HEAT PUMPS AND DISTRICT HEATING SYSTEMS

E. Bubelis, K. Marcinauskas, R. Skema
Lithuanian Energy Institute,
Kaunas, Lithuania

Abstract

Data on recoverable and renewable energy resources available in industrial enterprises having large circulation water cooling systems and municipal water purification plants are collected and analysed. Volume of low potential heat produced by heat pumps and electric energy used for they are evaluated. It is indicated that application of heat pumps permits to save great quantities of fossil fuel and to reduce environmental pollution. Necessary economic prerequisites for wide application of heat pumps in district heating systems are indicated.

KEYWORDS

Heat pump, recoverable energy sources, renewable energy sources.

INTRODUCTION

With privatisation development under way and current changes in production character large-scale industrial heat consumers gradually withdraw from the District Heating Systems (DHS), in doing so they worsen the situation of remaining heat consumers. DHS, up to now consider as the most advantageous one from economic point of view, becomes less and less competitive relative to decentralised heat production systems. In this situation municipal heat suppliers must direct their attention to alternative ways of heat generation, allowing cost-effective work without increasing tariffs of heat supply to consumers.

Lithuania ratified Montreal Protocol and also Energy Charter treaty as most countries in the world did and thereby assumed obligations to pursue energy saving policies, utilising recoverable and renewable (sustainable) energy resources to reduce harmful emissions into the atmosphere. Regaining independence Lithuania inherited huge and highly developed energy economy, which considerably exceeds demands needs of consumers. With such economy sector in possession rational management of power is very important. In the modern market circumstances the choice of proper energy sources becomes particularly important: to use boiler plants for low potential heat supply, or CHP plants, or compressor houses for heat pumps, or, at last, to choose some combined way of low potential heat generation.

In the western countries a general conclusion has been reached long time ago that heat pumps are most efficient and often unique means of utilisation of recoverable and renewable energy resources. For example, in Germany about 49 thousand heat pump units are in operation for heating purposes and constant rise of their number is observed in recent years. Application of heat pumps provides considerable energy savings and reduction of CO_2 emissions into the atmosphere to 55% [1]. It is obvious, that power export should be promoted and excess power must be used up and, where it is feasible, conditions must be created for heat pump utilisation, which are implemented all around the world if for no other reason than to reduce consumption of fossil fuel for low potential heat production and thereby to reduce environmental pollution.

THE AVAILABILITY OF RECOVERABLE AND RENEWABLE ENERGY RESOURCES IN INDUSTRIAL ENTERPRISES AND MUNICIPAL WATER PURIFICATION PLANTS INVESTIGATED

It is common knowledge that heat pumps work more efficiently when low potential source temperature exceeds temperature of the environment. Utilisation of recoverable energy of secondary

energy sources, occurring in industrial enterprises is particularly urgent, as they release much heat into the atmosphere.

In 1998 eighteen industrial enterprises investigated released into the atmosphere 4978185.8 MWh of heat (Table 1).

Table 1. Summarising table of available and utilised recoverable energy resources according to industry branches.

Industry branch	Vapour condensate	Warm water drained	Warm air released by ventilation system	Combustion products	Circulation water cooling systems	Amount of recoverable energy resources	In all
	MWh / yr						
5 enterprises of food industry	5113,4	4066,0	167,7	6057,0	36333,8	-	51738,2
%	9,88	7,86	0,33	11,7	70,2	-	100
3 enterprises of building industry	2015,4	-	-	154815,4	24478,4	22528,5	203837,7
%	0,99	-	-	75,95	12,01	11,05	100
3 enterprises of textile industry	8865,8	28126,4	208243,9	1273,0	111227,0	8954,0	366690,0
%	2,42	7,67	56,79	0,35	30,33	2,44	100
3 enterprises of woodwork and furniture industry	2412,5	10049,6	54616,9	18020,2	6556,6	12298,7	103954,5
%	2,32	9,67	52,54	17,33	6,31	11,83	100
1 enterprise of electronic industry	503,1	-	55013,3	10371,4	66867,1	7268,7	140023,8
%	0,36	-	39,29	7,41	47,75	5,19	100
3 enterprises of chemical industry	90678,7	256277,6	11462,4	650500,1	2234099,3	868923,8	4111942,1
%	2,21	6,23	0,28	15,82	54,33	21,13	100
In all:	**109589,0**	**298519,6**	**329504,2**	**841037,1**	**2479562,2**	**919973,7**	**4978185,8**
tae	**13461,4**	**36668,7**	**40474,7**	**103309,4**	**304577,1**	**113005,0**	**611496,1**
tne	**9422,9**	**25668,1**	**28332,3**	**72316,6**	**213204,0**	**79103,5**	**428047,3**
%	**2,20**	**6,00**	**6,62**	**16,89**	**49,81**	**18,48**	**100**

