fuel feed. Air mass flow was controlled by specifying the oxygen concentration in the flue gas.

In the MODiS concept, the water flow in the network is variable. In the APROS model of MODiS, variable speed circulation pumps controlled the supply pressure by defining the minimum pressure difference of the network.

In consumer substations, plate heat exchangers were used for both heating and domestic hot water. Heat transfer coefficients in the APROS model were adjusted by efficiency parameters to achieve the design conditions of the MODiS system. The input data for dimensioning the heat exchangers was calculated with the CeteLite™ program of Cetetherm Oy. Radiators in the apartments were modelled as steel heat-conducting structures with water flowing on one side and indoor air on the other. In the ejector model, the design conditions (mixing factor, mass flows, and temperatures) were adjusted by modifying the theoretical form loss coefficients.

A minimum number of control circuits were used for the MODiS model. The control system was composed of PI-controllers, analogue signals, measurements and elemetary components, as well as continous device controllers.

6.5.3 Simulation results of the MODiS case study

Input data for the case study follow the definitions presented in Chapter 6.2. Network routing and dimensioning are shown in Figure 24 and Table 28 respectively. The heat consumption of consumers is presented in Table 26. The specifications of the boiler plant are given in Tables 30 and 31. The only exception was that, instead of two 10 MW boilers, one 20 MW boiler was used to model heat production. The outdoor temperature in the design situation was -28 °C.

An alternative DH network for the case study was created by connecting consumers 15 and 20 (see Figure 24) with a DN125 pipe. The main pipeline from point H5 to point H24, was also changed to DN125. The performance of this DH system was evaluated with a simulated DH water leakage from the supply pipe at point H44. The pipe breakdown simulations are shown in Appendix B and in Table 35. The first simulation in Appendix B represents normal operation with a ring-pipe and the second represents the situation after a pipe rupture. In the third simulation, DH water flow in the damaged area was closed with valves. The fourth simulation shown in Appendix B represents a pipe breakdown in the DH system without a ring-pipe. The simulation results indicate that the reliability of the example DH system was considerably increased by the inclusion of the ring-pipe structure. In the case of a pipe rupture in branch-type system, the network pressure crashed, and the risk of water boiling in the network was obvious. With the ring-pipe, pressures in the network were maintained at acceptable values. However, it should be noted, that with such high water leakage, a make-up water tank would have been emptied in a few minutes, if the damaged area were not isolated.

Table 35. Comparison of operation of example DH network with a branch-type structure and with a ring-pipe structure.

Case	Normal operation		Pipe rupture		
	Branch	Ring-pipe	Branch	Ring-pipe	Ring-pipe / construction
Pumping					
Supply pressure, MPa	0.418	0.413	0.275	0.418	0.596
Return pressure, MPa	0.200	0.200	0.038	0.188	0.200
Mass flow, kg/s	117.9	117.9	133.4	140.5	117.9
Water leakage, kg/s	0.0	0.0	15.5	22.6	0.0

In the example simulating a partial renovation, the network routing was different for the southern part of the network with ejectors, as shown in Appendix C. The minimum network pressure difference was raised to at least 0.25 MPa in the ejector part of the network, to ensure satisfactory operation of the ejectors.

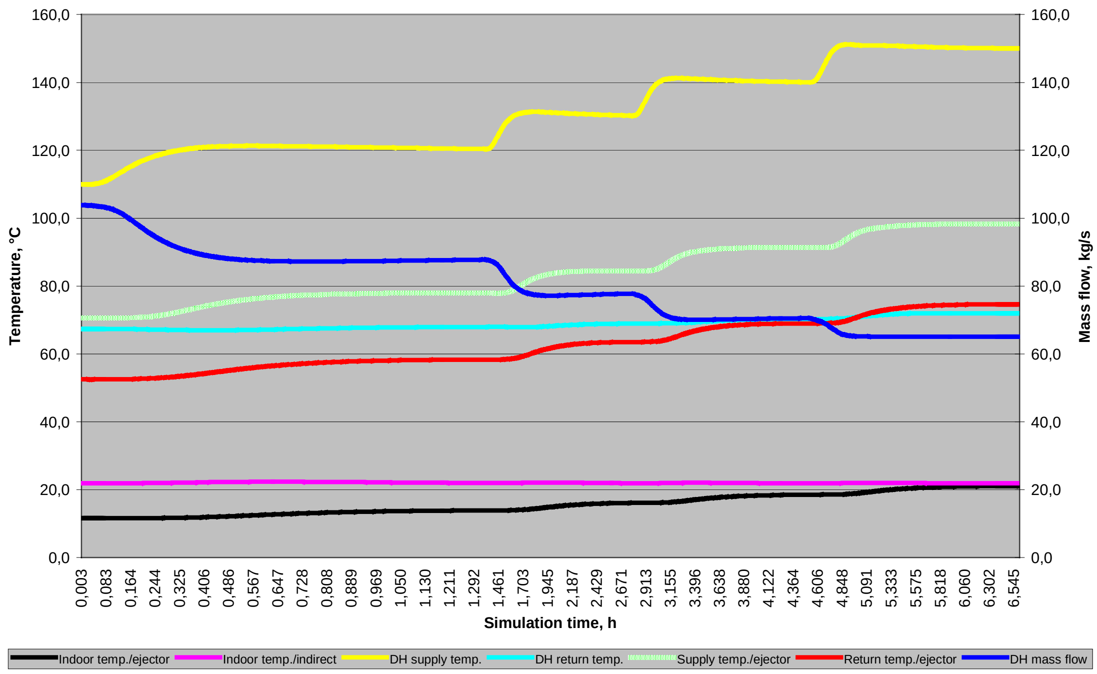

Figure 43. Simulation example with indirect and ejector connections. Minimum pressure difference in the network 0.25 MPa, outdoor temperature -28 °C.

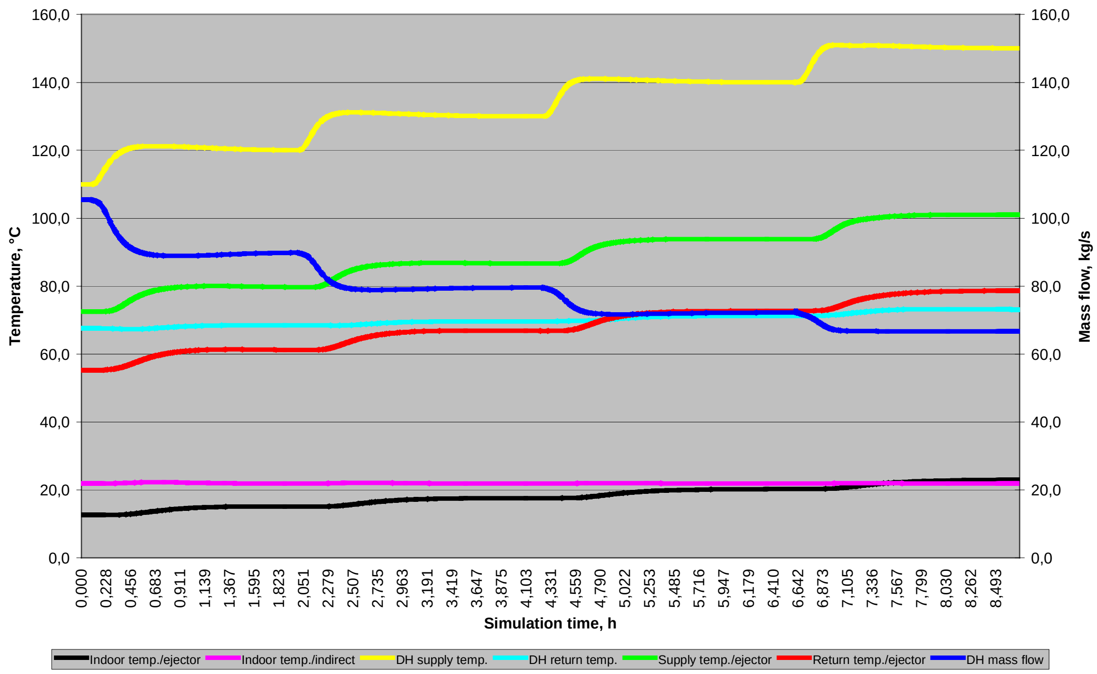

Figure 44. Simulation example with indirect and ejector connections. Minimum pressure difference in the network 0.30 MPa, outdoor temperature -28 °C.

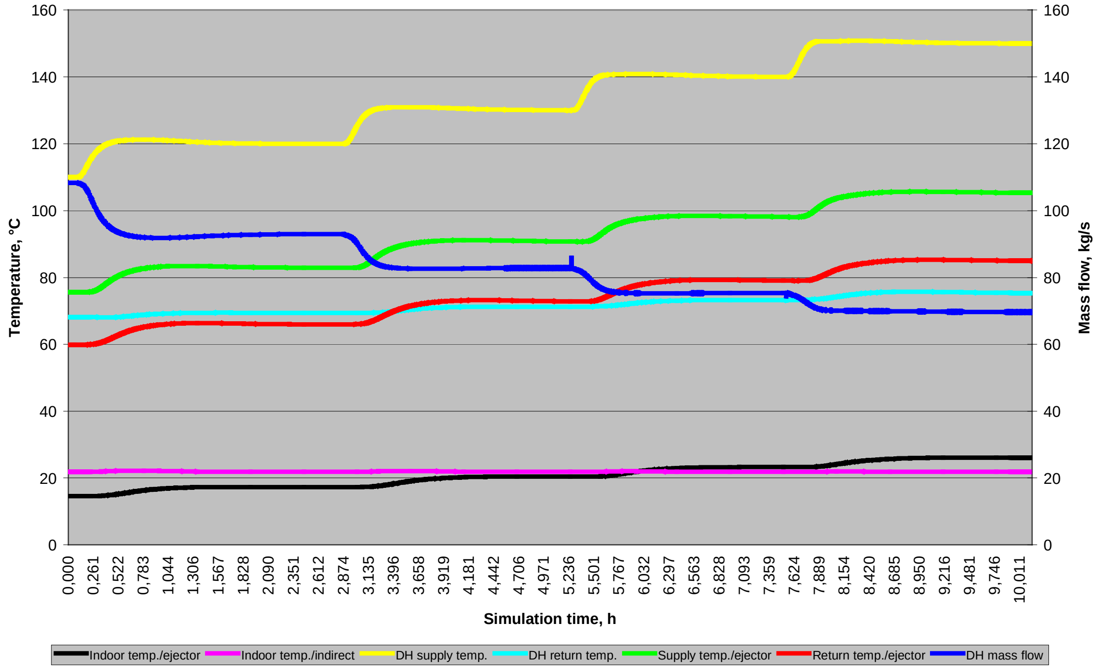

Figure 45. Simulation example with indirect and ejector connections. Minimum pressure difference in the network 0.40 MPa, outdoor temperature -28 °C.

In Figure 43, 44 and 45 the simulation results with 'mixed consumer connections' are shown under design conditions (outdoor temperature -28 °C). In these figures the minimum pressure difference in the network was kept constant (0.25 MPa, 0.30 MPa and 0.40 MPa) and the temperature of the DH supply water was varied between 110 °C and 150 °C (yellow line). The minimum pressure of the return DH water was raised from 0.2 MPa with 110 °C supply temperature to 0.5 MPa with 150 °C supply temperature to avoid boiling of the DH water. For simplicity, it was assumed that the temperature of the DH return water from the heat exchanger units was approximately constant. The red line shows the temperature of the DH return water from the ejector and the light blue line the DH return water temperature measured before the boiler house. It can be seen that even though the return temperature of the ejector is increased by about 20 °C, only a minor increase in the return temperature of the DH water flowing to the boiler is observed. However, if we increase the number of ejectors, the increase in the DH return water temperature may be substantial.

