Heat Pumps and Low-temperature Combined Heating: Slovakian Experiences

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ABSTRACT

Low-temperature heating belongs to the progressive systems applying low-potential energy. These systems can provide the heat transfer from the heaters/surfaces to the space by convection and/or by radiation. The purpose of the paper is to specify the conditions for the design and operation of the so called low-temperature combine heating systems, where the both heat transfer principles are applied in the space and/or in the buildings. In the conclusion the requirements for the design and operation of low-temperature combine heating systems for sustainable low-energy buildings will be presented from the point of view of energy consumption and indoor environment as well.

The use of renewable and secondary energy sources becomes more and more compeling both in terms of the expected availability and price of primary energy sources as well as in terms of environmental impacts. Results of the geological research and exploration works investigating the geothermal energy sources in Slovakia indicate, that within Europe the Slovak territory has a superior potential of its possible effective utilization. The utilization of ambient heat is most commoly carried out by using heat pumps technology. A very important field of advantage of the heat pumps technology are exploitation of low temperature geothermal energy for spa building heatig and hot water preparation.

1. INTRODUCTION

Low energy buildings are generally characterized by energy consumption for heating between 30 ÷ 70 kWh.m^{-2}.year. I.E. by energy demand about 10 ÷ 15 W.m^{-3}. Therefore low-temperature heating is required for these, especially so called large-area heating system as the floor, wall and ceiling heating.

The aim of the paper is to evaluate application of the large-area radiant heating systems in low energy buildings. The problems of the energy conservation and thermal comfort/discomfort in the radiant heated spaces will be analyzed.

The heat and mass transfer physical model was used as the methodology of evaluation. Because the direct influence of radiant heating systems on human body, estimation of comfort conditions, elimination of discomfort causes and definition of energy demands will be presented in conclusions. Low temperature heating systems represent so-called large-area heating where the heating pipes are placed into the one of the building structures e.g. floor, wall and ceiling. The common heating medium is hot water which temperature must be adequate to surface temperature of building structures, because the required thermal comfort conditions.

2. LOW-TEMPERATURE HEATING

At the present the requirements for thermo-technical properties of external building structures and buildings themselves prefer energy aspects, concerning hygienic criteria. It is appropriate to design for low-energy buildings also adequate heating systems as low-temperature ones. In this case the temperature of medium is almost of a half value of the temperature used in other heating systems that means less than 50°C.

Assuming the heat preparation, low temperature heating systems fall into the following categories:

- Monovalent,
- Bivalent,
- Combined.

Monovalent systems have one or two heat sources that are of the same type. The most suitable are low-temperature boilers that eliminate to use additional mixing fittings. ***Bivalent systems*** use two heat sources based on the principle that the pick one is in operation only during heating season, depending on the outdoor air temperature. ***Combined systems*** use the second source also as a paralel one because of the heat demand. While the heat transfer medium is direct or indirect via heat exchangers and reservoirs.

The most common medium, especially for low-temperature heating, is water. It is due to its physical properties, which is possible to determine via simple mathematical equations, under the conditions of the temperature not higher than 50°C. Theoretically, it is also possible to use a steam, for instance a water steam. Similarly to vacuum heating systems, water based, the required operation pressure is more than 0.02 MPa. That is corresponding to the saturated steam temperature higher than 60°C. When we consider the low-temperature heating with the temperature of medium lower than 45°C, the steam pressure should be lower than 0.012 MPa and at the temperature of 30°C lower than 0.043 MPa. The application of air as a medium is also not very appropriate because of the possible economical and hygienic problems. Considering all the facts mentioned above it is possible to say that water is the most suitable medium.

Considering possibilities how to transfer the heat into interior we can speak about large-scale heating systems as well as, theoretically, convection systems. Large-scale radiant heating represents more progressive elements. At the first it permits to apply renewable energy sources like for instance solar, geothermal energy and energy of the surroundings (water, earth, air). Then the heat from heating system to interior is transferred via large-scale heating surfaces (floor, wall, ceiling) with a dominant radiant part of thermal flow.

All the characteristics of low-temperature heating mentioned above predetermine to its application in low-energy and ecological buildings. Low energy consumption is typical for these types of buildings. The thermal losses via building structures are minimized and at the same time internal and external thermal gains are used. Anyway, the optimum thermal state in heated interiors, with excluded thermal discomfort, is guaranted.