Recoverable energy resources (r.e.r.) are formed in these industrial enterprises. It was established that:

- most of r.e.r appear in circulation water cooling systems (49.81%);
- emission of heat together with combustion products is on the second place (16.89%);
- release of heat by ventilation systems occupies the third place (6.62%);
- less r.e.r are lost with sewage waters and vapour condensate not returned to boiler houses (6.0 and 2.20% correspondingly);
- in enterprises heat is utilised by boilers – utilizators, by heat exchangers, both recuperative and regenerative, while in the joint stock company Dirbtinis Pluoštas (Synthetic Fibber) 919973.7 MWh/yr of recoverable heat is utilised using heat pump or 18.48% of total heat released into atmosphere.

Distribution of emission (as a percentage) according to the branches of industry is somewhat different:

- in enterprises of buildings material industry 75.95% of heat are discharged with combustion products;
- enterprises of textile and woodwork industry release heat mostly though ventilation systems (56.79% and 52.54% correspondingly);
- enterprises of food industry, chemical technology and electronics industries discharge heat though their water cooling systems 70.2%, 54.33% and 47.75% correspondingly.

The largest quantity of secondary energy resources is in factories of chemical industries. It amounts to 4 111 942.1 MWh/yr, that is 82.59% of total resources in all industrial enterprises. The total huge sum of recoverable energy resources, which arise in large water cooling systems of enterprises, may be recovered only by the means of large (up to 30 MW_t) heat pumps. Large circulation water cooling systems of industrial enterprises of Lithuania discharge 2407739 MWh/yr of heat and it amounts to 97.18% of heat, released by similar systems of all 18 enterprises investigated (2479562.2 MWh/yr). Six enterprises have such circulation water cooling systems: joint stock companies Mažeikių Nafta, Lifosa, Achema, Ekranas, Dirbtinis Pluoštas, Alytaus Tekstilė. These recoverable energy resources are huge. Therefore, we must consider utilisation of these resources with large-scale heat consumers in mind, as consumer needs of these enterprises themselves are considerably lower. Compressor plants of heat pumps, using these sources of low potential heat, are able to deliver to the city heat delivery network approximately the same amount of heat, which is needed during summer period. The flow-rate of circulation water cooling systems of enterprises mentioned above allows for construction of compressor plants having heat power equal to 426 MW_t and electric power installed up to 123.8 MW_e. However, recovering such amount of heat is limited by capacities of consumer. So, flowrate of circulation water cooling systems of the joint stock company Mazeikių Nafta allows to install 5 heat pumps HPC 600 of the firm ABB STAL AB, which using 45 MW_e of electric energy can produce 150 MW_t of heat. However, heat consumer is situated about 15 kilometres away from joint stock company Mazeikių Nafta. This case of heat supply may be contemplated theoretically, however, actual calculation taking into account all expenses for construction of supply line and installation reveals too great payback time of the project. Joint stock company Alytaus Tekstile intends to lower the load of pressure air compressor station. In this case runoff of the circulation water cooler would be reduced accordingly. Therefore, implementing of this scheme is risky, the more so, because municipal purification facilities, possessed by the joint stock company Dzukijos Vandenys, have similar sink flowrate, utilisation of which by heat pumps may ensure heat supply to the city throughout the year.

Actually, available heat of powerful water cooler systems of four industrial enterprises if used can enable installation of compressor stations of heat pumps with the total heat capacity of 76.59 MW_t and electric power equal to 23.6MW_e. For the execution of this project the investment of 125.26 mln. Lt* is needed (Table 2, p. 1-4). Operation of compressor heat pumps would enable to avoid releasing into the atmosphere:

- 141182 t CO_2 and 307 t NO_x produced by combustion of 74.86 mln. m^3 of natural gas, or
- 204234 t CO_2, 3260 t SO_2, 891 t NO_x and 13 t V_2O_5 produced by combustion of 65212 t of fuel oil (Table 3, p. 1-4).