Above, the light green line is the supply temperature of the DH water to the ejector and the blue line is the mass flow of the DH water to the boiler. The black and the pink lines represent the indoor temperatures of the apartment buildings 11 and 35 with an ejector and with a heat exchanger unit respectively. The indoor temperatures of other apartment buildings with an ejector were about the same or sightly higher. The results show that if we operate at a lower supply temperature and network pressure difference than the ejector design values of 150 °C and 2.5 MPa, insufficient heating is observed in apartment buildings with ejectors. If we increase the pressure difference in the network, a lower DH supply temperature is needed for the ejectors to reach the indoor temperature of 21 °C. In this simulation example, a DH supply temperature of 130 °C was needed for a network pressure difference of 0.4 MPa. Such a large pressure increase (compared to the design conditions) means a large increase in pumping work. The situation was illustrated by simulating the southern part of the network with a booster pump in the supply line (see Appendix 3) to increase the pressure to a level sufficient for the ejectors. The minimum pressure difference in the reconstructed network, maintained by the DH circulation pump, was 0.1 MPa. The results are shown in Table 36 and Figure 46.

Table 36. Simulation example with indirect and ejector connections. Comparison of the pumping power consumption with a circulation pump only, and with both circulating and booster pumps in the network.

Without booster pump				With booster pump					
Power	Temperature		DH pres.	Power			Temperature		DH pres.
Circ.	DH supply	$Indoor_{ej.}$	$dp_{min.}$	Circ.	Boost.	Total	DH supply	$Indoor_{ej.}$	$dp_{min.}$
kW	°C	°C	MPa	kW	kW	kW	°C	°C	MPa
36.8	110	11.6	0.25	24.9	3.2	28.1	110	11.0	0.1/0.25
34.0	120	13.9	0.25	17.6	3.9	21.5	120	13.4	0.1/0.25
32.3	130	16.1	0.25	13.8	4.3	18.1	130	15.8	0.1/0.25
29.1	140	18.5	0.25	12.1	4.3	16.4	140	18.6	0.1/0.25
26.1	150	21.1	0.25	11.1	4.4	15.5	150	21.4	0.1/0.25
52.8	110	12.6	0.30	25.3	5.0	30.3	110	12.6	0.1/0.30
44.6	120	15.1	0.30	17.9	5.8	23.7	120	14.9	0.1/0.30
39.2	130	17.6	0.30	14.2	6.1	20.3	130	17.6	0.1/0.30
35.4	140	20.3	0.30	12.8	6.2	19.0	140	20.4	0.1/0.30
32.6	150	23.0	0.30	11.8	6.2	18.0	150	23.6	0.1/0.30
70.9	110	14.6	0.40	26.0	9.3	35.3	110	14.6	0.1/0.40
60.3	120	17.3	0.40	18.5	10.1	28.6	120	17.2	0.1/0.40
54.9	130	20.3	0.40	15.7	10.3	26.0	130	20.2	0.1/0.40
49.6	140	23.3	0.40	14.1	10.4	24.1	140	23.1	0.1/0.40
45.0	150	26.1	0.40	13.0	10.4	23.4	150	26.2	0.1/0.40

In Figure 46, lines of different colours represent the variation in the minimum pressure difference of the old part of the network. The numbers next to the plotted points are the indoor temperatures of apartment building 11 with an ejector connection. The results show that in this example, 50% savings were achieved in power consumption when a booster pump was utilised in the old part of the network. If we decrease the number of ejector connections (i.e. renovate the old network) the differences in power consumption shown below would become smaller. To conclude, with 'mixed consumer connections' network design should be considered carefully, keeping in mind the temperature and pressure requirements for ejector systems. The end solution would be case specific and a question of optimisation between capital and operating costs.

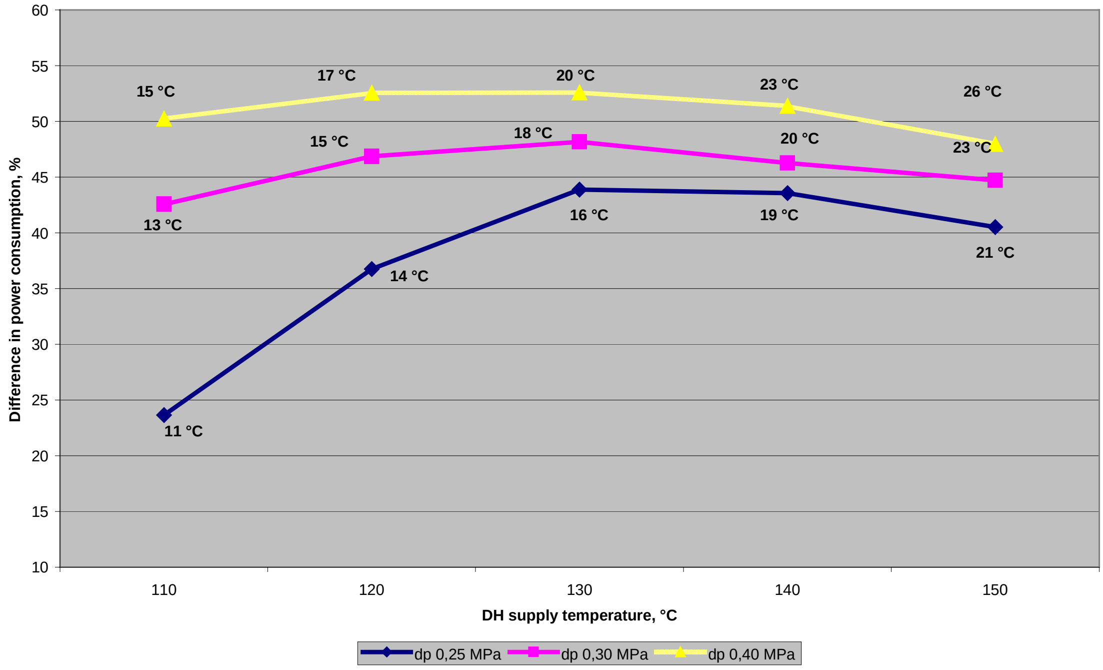

Figure 46. Difference between power consumption of DH water pumping with and without booster pump. Numbers on the sheet are the indoor temperatures of ejector-connected apartment buildings (outdoor temperature -28 °C).

6.6 Corrosion estimation

6.6.1 Knowledge-based tool

Corrosion has been a primary concern in the technical development of DH-pipes and equipment. There has been a drive to improve the quality of DH-water to the level where corrosion is no longer a technical or economic problem in West Europe. In the former East-bloc countries, corrosion is a well known and serious problem and, due to poor protection, causes economic losses and lowers the reliability of the whole DH-system.

In Russian DH-systems, direct connection is used in space heating and open connection is widely used for hot tap water, which means heavy susceptibility to pipeline corrosion. The normally used DH-water and the supplementary make-up water are a potential threat to the pipes, and an operation time of only four to six years for pipes is not unusual. Unsatisfactory water contains plenty of corrosive matter, such as chlorine, oxygen, particles, iron and ferrous oxides, and causes the pH-value to vary widely. Oxygen, a necessary element in drinking water, is especially responsible for corrosion in pipes.

As a part of the MODIS-research, a knowledge-based application was developed to estimate corrosion on the internal surface of DH-pipes, and a tool has been built to easily investigate different cases. The program-tool utilises environment software called LEVEL5 Object. LEVEL5 Object is a development environment with a user interface for making embedded tools, in this case for corrosion estimation. The knowledge-based tool requires experts to input the data concerning pipe dimensions and corrosion phenomena to the program. The tool is a knowledge representation mechanism that can be affected by the methodology of the user.

The expert system named PIPECOR estimates the corrosion resistance of carbon steel district heating pipes in various water types used for heat transfer. The program gives an estimate of the remaining service life of the pipe under the conditions defined by the user, and for the current corrosion rate.

The PIPECOR program has been constructed to appropriately take into account the effects of all important factors that may contribute to steel corrosion in the water used for district heating in the former East-bloc countries.

The corrosion has been assumed to be mainly uniform (general) corrosion. The prediction of the service life is based on this assumption. A warning of the possibility of pitting corrosion will also be given if the chloride and/or sulphate contents are high and the value of alkalinity is low compared to these values.

The most important factor determining the corrosion rate is the oxygen content of the water. The temperature and the flow rate also have a great influence.

High values of alkalinity and hardness retard corrosion. In very hard water, however, deposits (scale) can be formed that impair the heat transfer from the steel to the water and vice versa, and increase pressure losses in heat exchangers and boilers.

The main work sheet of PIPECOR, shown in Figure 47, enables the input of relevant data and displays the estimation of correction. The results also include a short conclusion covering the corrosion considered in the case. The main input variables are the following:

- pipe size and wall thickness
- flow rate
- water temperature
- oxygen content
- pH value

- alkalinity
- hardness
- chloride content
- sulphate content
- conductivity
- actual age of pipeline.

The main output variables are following:

- depth of attack
- corrosion rate
- remaining service life
- qualitative comments on the results and improvement suggestions.

The tool contains also links to other programs to continue visualisation of results.

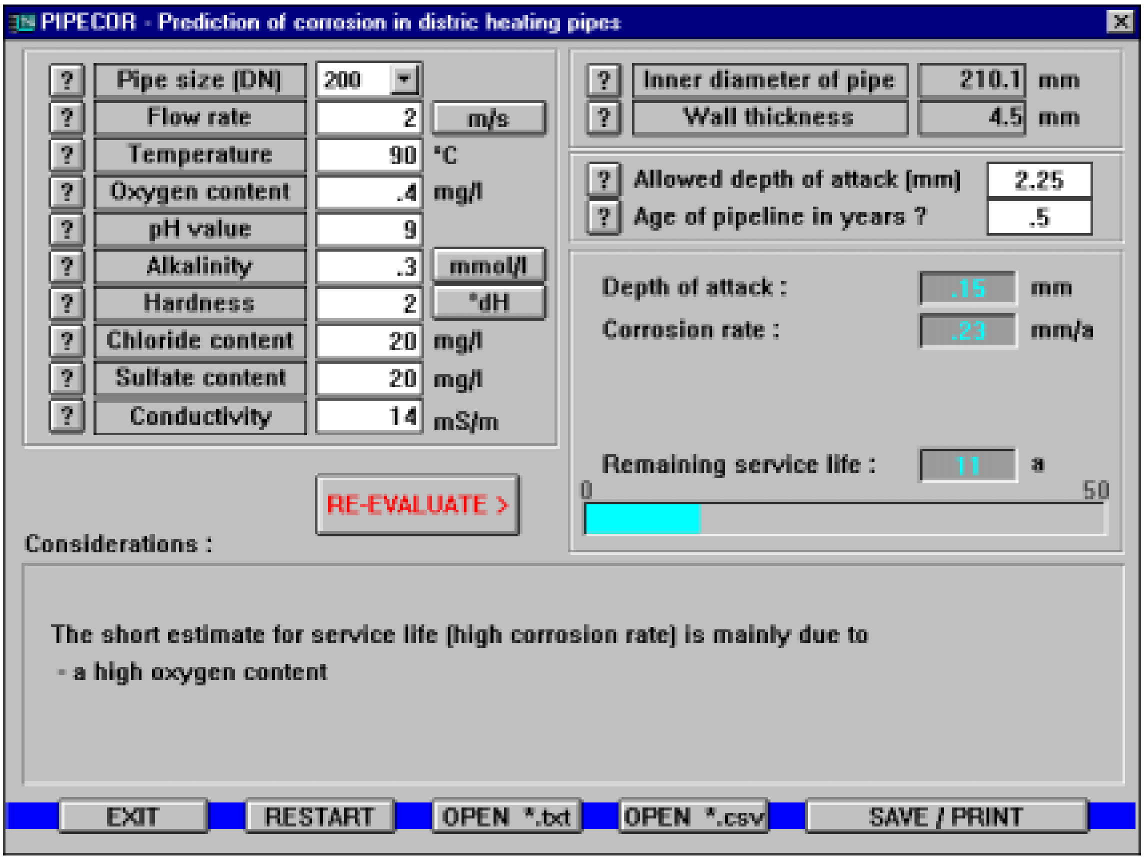

Figure 47. Main worksheet for input and output in the PIPECOR program.