3. LOW-TEMPERATURE COMBINED HEATING

Low-temperature combined heating system consists from large-area heating systems and the convective heating system operating in the one space (e.g. one room or whole building).

3. 1 Low-temperature radiant heating system

As implied by the recommended values which characterise the energy balance of low energy house, such building objects have to be equiped with low-temperature heating systems using large surface radiant heating panels mounted on the ceiling, on the walls and floor heating. Such heating systems are typical with their need of large heat exchanging surfaces, which in turn may cause extreme heat accumulation and subsequently a high degree of thermal inertia of the indoor space. Low temperature heating systems represent so-called large-area heating where the heating pipes are placed into the one of the building structures e.g. floor, wall and ceiling. The common heating medium is hot water which temperature must be adequate to surface temperature of building structures, because the required thermal comfort conditions.

Large-area floor heating is characterized by the heat flow coming largely from the floor upwards (radiation-to-convection ratio = 55 : 45 %), essentially from hot water or electrical heating (hot air heating respectively), at a specific heating power of 60 to 120 W.m^{-2}, with floor surface temperature limits of 29 ^{o}C and/or 32 ÷ 33 ^{o}C for a short-term stay.

Large-area wall heating is characterized by the heat flow coming largely from the wall upwards (radiation-to-convection ratio = 65 : 35 %), essentially from hot water or electrical heating (hot air heating respectively), at a specific heating power of 300 to 500 W.m^{-2}, with wall surface temperature limits of 60 ^{o}C.

Large-area ceiling heating is characterized by the heat flow coming largely from the ceiling upwards (radiation-to-convection ratio = 80 : 20 %), essentially from hot water or electrical heating (hot air heating respectively), at a specific heating power of 100 to 200 W.m^{-2}, with ceiling surface temperature limits of 50 ^{o}C.

Tab. 1. Coefficient of heat transfer from surface α_p (W.m^{-2}.K^{-1}) and specific heat power q (W.m^{-2}) of ceiling, floor and wall heating surface by $t_v = t_c = 18$ ^{o}C

		Surface temperature t_p (^{o}C)							
		25	30	35	40	45	50	55	60
Ceiling surface	α_p (W.m^{-2}.K^{-1})	-	-	7,4	7,5	7,7	-	-	-
	q (W.m^{-2})	-	-	126	165	208	-	-	-
Floor surface	α_p (W.m^{-2}.K^{-1})	9,2	10,0	-	-	-	-	-	-
	q (W.m^{-2})	64,4	120,0	-	-	-	-	-	-
Wall surface	α_p (W.m^{-2}.K^{-1})	-	-	-	-	-	11,0	11,4	11,7
	q (W.m^{-2})	-	-	-	-	-	352	421,8	491,4

3. 2 Low-temperature combined heating systems

Concerning thought mentioned above combined hot – water system, plastic piping distribution based, can be designed as far as required temperature of heating medium construction, and operation regime are concerned, as follows:

a) central hot – water heat source producing direct hot water for a convection distribution with an application of water (two-way and three-way fittings) for low-temperature large – scale radiant heating.
b) central low-temperature source of heat – producing water for the whole combined low – temperature system with system with an additional larger areas of heating bodies.
c) central hot-water source of heat – producing direct heating water for convective heating system but with application of a heat – exchanger stations for less – temperature large – scale radiant heating system.

These three solutions differ in technical and material demands. Currently the „a“ alternative is the most common one in spite the fact two separate heating systems are in use. „B“ alternative is possible to use in low-energy building with specific thermal losses of 15 ÷ 20 W.m^{-3} due to decreased thermal input of convection heating bodies. „C“ solution is theoretically the most excellent. If consists of 2 heat and pressure independent circuits. In the case of low temperature large-scale radiant heating the circuit is protected from emissions in boiler circuit as well as resistant to oxygen diffusion influence. The solution mentioned above showed the possible solution for combined heating from heat source and heating water production point of view. The system should have an appropriate construction in order to be considered as a progressive one. In other words the material basis should be the same. Plastic one fulfills the requirement. Screened polyethylene and polybuten are the most common materials used in a low temperature heating systems. If we want to use plastic piping in a convective heating a new conception should be applied. It should differ from the old one based on horizontal distribution in flats or branches, one or two – pipe system. The current requirements on thermal and pressure parameters have to be in agreement with requirements to this type of heating system. It is possible to meet following cases:

a) 2 – pipe system with a central distribution on a floor,
b) 2 – pipe system connected with a central riser and the shortest installations,
c) 2 – pipe system with a connection to a central riser and a distribution next to a wall,
d) one – pipe system connected with a central/main riser and a distribution along a wall.