Table 2. Actual possibilities of heat utilisation by heat pumps using heat from powerful circulation water cooling systems of enterprises and waste water of purification plants

Circulation water cooling systems of enterprises	flowrate m^3/day	HPC 600	HPC 500	HPC 300	UNITOP 33CY	Capacity installed		Investment mln. Lt*
		Number of heat pumps				Electric MW_e	Thermal MW_t	
1.“Lifosa”	34560	-	-	2	-	4,8	15,87	27,0
2.“Achema”	67392	-	1	1	-	9,1	28,60	51,0
3.“Ekranas”	34560	-	-	2	-	4,8	15,87	27,0
4.“Dirbtinis Pluoštas”	21600	-	-	-	3	4,9	16,25	20,26
In all:		**-**	**1**	**5**	**3**	**23,6**	**76,59**	**125,26**
Total flowrate of waste water								
5.Vilnius	137630	4	-	-	-	38,4	120,0	140,0
6.Kaunas	125000	3	-	-	-	29,8	90,0	125,0
7.Klaipėda	70000	1	-	-	-	10,2	30,0	50,0
8.Alytus	20967	-	-	-	3	5,1	15,4	27,5
In all:		**8**	**-**	**-**	**3**	**83,5**	**255,4**	**342,5**
Total:		**8**	**1**	**5**	**6**	**107,1**	**331,9**	**467,76**

Note. * - There are 1 Lt = 1/4 US $ as established by the Lit Stabilization Law of 17 March 1994.

Table 3. Fuel savings and reduction of pollutant amount when heat pumps are used for low potential heat production

Circulation water cooling systems of enterprises	Fossil fuel	Annual fuel savings		Amount of harmful emissions t/yr			
	natural gas / fuel oil	Natural gas, thousand m^3	2,5% fuel oil, t	CO_2	SO_2	NO_x	V_2O_5
1.“Lifosa”	natural gas	12590,0	-	23737,0	-	51,6	-
	fuel oil	-	10963,0	34334,0	548,0	148,0	2,19
2.“Achema”	natural gas	29360,0	-	55372,0	-	120,4	-
	fuel oil	-	25571,0	80083,0	1278,5	350,3	5,1
3.“Ekranas”	natural gas	16260,0	-	30669,0	-	67,0	-
	fuel oil	-	14164,0	44360,0	708,0	194,0	2,8
4.“Dirbtinis Pluoštas”	natural gas	16650,0	-	31404,0	-	68,0	-
	fuel oil	-	14514,0	45457,0	725,7	198,8	2,9
In all:	natural gas	**74860,0**	**-**	**141182,0**	**-**	**307,0**	**-**
	fuel oil	**-**	**65212,0**	**204234,0**	**3260,2**	**891,1**	**12,99**
Waste water flowrate							
5.Vilnius	natural gas	106393,0	-	200658,0		436,0	-
	fuel oil	-	100106,0	313454,0	5005,0	1371,0	20,0
6.Kaunas	natural gas	75983,0	-	143304,0	-	311,5	-
	fuel oil	-	76960,0	240979,0	3848,0	1054,0	15,9
7.Klaipėda	natural gas	28098,0	-	52882,0	-	115,0	-
	fuel oil	-	28459,0	89110,0	1423,0	389,0	5,9
8.Alytus	natural gas	14358,0	-	27079,0	-	58,9	-
	fuel oil	-	14543,0	45537,0	727,0	119,0	3,0
In all:	natural gas	**224832,0**	**-**	**423923,0**	**-**	**921,4**	**-**
	fuel oil	**-**	**220068,0**	**689080,0**	**11003,0**	**30130**	**44,8**
TOTAL:	natural gas	**299692,0**	**-**	**628157,0**	**-**	**1228,4**	**-**
	fuel oil		**285280,0**	**893314,0**	**14263,2**	**3904,1**	**57,79**

Heat pumps would produce considerably greater quantities of low potential heat using wastewater heat from the water purification plants of Vilnius, Kaunas, Klaipėda and Alytus. Their total capacity would reach about 255.4 MW_t and electric power 83.5 MW_e. For execution of these projects about 342.5 mln. Lt must be invested (Table 3, p. 5-8). It would make dispensable buying 224.83 mln. m^3 of natural gas or 220 thousand t of fuel oil and in doing so would reduce environmental pollution (Table 3, p. 5-8).

With installation of heat pumps recovering waste heat of the four-circulation water cooling systems and heat from the water purification plants of the four large cities of Lithuania, a new electricity consumer – compressor plants of heat pumps would appear. The new consumer would have total electric power of up to 107.1 MW_e and thermal power of up to 331.9 MW (Table 2).

It would dispensable import of 299.69 mln. m^3 of natural gas or 285.28 thousand t of fuel oil, and it would considerably reduce emissions of CO_2, SO_2, NO_x and V_2O_5 (Table 3).