6.6.2 Some applications

In a district heating network, the conditions vary according to the season. Supply temperature varies in the range of 150–70 °C, and the return temperature varies in the range of 70–45 °C depending on both the outdoor temperature, and the consumer's heating equipment. However, the ambient temperature stays around zero degrees Celsius for the major part of the year. In Central Finland, the average yearly outdoor temperature is 5.3 °C, and 1.5 °C during the period that space heating is in use. Thus, the average supply temperature in a district heating pipeline is about 80 °C, and the average return temperature 48 °C, during the year.

Figure 48 shows how the corrosion rate depends on the water temperature, when the other values of water quality are kept at a fixed level. The corrosion rate in the pipe wall is 0.08–0.11 mm/a and is over 30% higher in supply pipes than in return pipes due to the temperature difference when considering uniform corrosion. In this particular case, the risk of pitting corrosion is remarkably high, 0.3–0.4 mm/a.

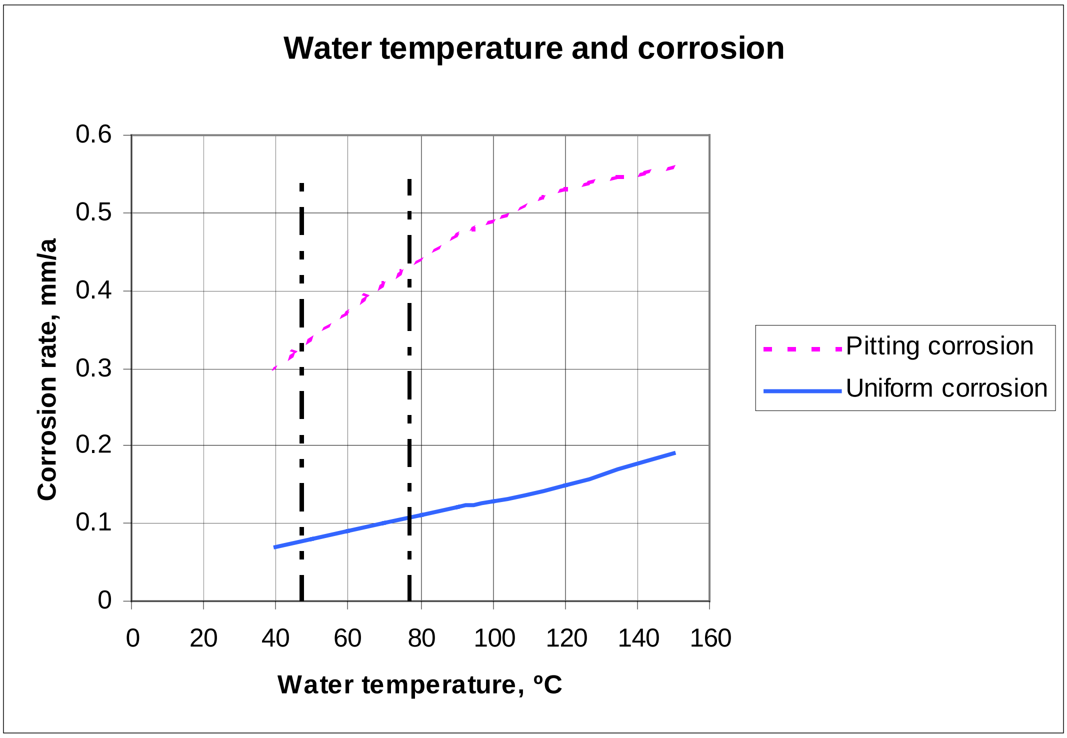

Figure 48. The impact of the temperature in DH-water on uniform corrosion and pitting assuming a defined water quality.

The oxygen content has the greatest impact on corrosion, as shown in Figure 49. If, for example, the oxygen value is 1 mg/l, the corrosion rate would be nearly 0.4 mm/a in the supply pipe wall and 0.27 mm/a in the return pipes. The difference between the supply and return pipe depends on the corresponding temperature difference. Halving the oxygen content to 0.5 mg/l would be insufficient to achieve an appropriate lifetime for the pipes.

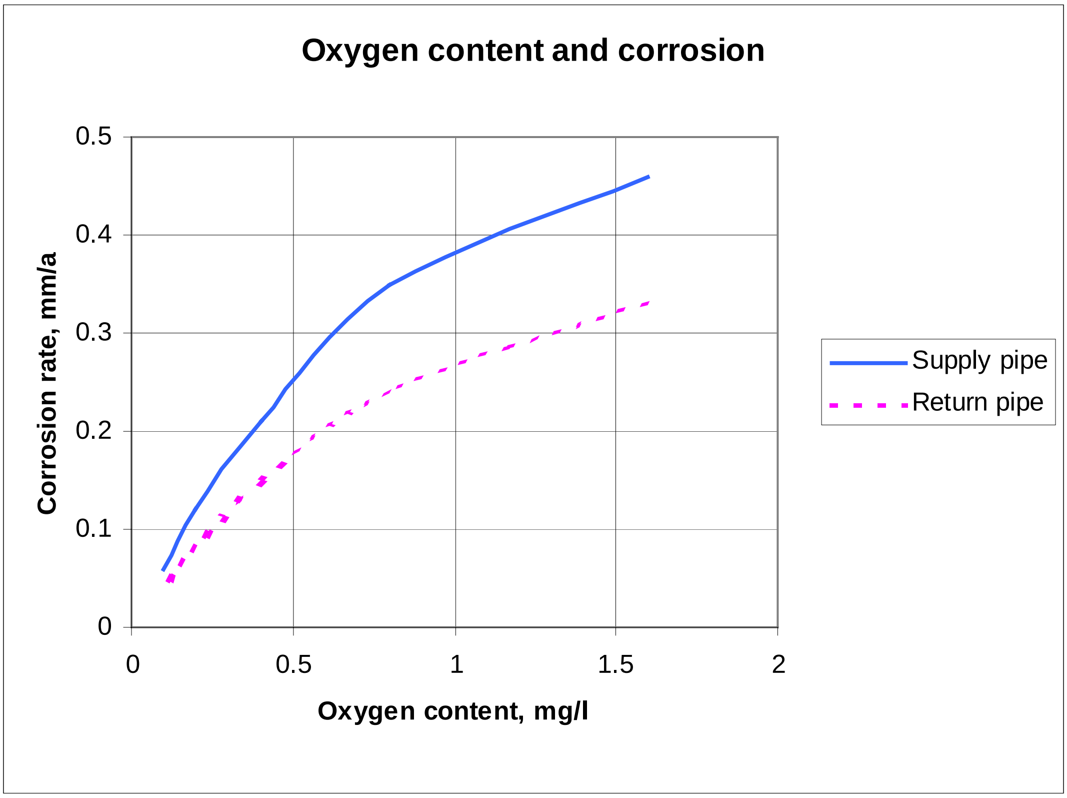

Figure 49. Impact oxygen content corrosion rate.

7. Summary

MODiS principles and working packages

MODiS, the Modular District Heating System, comprises highly integrated prefabricated modules, where the modules themselves may be boilers, pumping stations, substations, metering devices, automation equipment, planning tools, information and management systems, etc. The modules and their components are tested at the factories prior to delivery. The modules are all physically and electrically compatible and have their own local measurement and automation systems, which can be connected to the open MODiS information system. The MODiS information system connects all the modules together electrically, so that information can be sent from each device to the energy business management level, and vice versa. MODiS, with the inclusion of the relevant technical and economic details, thus forms both a far-sighted approach and a strong backbone for the building and development of district heating systems.

The main aim of the MODiS project was to develop products for either building an entirely new district heating (DH) system or for renovating and extending an existing district heating system in East European countries. Good planning of the parts that constitute DH-systems, optimal implementation and functioning, short construction time, and significant lengthening of the service life of the whole system, where also important objectives. The planning and operation of the whole DH system were verified by static and dynamic modelling. In this way it was possible to ensure of the compatibility of new modules to the old DH systems and that they would function adequately in both the present and the future based on the new parameters. The models were able to simulate the performance of a DH system under both normal and exceptional operational conditions. In the dynamic simulation model, the parameter settings of the various operation devices could be pre-set.

The MODiS project was divided into seven Working Packages (WPs 1–7), which have been guided by both the product development interests of companies in the heating industry and the targets of the MODiS family. In addition, requirements and rules are to be developed for new components that will later be added to the MODiS product family. Each of the 21 project partners has been involved in a working package through which, from their respective fields of expertise and interest, they have supported the basic development work. The essential condition was that this work had to serve the R&D work of the industry.

East European district heating systems

The district heating (DH) technology, used in the Central and East European countries, was mainly developed in Russia in the time of the Soviet Union. As a result, most of the DH systems in the MODiS target area use Russian DH technology. The Russian DH technology has a history of about one hundred years. Current Russian DH systems differ from the West European DH systems in several ways. The main difference is that the water flow of the network is constant, which means that the heat capacity is regulated solely by means of the supply temperature. The networks are usually designed to operate at higher supply temperatures and network pressures than the West European DH systems. Moreover, in the MODiS target area countries, the consumer is usually connected directly to the DH-system through ejectors and the same DH water circulates in the consumers' radiators. Domestic hot water (DHW) is taken from the DH network, which means that oxygen is leaked into the system causing serious corrosion problems. Today, the largest district heating network in the world is in Russia. The total length of the Russian DH network (2 pipe system) is estimated to be over 260 000 km. Large DH networks are also found in the Ukraine, Poland, Romania, the Czech Republic and Belarus. The largest DH systems are in St. Petersburg, Moscow, Warsaw and Prague.

MODiS system definitions

The MODiS system can be divided into three levels. The first level includes the heat production, transfer and consumer subsystems. The subsystems consist of modules based on either components made by several producers or on individual components. In the second level every subsystem has its own information system, incorporating measurement, data collection, alarm, control and regulation equipment. The Lonworks technology is used for the interoperable control of the modules in the subsystems. In the future the subinformation systems will all be connected to one main information system, which will allow two-way information transfer. The third level will be management systems, which will utilise the two first levels. The management level consists of general organisational and administrative management systems. The planning, operation and maintenance of the MODiS system, and customer management are also included in this level.

The starting point for the basic MODiS system is the DH system in Scandinavia and Russia that exists at the moment. At this initial stage, the parameters specified for the MODiS system are basically a compromise between the parameters currently in use in Scandinavia and Russia. In Scandinavia the maximum outgoing temperature is 115 °C with a 50 °C temperature drop due to cooling and a typical design pressure of 1.0–1.6 MPa. The outgoing temperature of the Russian DH-system is 150 °C and the pressure 1.6–2.5 MPa. Most of the Russian DH systems have a constant water flow. The cooling in the Russian network is nowadays about 40 °C. Temperatures after the ejector in the secondary side are 90 °C for the outgoing water entering the radiator circle and 70 °C for the return water. The domestic hot water is taken out before the ejector and is regulated to 65 °C by the return water temperature of the radiator circle.

In essence, the MODiS system consists of a closed 2-pipeline system, in which the water flow is regulated by pumps. Combined heat and power (CHP) production units are connected to the network via a heat exchanger. The boiler plant is connected directly to the heat transfer network but consumers are mainly connected indirectly. In this way the oxygen content of the district heating water can be kept at a low level. The domestic hot water comes from cold water that has passed through the heat exchanger. The pressure variation in the DH-network is therefore less dependent on consumer equipment.

Combined heat and power (CHP) plant

Combined Heat and Power (CHP) is an energy conversion process where electricity and useful heat are produced simultaneously in a single process. The useful heat is used for district heating or industrial processes. Electricity generation is a function of simultaneous heat production. The power to heat ratio describes this relationship, which is called the characteristic curve of a CHP plant. The characteristic curve is also a function of the temperature and pressure of the output heat. CHP production has high overall efficiency, which annually can be as high as 85–90%. This is much higher than the 40–45% efficiency of a condensing power plant that generates only electricity. CHP production needs about 40% less fuel than the corresponding separated boiler and condensing power plant production. Conservation of fossil fuels and a reduction of combustion-related emissions are the benefits that result from using CHP heat in a DH-system. Heat outlet from condensing power plants into lakes, rivers or the air can also be avoided. District heating systems with multiple units can optimise overall plant efficiency by selectively operating fewer units at or near maximum efficiency during partial load conditions. Improved efficiency means less fuel use for the same amount of energy produced, which in turn results in the conservation of fossil fuels, reduced emissions, and improved air quality. MW gas-fired CHP plant decreases green house gas emissions by about one million tons a year when compared to equivalent separated coal-fired conventional production and by about a half of that amount when compared to separated gas-fired production. Biomass combustion is considered to be a means of zero net production of CO_2.

Boiler plant, pipelines and consumers substations

Boiler plants are delivered in complete operational units including all necessary components and functions. Boiler plants are gas or oil fired. Solid fuel-fired units are also available. Three-pass shell boilers are the most used boiler configuration. This reliable and highly regarded technology achieves a thermal efficiency of 90% without economisers. Water treatment and a high level of water quality control ensures the high availability of boiler plants as well as a long service life for pipelines and auxiliaries. The heating output from a supply boiler plant could be 1–200 MW, which can be divided into basic modules. A boiler plant of up to 15 MW thermal power can be transported in one modular container. The size of a plant with higher thermal power would require the boiler plant to be divided into more than one modular container for transportation.

A pipeline consists of two pipes: the outgoing and the return pipe. Pipes with steel walls are covered by fixed rigid foam insulation. The pipe elements are made in 6 and 12 metre lengths. A waterproof plastic duct covers the pipeline. Pipelines sections between branches and fixed points form pipeline modules. Pump stations also form a module in the network.

The basic connection of a consumer substation is a so-called two-stage coupling substation. The primary side is divided into two parallel water flows in the first stage, one for the space heating side and the other for the domestic hot water side. In the first stage, the primary flow is cooled separately and then united prior to entering the tap water preheater in the second stage before returning to the district heating return pipe line. In effect, the hot water heat exchanger runs into the second stage of the heat exchanger. The energy used by each consumer is measured so that the consumer pays for just that amount of energy, which he has used.

Information systems

The local network communication system (LNCS) is used for the measured data transmission in the MODiS DH-system. The remote control system is used for monitoring and controlling a plant, DH-network and different types of buildings. The operator can see what is happening to, for example, the heating, ventilation and climate, and as well, he can influence the operation directly by changing the set points. The operation unit consists of a personal computer, where with colour graphics, the operator can control, regulate and monitor the entire system. The operator units communicate through the network module to the operator units within the same network. Process units are mostly directly connected to the operator unit. Sometimes operator or process units might be connected with a dial-up connection via modem. The system can perform the download/upload of parameters and applications to/from several process units at the same time.

A remote network communication system (RNCS) consisting of several operator units is a so-called peer-to-peer network, where all the operator units are equal and communication between them is initiated when needed. The database is decentralised and can be reached from all the nodes in the network. RNCS supports the following types of networks:

- LAN (Local Area Network), where the operation units for an object system are connected to a network.

- WAN (Wide Area Network). A WAN includes operator units from two or more local area networks (LAN).

RNCS also supports wide area networks using ISDN communication (Integrated Services Digital Network). Through so-called ISDN routers, several local networks can be connected into a wide area network. Communication using ISDN has short connection times and high communication speed. The TCP/IP network protocol is used for communication between operator units. Data from the units in the plant is stored in the operator units to which the units are connected, but can be reached from every operation unit in the network. When using WAN and ISDN services, an ISDN router are needed for each of the local area networks that contain the operator units that are to be included in the wide area network. A WAN operator unit can also be remotely connected to a subsystem via modem.

MODiS software and management

The district heating system and indeed the entire energy system involve a high number of measurements and control signals, and therefore need instruments to handle the consequent data flows and to make decisions based on that information. The data transmission requirements (input and output) in the MODiS software system has been defined and the media for controlling the data transmission between different points have been defined.

The management system consists of, in addition to general management within the field of district heating, comprehensive coverage of strategic and operational planning, operation in practice, maintenance, training, project planning and management, customer management, as well as economic and financial issues. The MODiS management package can provide diverse benefits based on wide professional knowledge and broad based practical experience. MODiS is designed to improve the operational, financial and technical performance of district heating organisations.

MODiS planning tools

A calculation tool for the rough planning of a MODiS district heating system, called the MODiS Concept tool (version 2.0), has been developed by VTT Energy. The tool can also be used for DH systems with loops by cutting the loops open so that they can be analysed as branches. The MODiS Concept tool can be saved to the hard disk of a portable PC, so anyone can sit down with the customer, fill the system questionnaire table in the main level of the PC-model and evaluate the construction and budget price of the new or renovated DH-system. The model uses the Excel table format. As a result, the MODiS Concept model can produce the budget for the DH-system divided into boiler plant, district heating network and consumer equipment. Size, type and the quantity of pipes and equipment are calculated as well. The annual investment and running cost of the system are evaluated at the end of the calculation as well as the cash flow at a predetermined district heating tariff. A case study involving the renovation of a Russian DH area was presented as an example.

The dynamic simulation model of MODiS was created with a real time simulation tool called APROS, a commercially available product from VTT and Fortum. The APROS simulation tool is well suited for dynamic calculations of district heating (DH) systems. Appropriate library modules exist for modelling boiler houses, district heating networks and different types of consumer substations. Different fuels, such as oil, gas, coal or biomass may be utilised as an energy source. If we consider a full scale MODiS (or other DH) project, APROS is well suited for equipment, automation, and detailed process design. APROS can also be tuned for training or for use as an analysis simulator. An APROS training simulator tool can be built already months before start-up enabling operators to practise process control, emergency situations, start-up and shut-down in a graphical user display environment. By visualising process responses, a comprehensive view of the whole system operation can be created. The control systems may be tuned and tested by APROS real time simulations. This saves time and money during the construction and start-up period. The simulator can be used for studying normal operation, emergency conditions, and process failures.

During the MODiS project both MODiS DH systems and Russian DH systems were simulated. The aim of the APROS simulations was to pilot the real time operation of the whole MODiS DH system. As an example, a DH system in a Russian district heating zone was modelled with APROS. For the reconstructed network, a good correlation was obtained between the results calculated with APROS and the static DH-model of the Flora-Win or Heat Nexus program.

Ejector module

The APROS simulation program was used for investigating the ejector connection in an apartment building and for analysing the operation of the ejector in the context of the entire heating system. The simulation results of the APROS ejector module correlated very well with the performance of standard Russian ejectors cited in Russian publications. The ejector and the distribution network of the building are located between the supply and return pipelines of the DH-network. A valve is needed to compensate the excess pressure difference between the supply and return pipelines. A constant pressure difference of more than two bars is maintained at the ejector connection. The inlet flow of DH-water to the ejector is a driving flow, and this is mixed with the suction flow from the return pipeline of the heating network. The resulting outlet flow from the ejector forms the supply flow for the heating network in the building. The driving flow is equal to the return flow back to the DH-network, and both of them are smaller than the flow suctioned from the DH-network into the ejector. The supply temperature is lowered in the ejector to a suitable level for the heating network. The indoor temperature during the heating period does not stay constant, but rises with an increase in outdoor temperature. Indoor temperatures are insufficient and fall below comfortable levels during winter frosts (< 0°C) and become uncomfortably high at other times (> +5°C), causing excessive heat losses.

The heat index is defined as the ratio of the heat energy consumed in a heat exchanger connected building to the heat energy consumed in an ejector connected building. In calculating the heat index, it has been assumed that the heating system has been designed to produce a sufficient indoor temperature during the coldest period of the year, and this is certain to result in excessive indoor temperatures at other times of the year. A balanced indoor temperature was assumed to result from using an indirect connection. The APROS program has carried out simulations of the heating system for both direct and indirect connections. The apartment block simulated by APROS had five storeys and the volume of the building was 14 000 m^3. The potential heat saving to be gained by replacing an ejector system with a heat exchanger system is then 19% according to theoretical calculations. Some practical measurements also indicated the same level of energy saving.

One way to save energy is to regulate the speed of the circulation pump in the heating network of the building. This method is normally utilised in western countries, but flow regulation can not be applied to an ejector connection. Replacing the ejector with a heat exchanger makes it technically feasible to apply flow regulation. The basic alternative is constant flow and this was compared with flow regulated by a pump fitted with rotation speed adjustment. The heating network and building simulated by APROS were the same as were used in the calculation of the heat index described above. Using an adjustable circulation pump in the heating network of buildings achieves a remarkable saving in electricity consumption (up to 86%, based on theoretical calculation). However, flow regulation can not be recommended for heating systems in the former USSR countries without thorough renovation of the radiator network. This is because the series connection of the radiators in buildings would cause differing temperatures in the apartments on different floors. The apartments in upper floors would be warm and the apartments in lower floors would be cold if flow regulation were used without making other changes.

Corrosion and service life estimation for pipeline system

An expert system called PIPECOR was developed in the MODiS project. This knowledge-based tool estimates the corrosion resistance of carbon steel district heating pipes in the various water types used for heat transfer. The program gives an estimate of the remaining service life of the pipe under the conditions defined by the user, and for the current corrosion rate. The input data concerns pipe dimensions and corrosion phenomena inside the pipelines. The open DH systems used in Russian are highly susceptible to pipeline corrosion. Unsatisfactory water contains a high quantity of corrosive matter, such as chlorine, oxygen, particles, iron and ferrous oxides, and causes the pH-value to vary widely. Oxygen, a necessary element in drinking water, is especially responsible for corrosion in pipes. The corrosion has been assumed to be mainly uniform (general) corrosion. The prediction of the service life is based on this assumption. A warning of the possibility of pitting corrosion will also be given if the chloride and/or sulphate contents are high and the value of alkalinity is low compared to these values. The most important factor determining the corrosion rate is the oxygen content of the water. The temperature and the flow rate also have a great influence. High values of alkalinity and hardness retard corrosion. In very hard water, however, deposits (scale) can be formed that impair the heat transfer from the steel to the water and vice versa, and increase pressure losses in heat exchangers and boilers.