ECONOMIC PREREQUISITES FOR EMPLOYMENT OF HEAT PUMPS IN THE SYSTEMS OF DISTRICT HEATING

Energy efficiency of the heat pump is determined by its conversion factor. As this factor always exceeds unity (>1), heat supply by means of the heat pump is always preferable to direct electrical heating. In case electricity is supplied by CHP plant with efficiency $\eta = L/q_T \leq 0.4$ (that is, to obtain 1 kWh of electricity about 2.5 kWh of thermal energy are spent), conversion factor being more than 2.5 ($\varphi > 2.5$), the heat pump is even superior economically over direct fuel combustion.

Fossil fuel savings during payback period of the heat pump depends essentially upon the price ratio K_e/K_t. Heat pump application experience all over the world indicates that the best suited payback period corresponds to $K_e/K_t \leq 3$ [2]. In the former Soviet Union the tariff ratio sometimes reached 10, however, this has little to do with real expenses for electricity generation and was based on socialist planning and administration decisions. With independence regained and market relations developing in Lithuania fuel prices increased and tariffs of electricity and heat began to increase. As in the whole western world possibility appeared to recover with the

help of heat pump from recoverable and renewable energy resources and to supply low potential heat to consumers reducing fuel import and environmental pollution.

Unfortunately, these opportunities were never used. The State Commission of Prices and Control of Energy Activities in its decree No.123 of 22.12.1999 established power tariff equal to 17.8 cnt/kWh (without VAT) for consumers receiving power from transmission networks of lower than 110 kV voltage but not less than 6 kV (large heat pumps fall into this category). At this power price the ratio K_e/K_t increases reaching value of 4.45 when gas is used) and heat pumps (with efficient equipment saving fuel) becomes economically inferior to district boiler-plants. At present regulations issued under the name "Methods of determination of power prices" are ready and will be presented for approval. They include the item 45, which states that "for heat pumps the 50% discount of power price is provided in comparison with power consumers of the same type of connection to power transmission lines".

Our feasibility calculations presented indicate, that at 50% discount payback duration is less than 5 to 6 years and after payback period the unit can work profitably even at price of 17.8 cnt/kWh [3-5].
For cost – effective work of heat pumps not only 50% discount of power price is needed but also natural sources of low potential heat which allows heat pump operation throughout the year with full load, while exceeding power demand of cities by margin of 20% to 25%.

CONCLUSIONS

It was established that in 1998 in Lithuanian industrial enterprises investigated 919973.7 MWh/yr of recoverable energy sources were utilised, that is 18.48% of the total amount of heat released into the atmosphere.

The total flow-rate of circulation water cooling systems of four industrial enterprises makes it possible to install compressor plants of heat pumps having thermal capacity of 76.59 MW_t and installed electric power up to 23.6 MW_e, while runoff of waste waters of purification plants of the four large cities of Lithuania allows use of compressor-plants with total thermal power equal to 255.4 MW_t and installed electric power up to 83.5 MW_e.

With heat pumps built and completely equipped to recover heat from circulation water cooling systems and from waste of water purification plants of Vilnius, Kaunas, Klaipėda and Alytus a new power consumer appears - compressor plants of heat pumps, with total electric power of 107.1 MW_e and total thermal capacity equal to 331.9 MW_t.

Employment for municipal district heating systems of heat pumps in enterprises above mentioned and water purification plants enables saving 299.69 mln. m^3 of natural gas and 285.28 thousand of fuel oil and to reduce environmental pollution correspondingly.

The privilege power tariff (with 50% discount) of now existing tariff) to reduce payback period duration of compressor heat pumps is necessary at present time.

References

1. Die Heizungswärmepumpe ist im Kommen . HLH: Heizung, Luftung . Klima, Haustechn. – 1998. – 49, №8. – c. 10.
2. Кальнинь И.М. Перспективы развития тепловых насосов . Холодильная техника. 1994. № 1. .стр. 4-8.
3. Marcinauskas K., Škėma R. Klaipėdos miesto vandenvalos nuotekų šilumos įsisavinimo šilumos siurbliais ir jos panaudojimo miesto centralizuotos šilumos tiekimo sistemoje galimybės. Energetikos decentralizavimas : miestų energetikos ateitis. Klaipėda, TMK. 1999. pp. 103-109
4. Бубялис Э., Марцинаускас К. Теплота городских сточных вод в системах централизованного теплоснабжения г. Алитуса . Промышленная теплотехника. 1999. Т. 21, № 2-3. Стр. 141-145.
5. Марцинаускас К., Бубялис Э., Шкема Р. Возможности использования тепловых насосов в системах централизованного теплоснабжения (ЦТС) в крупных городах Литвы . Промышленная теплотехника. 1999. Т. 21, № 6. Стр.81-88