Renovation of the East European district heating systems

Large district heating systems should be divided into renovation areas that are separated from the mother DH system by a heat exchanger. The local area pipeline systems would then be renovated as a closed-loop system with MODiS components and modules. The water would be taken from the mother DH system and fed through a water-handling unit into the local pipeline system. A gas- or oil-fired peak boiler could be built into the local area system for extra reserve and peak hour capacity. The renovation work should be started from the top of the network branches and then progress to the body pipelines, the base load boiler plants and the combined heat and power plants. The peak boilers, water handling units and heat exchangers, which are housed in containers, would then be moved on following the renovation, when they are no longer needed.

The most important renovation task in East European DH systems is to make the network watertight and reduce heat loss by fitting better insulation. The outgoing temperature in the pipeline should be limited to 100–120 °C to reduce heat losses in the pipelines. The pressure level of pipelines should be limited to 1,6 MPa or less. In that way the DH network can be constructed more lightly, and the investments will be lower. In long pipelines, booster pumps can be used to lower maximum pressure level. The pumps should be speed controlled and able to operate by remote control from the central operation room. The consumers should be separated from the network by fitting heat exchangers. In that way oxygen diffusion from consumer equipment and pressure variation problems will be avoided. The DH water should also be treated, with the addition of oxygen inhibitor to prevent corrosion, and toner to aid the detection of water leakage. If the warm water is to be produced in the buildings, it must be ensured that the capacity and condition of the cold water pipelines are adequate. The substation can usually be situated in the ejector room and from there, connected to the building system. An expansion tank has to be connected to the heating system of the buildings. Renovation of thermal power plants and boiler plants must be done and synchronised with the renovation programme for the whole DH system, and conform with the new parameters for the DH system.

There might be ejector problems in areas where the DH water flow is regulated and where there exists a mixture of both indirect and direct connection to the consumers. If the pressure difference over the ejector to the consumer is too low, the ejector will not work. Such a problem would have to be solved, for example, by installing flow-limiting devices before consumers that have a modern substation or by installing a booster pump driving with a constant pressure difference before a consumer group using ejectors.

The buildings will also require basic renovation to the windows and doors, the walls and roofs (more insulation), etc. Machine driven air conditioning should be fitted with recuperators, and new water fittings installed. Such steps will certainly lower heat demand, but how should such extensive work to be curried out? One way would be to adopt the methods used in the energy saving program in Finland following the oil crises in the 70's and 80's.

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Appendix A

MODiS-software program packages

SOFTWARE: maintenance	**FIKSU - Map based district heating network planning and application**
COMPANY:	**Basepoint Oy**

DESCRIPTION

The FIKSU (SMART in English) software family includes two map based applications for the district heating market: a network planning application and software for the maintenance of district heating networks. This software operates in the AutoCAD environment.

The FIKSU planning application is based on standards and symbols that are widely approved and used. The symbols include, for example, chambers, pipelines, elbows, branches, drainage, valves, fixed points, compensators, consumers, heating plants, booster pump stations, etc. Each symbol includes attribute information, for example, type, dimensions, manufacturer etc. The program also creates a break down of the individual parts of the network and a calculation for the ground digging. The district heating network planning system can be connected to network dimensioning and simulation programs. The FIKSU-maintenance application is used for handling large amounts of information concerning the location and characteristics of an underground district heating network and elements connected to it. This information is stored in a data base, from which the user can access information by using various criteria.

SOFTWARE: Planning

COMPANY: Komartek Oy

DESCRIPTION

A system for planning a DH network and for calculating the pressure and temperature balances. Network Planning provides a means for the quick design of a new network or for planning repairs on an existing network. It can also be used for analysing possible damages and for optimising the operation of the network.

The Windows-based Enerteam-Planning system is designed for planning DH networks and to solve the problems that appear in the dimensioning and analysis of district heating (DH) networks. Enerteam-Planning is the undoubted leader in the Finnish market. A lot of DH enterprises outside Finland also use this program, and numerous foreign projects are planned with help from Enerteam-Planning. In the beginning the system was designed especially for planning networks, but experienced and competent users have, for a long time, also used it for the control and planning of network operations. Now a new program has been designed, which particularly facilitates the operation of already planned networks and the analysis of the different situations that can occur in a network. The Enerteam-Planning system supports a range of user requirements.

Based on Windows, Flowra-Win is suitable for a single workstation as well as for a network. The programming language is C++ and the database is Dbase or another database that supports an ODBC interface.

SOFTWARE:	**Billing and Customer Management**
COMPANY:	**Komartek Oy**

DESCRIPTION

Invoicing and Payment Collection System, consumer data management - the system is used for managing customer information, for producing invoices to the DH customers and for payment control. The system contains several features to control the metering and correctness of the invoices as well as information on maintenance of the heat meters. Billing and Customer Management - software for invoicing the district heating network consumers. The system helps also with customer data monitoring, accumulating district heat statistics, heat- and flow meters registration and service, heat consumption control and account ledger keeping. The system provides a real profit for the supplier due to perfect invoicing and comprehensive payment control. The main function of the Billing and Customer Management system is to provide monthly invoicing based on tariffs. The user can define different tariffs for different classes of consumers. For example, the base of the fixed monthly tariffs may be defined as the user's contracted energy or flow consumption, the consumer's apartment area, the number of inhabitants, or any other base. Different base unit prices may be defined and prices may be scaled according to the base value. The user may also define different stepped energy unit prices, which are used in estimated consumption invoicing and compensatory invoicing, based on meter readings. Various other fees may be defined.

SOFTWARE: Energy Analysis

COMPANY: Komartek Oy

DESCRIPTION

Energy Analysis is a system developed for calculating the heat consumption and heat load of buildings. Achievable energy saving measures can also be estimated and their efficiency and economy calculated. Calculations may be performed for all types of heating systems using different energy sources, for example district heating, oil, electricity etc.

Use of Energy Analysis gives benefits to heating companies, building owners and to those who are in charge of the maintenance and operation of buildings. Energy Analysis lays an effective basis for economical energy saving plans and investments. The system includes a comprehensive array of programs and databases to support the analysis. The software can either be used in a single computer, or in a local computer network. Energy Analysis will be used for:

- calculating the heat load and energy consumption of buildings or groups of buildings.

- determining the basis for the fixed monthly fees for DH customer invoicing.

- analysis of energy saving measures.

These three aspects have great significance when optimising the heat supply system from network planning to invoicing and promoting energy saving. The bases for calculations are the construction characteristics of the building and the parameters of the heat regulation system. First, a mathematical model of the building is created. The accuracy of the model depends on the basic data of the building and the heat consumption data. If heat consumption data exists, the program creates a more exact model using information from the basic data. By modifying the data it is possible to evaluate the influence on heat consumption of, for example, different kinds of insulation, types of windows etc. It is also possible to analyse the economy of the proposed energy saving measure.

SOFTWARE: DH Maintenance System

COMPANY: Komartek Oy

DH Maintenance System - the system is used for maintaining a DH network and boiler plants. The system provides information on repairs based on calendar time and operating time.

DH Maintenance System - software is developed especially for the technical maintenance of a district heating system, including substations, networks and power plants. The system includes a comprehensive set of programs and databases to support the maintenance of DH components. The software is based on Windows and may be used in a single computer or in a local computer network. The equipment database for substations, heating plants and DH-networks simulates the hierarchical structure of equipment from complexes to details. The system supports different databases for the buildings, property and technological equipment of heating plants and also for the chambers and network devices of DH networks. The user does not need to input all equipment data at one time, but may begin from a rough concept and later work out the details in order to fully exploit the system. The equipment database includes specific forms for all the types of device used in DH-networks and heating plants. The preventive maintenance system may be used effectively, where a high level of working reliability, economy and safety are demanded.

The system is intended for the planning of maintenance based on calendar time and creates work order lists according to criteria given by the user. The user may apply the system to any level of the equipment hierarchy or to separate devices. The system also handles ready-made reports of the works and automatically updates data. The operating time-based maintenance system controls maintenance work, which must be done after the given devices have exceeded their operating time. Current operating time for devices may be updated by hand or entered from a timer through the database file. Defect reports may be inputted together with maintenance work reports and the system controls the fulfilment of repairs. Orders for defect repair and maintenance work may be assigned to DH-enterprise's own personnel or to contractors. Reports of repair work to defects must be entered and will be handled by the system. The shutdown work order list is prepared from defect reports. Those repairs, which must be made during a shutdown, will be included in this list. The system collects all off-put works, and makes the order list before shutdown. Linked documents for any device such as drawings, pictures or tables may be stored in the system. They may be, for example, power plant or chamber drafts. The user may view or print the linked documents. Linked documents may be prepared by any outside software. Expense control may be instituted for any device in the network or heating plant. The system sums up all works and spare part costs and the user may view them at any time. This aids maintenance analysis and enhances the ability to make the right decisions. Spare parts and stock control: The system updates the stock balances and gives a warning when the stock of spare parts drops below the specified limit. The system may prepare the lists of spare parts for a given spare part or given stock. Deliverer, manufacturer and contractor data is used in work order list preparation and stock control. It also includes information about contact persons (names, phone numbers, addresses etc.) and links to other systems.

The DH Maintenance System may be linked to other Komartek software or any other system used in your enterprise. It is compatible with a wide range of Windows based software. New parts of the software; consumer equipment and heat energy meter maintenance are under development.

SOFTWARE:	**MAP, Graphical User Interface**
COMPANY:	**Komartek Oy**
DESCRIPTION	
A User Interface for managing information about networks, plants, maintenance, billing, etc. in a graphical environment (GIS).	

SOFTWARE:	**Management Information System**
COMPANY:	**Komartek Oy**
DESCRIPTION	
A system for managing all relevant information about the district heating company to help decision making (for directors, managers etc). Connections to other Komartek software are essential for the functioning of this system.	

SOFTWARE:	**Heat NEXUS -** Software for District Heat Network Simulation
COMPANY:	**Process Vision Oy**

DESCRIPTION

This calculation software for district heating networks provides easy-to-use tools for the graphical design of the mathematical network model. The network can also be generated by importing functions from various planning systems. With its static model the simulator can be utilised, for example, in the dimensioning of new pipelines and pumping stations or in planning the most profitable way to operate the whole heating system. Annual calculation can be used for the analysis of operating costs. Different operating modes of the network are easily simulated with the help of controllers, scaling curves for consumer behaviour and heat plant start-up automation. The results can be analysed with a user definable monitoring system and illustrative result windows. Reports can be exported directly to a MS-Excel worksheet. To make planning more accurate, the same network can be calculated with a dynamic model and on-line measurements integrated to the simulator for the autotuning of the mathematical model. In addition to normal operation planning, risk situations associated with district heating systems can be easily analysed.

SOFTWARE:	**Heatex NEXUS** - Software for Dimensioning of DH substations
COMPANY:	**Process Vision Oy**

DESCRIPTION

Heatex software enables the inspection of a DH consumer installation. With the help of HEATEX it is possible to discover poorly cooling heat exchangers, carry out the required dimensioning and calculations for renewing the installation, and to check out contracted water flow and power. HEATEX can be utilised in energy plants, by heating consultants and in the training of operating and service personnel.

SOFTWARE: TAC Vista®

COMPANY: TAC - Com Oy

DESCRIPTION

TAC Vista® is a control, management and monitoring system for the heating, ventilation and climate control of all types of premises and buildings. It is a simple matter for the operator to monitor the plant and get information about values and alarms, in order to influence and control the plant directly. The basic functions are colour graphics, alarm handling, authorisation checking, and time control.

The TAC Vista® Basic Module includes the following: colour graphics with continuous updating of operating conditions, changes of values and operating conditions direct from the colour graphics, data logging in real time, continuous storage of current alarm status, a colour-coded display of alarm, time and event controlled alarm printouts to different printers, authorisation check per object in the building, automatic, forced and stand-by log-out, user profile and operator identification, automatic winter/summer time conversion and leap year adjustment, holiday handling and time synchronisation, and time control of objects or groups.

TAC Vista® is constructed around an open standard, with completely open architecture. This enables it to work with other software running under Windows®, and fetch information from all the components influencing daily operation and/or costs of the plant. TAC Vista® communicates in real time with the TAC Xenta® range of controllers on the LonWorks® network, as well as with any other LonMark® devices, LonWorks® being the new open network technology in building automation.

SOFTWARE: **TAC Signature** **COMPANY:** **TAC - Com Oy**
DESCRIPTION TAC Signature is a tool for the recording, budgeting or analysis of energy use. Logged data on energy use and ambient temperature provides input material for the graphical presentation of the energy signature, i.e. power requirements as a function of ambient temperature. This provides a check of actual energy use in relation to budgeted energy use for various ambient climatic conditions, in the form of a true comparison of actual with expected values. With the input of energy tariffs, TAC Signature can provide continuous cost control. Any change in the condition or use of a property, such as a change in the number of occupants or a different operating scenario, produces an immediate response in the form of a change in heating, electricity or water consumption. In order to provide a fast response to costs deviating from budgeted, the system generates an alarm at any required discrepancy level for display in the TAC Vista® alarm window. TAC Signature may be linked to buildings monitored by TAC Vista®. TAC Vista® defines the building as having a hierarchy of elements (element definition), for example, a house, floors, rooms and points for temperature measurement, energy meters etc. The element definition and logged values within TAC Vista® are transferred to TAC Signature in order to create an energy signature for the building.

SOFTWARE: TAC Xenta **COMPANY: TAC - Com Oy**
DESCRIPTION The TAC Xenta family is a new generation of controllers for intelligent building automation. The basic idea behind TAC Xenta is to provide more accurate management and control of the indoor climate, closer integration with other technical systems and even better operational cost-effectiveness. TAC Xenta is based on the Echelons network standard, LonWorks, with open protocols that simplify integration with other systems - known as 'open integration', making manufacturer-oriented technology irrelevant. TAC Xenta's general communications are based on LonTalk with SNVT technology. TAC Xenta can be used as an independent controller in a smaller installation or be part of a network in a larger building. All units can be controlled and monitored via a central building management system such as TAC Vista.

SOFTWARE: **Asterix**

COMPANY: **Tietosavo Oy**

DESCRIPTION

ASTERIX is an integrated marketing and customer service system designed for energy companies. It manages the flow of data between the company and its customers, beginning from the planning of market operations and going through the whole customer relationship life cycle. ASTERIX covers sales of electricity and district heating, and it can be adapted to the sale of natural gas and steam. Some of the system functions are common to each energy type and others differ from one type of energy to another. Asterix has also some additional areas such as management information and communications.

The Asterix customer information system covers the following subsystems:

- Asterix - marketing and sales
- Asterix - customer service
- Asterix - metering
- Asterix - meter reading and control of energy usage
- Asterix - invoicing
- Asterix - receivables management

For a description of each subsystem, please see below:

SOFTWARE: **Marketing and sales**

COMPANY: **Tietosavo Oy**

DESCRIPTION

Basic operations include the following: setting up product data with price and grouping information, browse and display functions, processing offers and agreements related to distribution and delivery, comparative product calculation, definition of comparison groups and typical users, sales planning, sales forecasts, sales monitoring and statistics.

SOFTWARE: Customer service

COMPANY: Tietosavo Oy

DESCRIPTION

The Customer Service is specifically designed for agreement-based customer service operations. Basic functions of the Customer Service module include the following: managing customer and delivery data, maintaining key and entry information for the delivery site, managing consumption forecasts, processing agreement transactions, initiating required operations, approving the invoicing impact of transactions, ordering invoices for separate delivery sites or customers outside the normal cycle, updating the consumption and characteristic consumption data of a typical user with actual data, monitoring energy consumption and issuing feedback (standard reports), entering single transactions to be invoiced, correcting consumption data if necessary and approving its effect on invoicing (eliminating the effect of an erroneous transaction to be invoiced or correcting the situation after an erroneous transaction), creating personal itemised invoices or other invoiced transactions, outage notification and advice, customer visits and contacts, and providing an overview of the customer for internal requirements (account statements etc.)

SOFTWARE: Metering

COMPANY: Tietosavo Oy

DESCRIPTION

This module includes services for various metering solutions, monitoring the condition of metering equipment under seasonal maintenance, and managing the entire set of metering equipment including transactions and inventories. The module also includes an interface for remote reading and control. Basic functions of the Metering module include the following: setting up metering equipment types and equipment, various browse functions, processing job requests and tasks concerning metering, approving the invoicing effect of tasks, choosing appropriate metering solutions, initiating, modifying, and completing delivery site metering, recording metering equipment transactions and maintaining an inventory of metering equipment, receiving remote readings, and managing metering equipment maintenance and alternative services.

SOFTWARE:	**Reading and consumption of energy usage**
COMPANY:	**Tietosavo Oy**

DESCRIPTION

The Reading module manages the planned reading of metering equipment and the implementation of separate reading requests related to, for example, agreement transactions. Basic functions of the Reading module include the following: updating readings data (reading area, routes, reader data; and updating target readings as part of delivery site maintenance), updating reading plans, selecting batches of readings and transferring their data to a hand-held reading device, printing on a readings list or self-read card, transferring data to a telephone service, storing readings by using the readings templates created during the selection of the batches of reading, receiving readings from a hand-held reading device, telephone or remote reading, calculating metering results, and checking the metered consumption and approving it for invoicing.

SOFTWARE:	**Invoicing**
COMPANY:	**Tietosavo Oy**

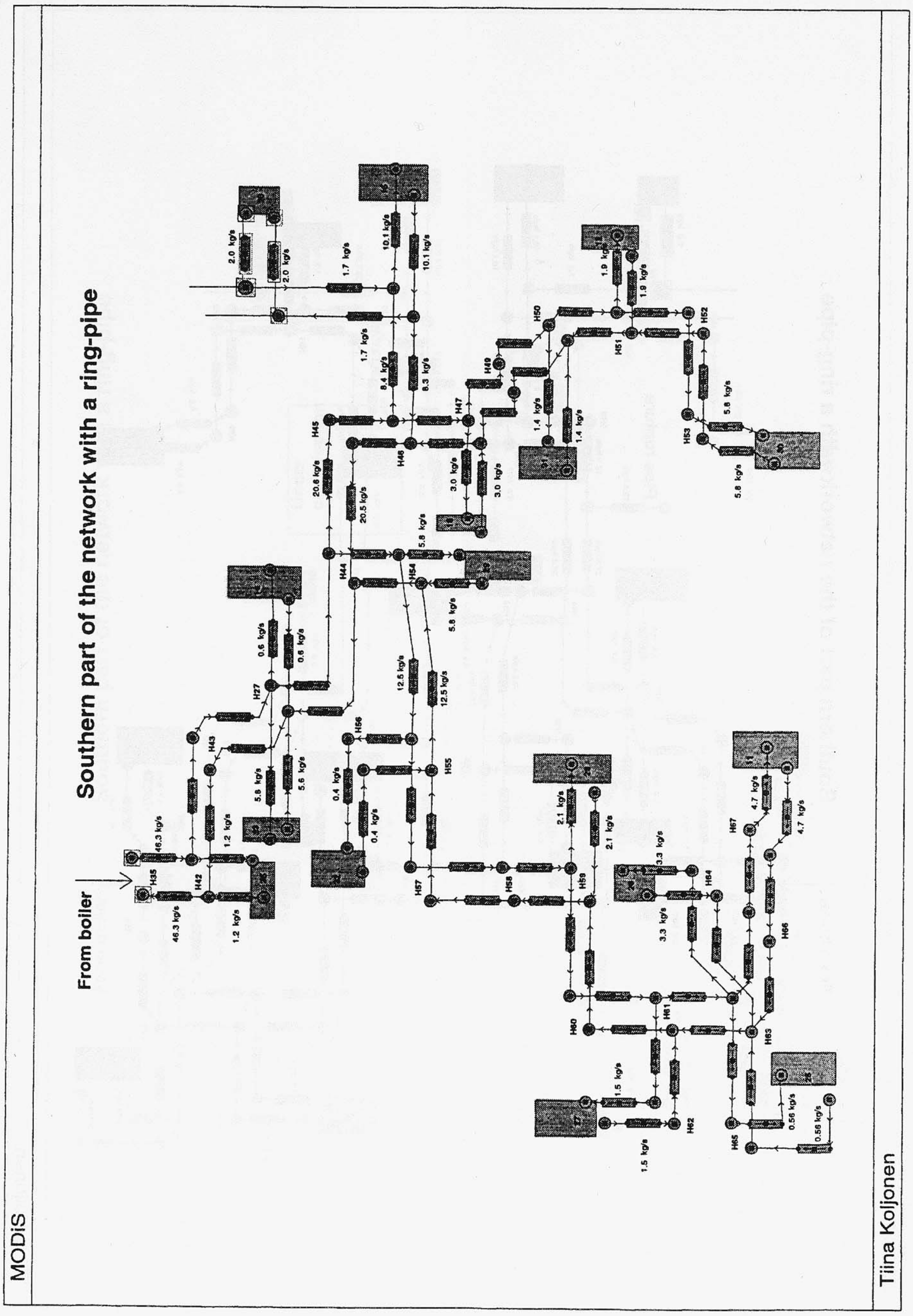
With the Invoicing module the company can manage both energy distribution invoices and other invoices. Flexible product specification assists, for example, product planning in marketing when the competitive situation changes, and facilitates the versatile utilisation of invoicing services. Basic functions of the Invoicing module include the following: creating future (estimate) invoice transactions based on agreement data (either according to the invoicing timetable or upon request, for example, when an agreement is revised), printing out preliminary invoicing reports, pricing transactions to be invoiced (with tax and price changes taken into account), creating invoices according to invoicing timetables, creating separate invoices (for example, in a customer service situation), and printing out itemised invoices with appendices. The information printed may include a preliminary invoicing report and a Customer Service bulletin on energy consumption, the transfer of invoicing data into automatic payment services, receivables control, the production invoicing summaries, the creation of credit notes for erroneous invoices, the cancellation of invoicing data on agreement, and consumption.

SOFTWARE:	**Receivables management**
COMPANY:	**Tietosavo Oy**

DESCRIPTION

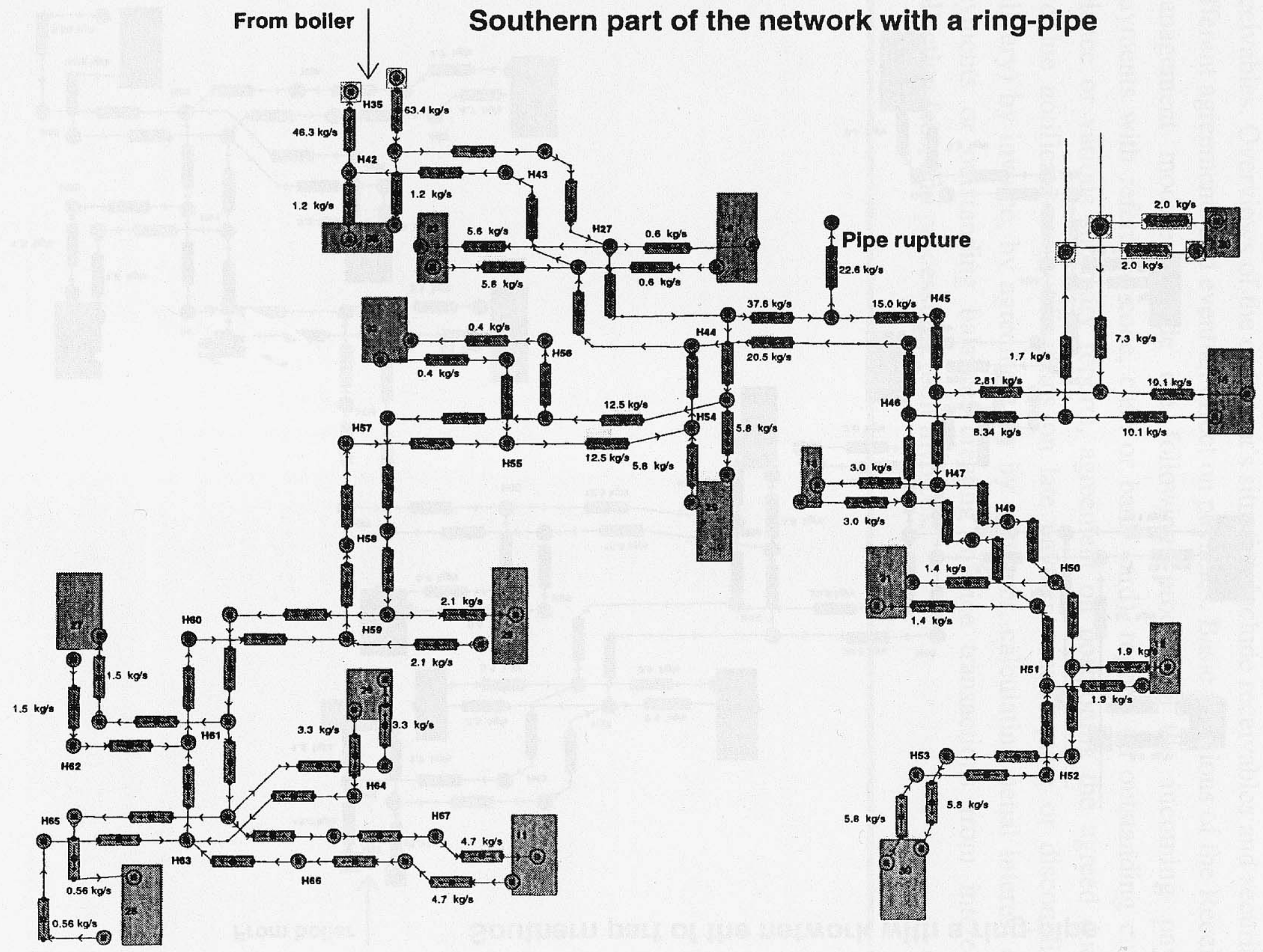
Receivables Management offers tools for the efficient monitoring and control of receivables. Overviews of the customer's situation include receivables and securities for different agreements and eventual effect on payables. Basic functions of the Receivables Management module include the following: processing the incoming payments (payments with reference code, cash or bank card), reports on outstanding customer balance or various summary reports, agreement on postponing the agreed due date, overdue notifications (notifications on late payment, interrupting or discounting the delivery) by invoice, by agreement, or by customer, calculating penal interest on late payments or outstanding balance; creating invoice transactions from interest and collection fees, and processing credit invoices.

Appendix B



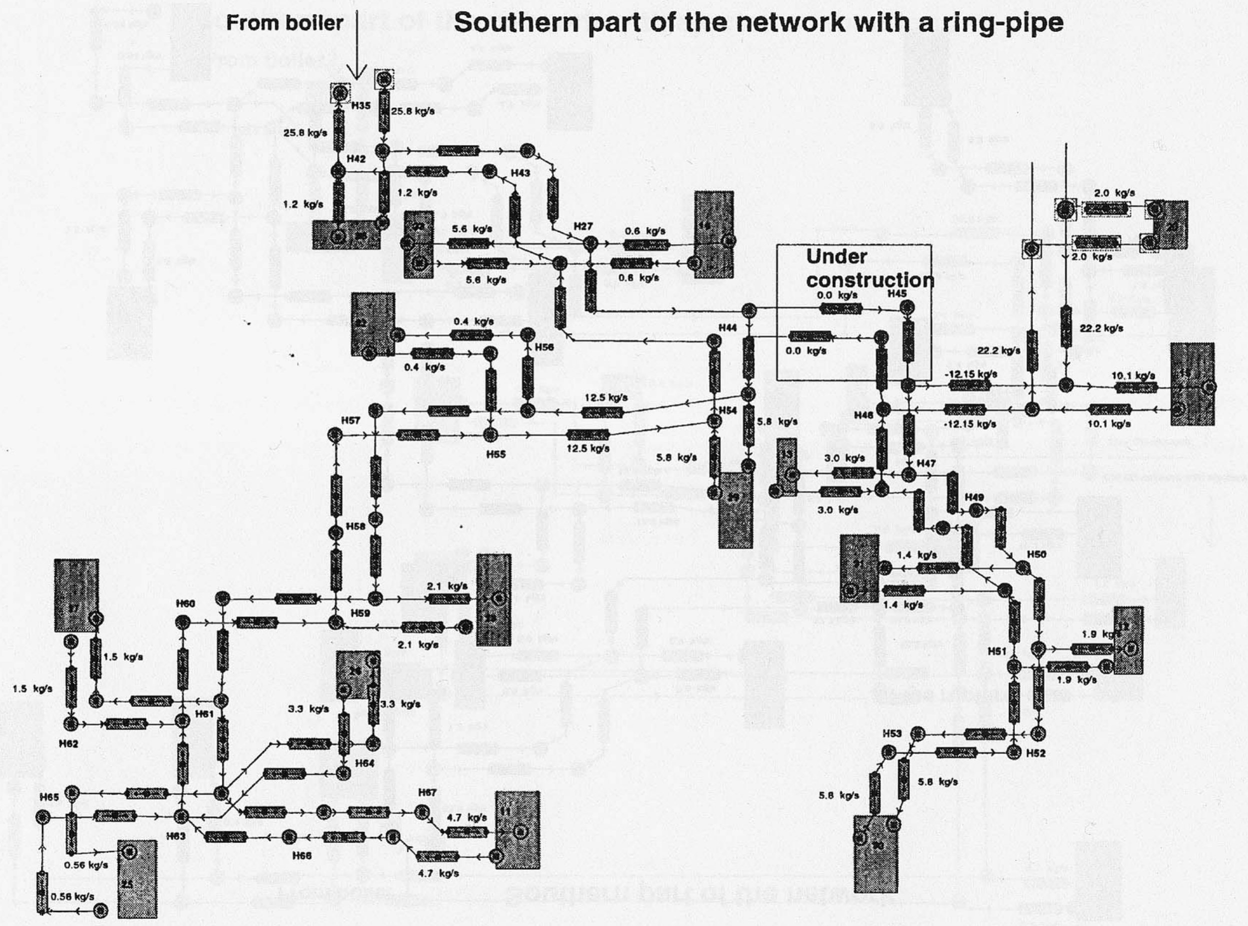
MODIS
Southern part of the network with a ring-pipe
From boiler
Tiina Koljonen

Southern part of the network with a ring-pipe



MODiS

Southern part of the network with a ring-pipe



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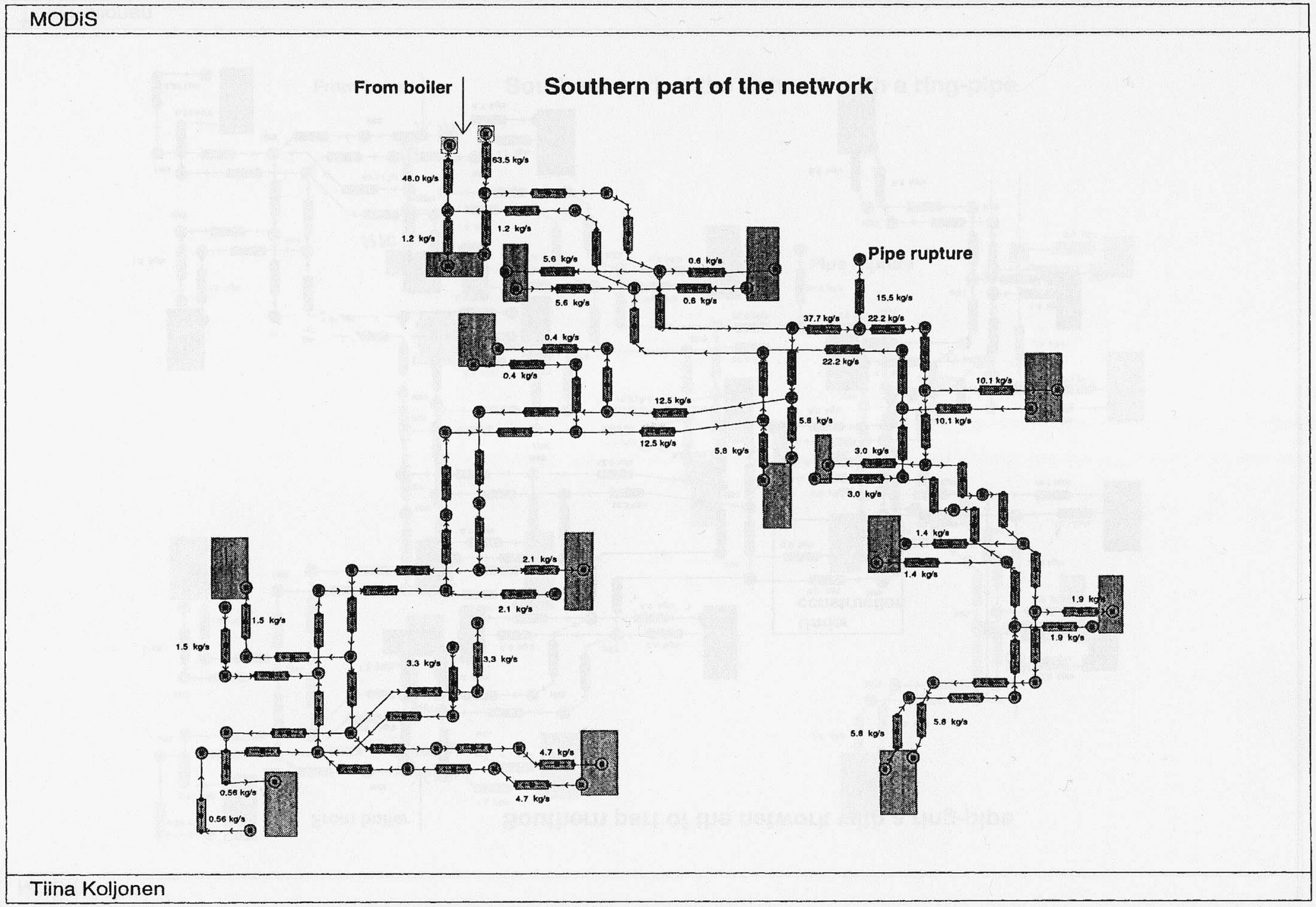
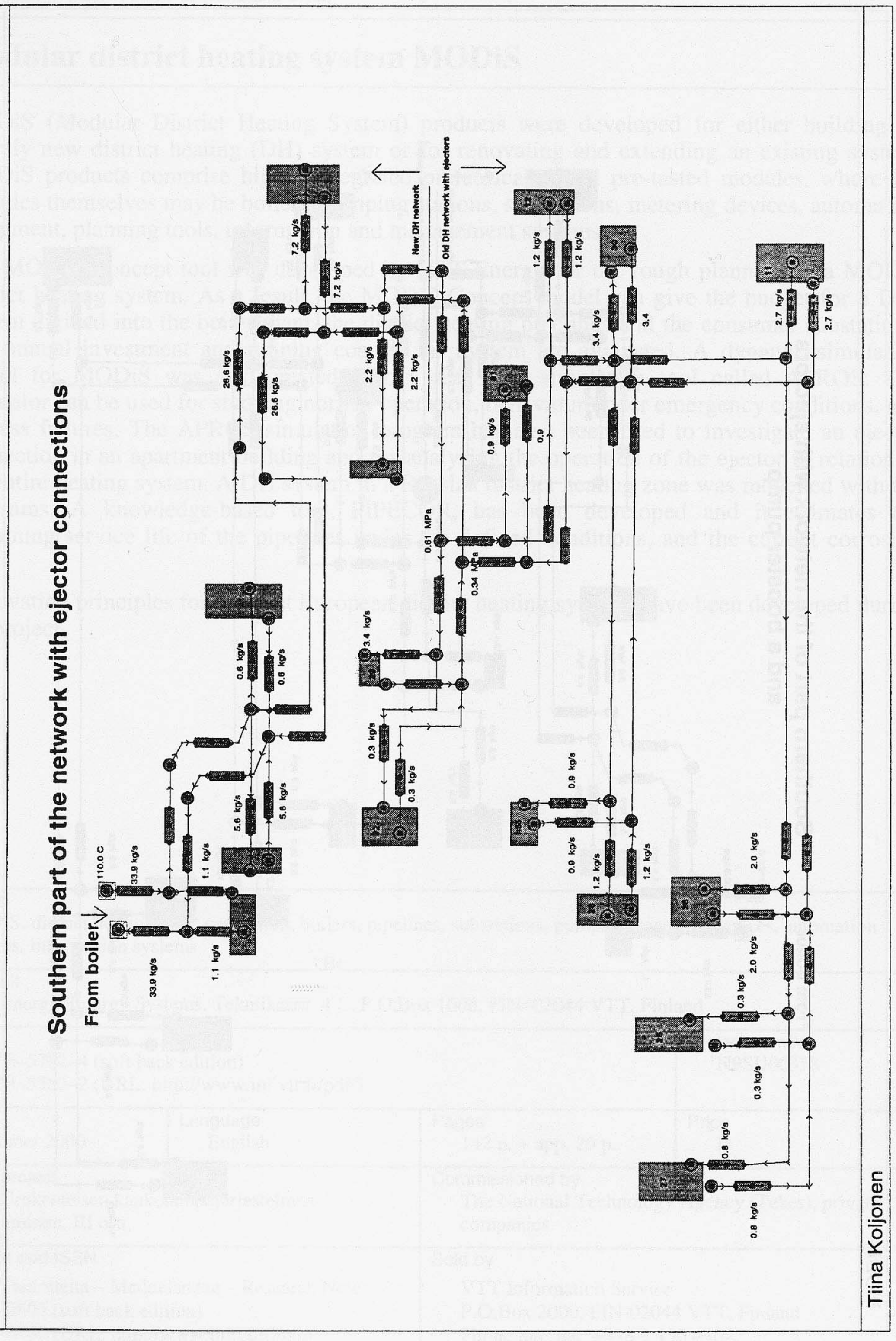
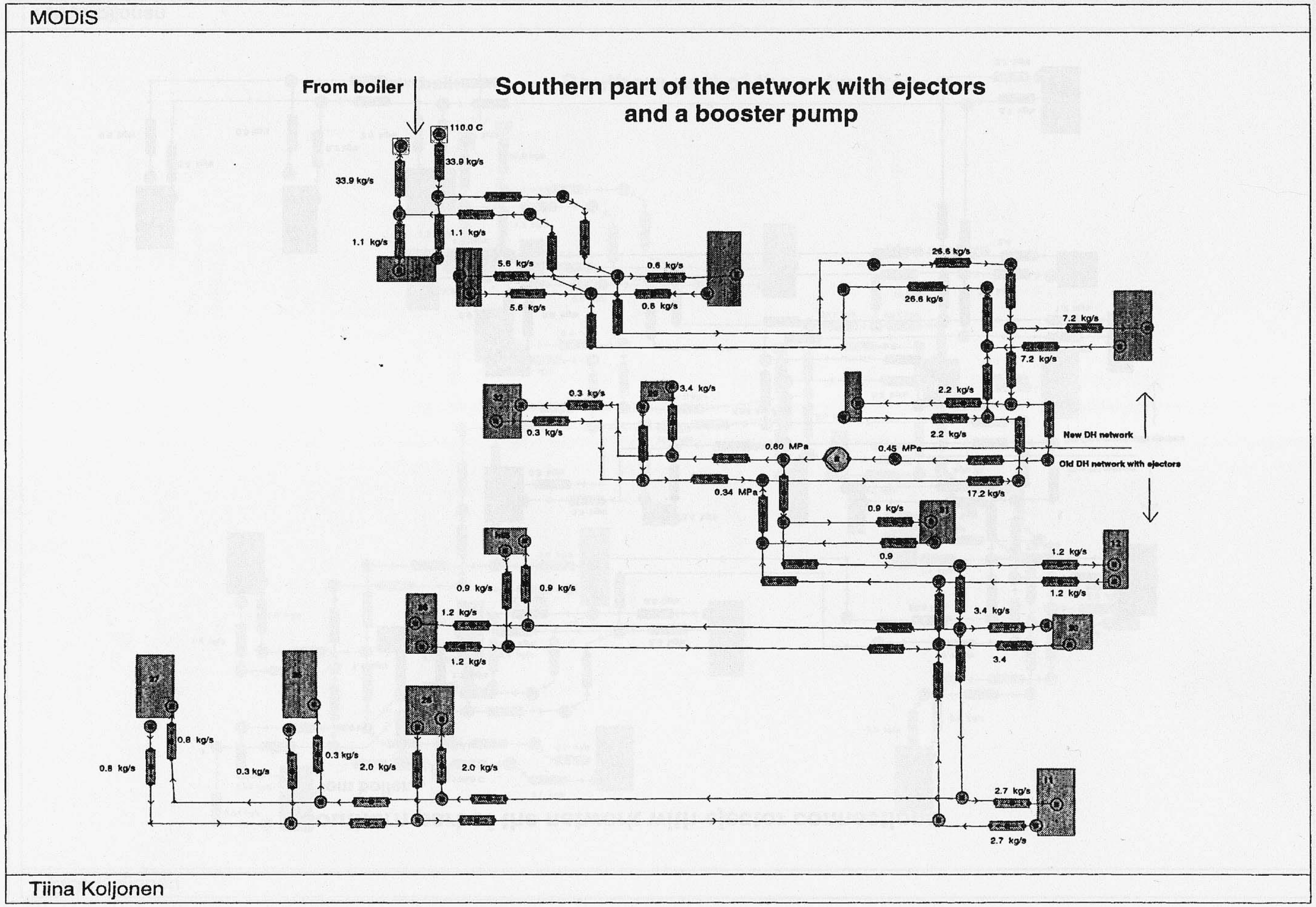

MODiS
Southern part of the network
From boiler
63.5 kg/s
48.0 kg/s
1.2 kg/s
1.2 kg/s
5.6 kg/s
5.6 kg/s
0.6 kg/s
0.6 kg/s
Pipe rupture
15.5 kg/s
37.7 kg/s
22.2 kg/s
22.2 kg/s
0.4 kg/s
0.4 kg/s
12.5 kg/s
12.5 kg/s
5.8 kg/s
5.8 kg/s
10.1 kg/s
10.1 kg/s
3.0 kg/s
3.0 kg/s
1.4 kg/s
1.4 kg/s
2.1 kg/s
2.1 kg/s
1.9 kg/s
1.9 kg/s
1.5 kg/s
1.5 kg/s
3.3 kg/s
3.3 kg/s
5.8 kg/s
5.8 kg/s
4.7 kg/s
4.7 kg/s
0.56 kg/s
0.56 kg/s
Tiina Koljonen

Appendix C


MODiS
Southern part of the network with ejector connections
From boiler
New DH network
Old DH network with ejectors
Tiina Koljonen


MODiS
Southern part of the network with ejectors and a booster pump
From boiler
110.0 C
33.9 kg/s
33.9 kg/s
1.1 kg/s
1.1 kg/s
5.6 kg/s
5.6 kg/s
0.6 kg/s
0.6 kg/s
26.6 kg/s
26.6 kg/s
7.2 kg/s
7.2 kg/s
2.2 kg/s
2.2 kg/s
0.3 kg/s
0.3 kg/s
3.4 kg/s
0.60 MPa
0.45 MPa
0.34 MPa
17.2 kg/s
New DH network
Old DH network with ejectors
0.9 kg/s
0.9
1.2 kg/s
1.2 kg/s
3.4 kg/s
3.4
0.9 kg/s
0.9 kg/s
1.2 kg/s
1.2 kg/s
0.8 kg/s
0.8 kg/s
0.3 kg/s
0.3 kg/s
2.0 kg/s
2.0 kg/s
2.7 kg/s
2.7 kg/s
Tiina Koljonen

Published by

Vuorimiehentie 5, P.O.Box 2000, FIN-02044 VTT, Finland
Phone internat. +358 9 4561
Fax +358 9 456 4374

Series title, number and report code of publication

VTT Research Notes 2071
VTT-TIED-2071

Author(s)
Sipilä, Kari, Ranne, Aulis & Koljonen, Tiina

Title

Modular district heating system MODiS

Abstract

MODiS (Modular District Heating System) products were developed for either building an entirely new district heating (DH) system or for renovating and extending an existing system. MODiS products comprise highly integrated prefabricated and pre-tested modules, where the modules themselves may be boilers, pumping stations, substations, metering devices, automation equipment, planning tools, information and management systems.

The MODiS Concept tool was developed by VTT Energy for the rough planning of a MODiS district heating system. As a result, the MODiS Concept model can give the budget for a DH-system divided into the boiler plant, the district heating pipelines and the consumer substations. The annual investment and running cost of the system are evaluated. A dynamic simulation model for MODiS was also created with a real time simulation tool called APROS. The simulator can be used for studying normal operation, behaviour under emergency conditions, and process failures. The APROS simulation program has also been used to investigate an ejector connection in an apartment building and for analysing the operation of the ejector in relation to the entire heating system. A DH system in a Russian district heating zone was modelled with the programs. A knowledge-based tool, PIPECOR, has been developed and it estimates the remaining service life of the pipelines under the defined conditions, and the current corrosion rate.

Renovation principles for the East European district heating systems have been developed during the project.

Keywords
MODIS, district heating, heat generation, boilers, pipelines, substations, pumps, measuring devices, automation systems, information systems

Activity unit
VTT Energy, Energy Systems, Tekniikantie 4 C, P.O.Box 1606, FIN–02044 VTT, Finland

ISBN
951–38–5782–4 (soft back edition)
951–38–5783–2 (URL: http://www.inf.vtt.fi/pdf/)

Project number
N9SU00338

Date	Language	Pages	Price
December 2000	English	142 p. + app. 20 p.	D

Name of project
Modulirakenteisen kaukolämpöjärjestelmän kehittäminen, III osa

Commissioned by
The National Technology Agency (Tekes), private companies

Series title and ISSN
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