4. HEAT PUMP TECHNOLOGY

Renewable sources of energy from the view of human life are inexhaustible, during the advantage are continously regenerated and with relative small changes are permanently in disposable. As for “renewable energy sources”, they can be continually renewable (permanent flux), renewable in short cycles (anual, for example), to span a generation or several generation; or, they can be partially or total renewable. This categoty are represented by solar-, wind-, geothermal energy and energy- of biomass and from water. General characteristics of renewable sources are wellknown and a preview is in Tab. 2.

Biomass means all organic matter known, and the energy released from biomass when it is eaten, burnt or converted into fuels is called biomass energy.

Geothermal energy taken from the heat coming from the centre of Earth.. This heat is stored in rock and water within the earth and can be extracted by drilling wells to tap anomalous concentrations of heat at dephts shallow enough to be economically feasible.

Low enthalpy resources (50 to 150 ^{o}C) can be used for heating purposes: large base load demands such as district heating, horticulture, recreational uses such as spas. Medium and high enthaply resources (>150 ^{o}C) are used for electricity production.

The conversion of solar radiation into heat for technological, comfort heating and cooking purposes.

Solar thermal heating is applied to water, air or structural materials. Conversion of light to heat can be achieved through passive systems or active systems (mechanically trasferring heat by means of working fluid such as air, water or oil).

Tab. 2. Prewiew of renewable energy sources

Solar Energy	Energy of Wind	Biomass Energy	Geothermal Energy	Energy of Water
Active systems - flat plate collectors - concentrated Collectors - solar thermal Station - photvoltaic cells ***Passive systems***	Wind drive Wind power station Wind parks	Forestry biomass Waste from wood industry Agricultural biomass	***Renewable sources*** ***Not renewedable*** ***sources*** Geothermal power stations Hot rock utilization Heat pumps for energy of ambient	Flow water power stations Accumulation (pumped) water power stations Water power station from ocean tide

With heat pump systems the natural heat flux from higher to lower temperature level can be reversed by adding high quality energy. When utilize heat pump systems, ambient heat is shiffed to a higher temperature level necessary for utilization, for space heating or/and hot water preparation. That means that heat pump units are only one part of a system consisting at least of the equipment for collecting ambient heat, the heat pump itself, and the equipment to distribute the heat on the desired temperature level for utilization.

The special advantages of heat pump are to,

- save energy,
- reduce emission,
- have a positive impact to the green house effect.

All these aspects are also included in the goals of an electricity utility. Accordig this it is correct and significant that utilities are promoting heat pumps. In all different applications the electricity is used as the power for energy saving. Many benefits can be realized by electric driven heat pumps.

Additional to these overall and approachig to the total community interests many other possibilities exists which are useful as well for the customers as for the utility. The positive contribution to the load management, the possibility of double use for heating and cooling with or without a storage system for heat or chill are very usefull.

This load leveling is profitable for both, the customer can avoid peak load and additional high fee to the utility only for power without many kWh; the utility has not to place at disposal eccesive peak power produced by more expensive power stations. The additional use of existing structurs in a bivalent mode with peak demand delivered from a storage system helps also to avoid investments in peak structures.

5. SLOVAKIAN EXPERIENCES

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Many sources of the low temperature geothermal waters in Slovakia are in the south part of country. At present, there are more than 50 boreholes with a yield of about 490 $l.s^{-1}$ with temperatures in the range of 40 - 92 ^{o}C . The low temperature geothermal waters of Slovakia have, until now, been utilized in agricultural plants, in geothermal direct heating systems and for recreation in thermal spas, baths and swimming pools. The utilization of geothermal waters needs complete technological equipment. The changes of chemical characteristics and the creation of gases. Some geothermal waters are inconvenient for thermal utilization due to improper chemical characteristics .

Complete utilization of the low temperature geothermal waters to the temperature level in the range of 10 - 15 ^oC requires heating systems connected with heat pumps. Geothermal boreholes have high thermal power output and therefore heat pumps connected with geothermal sources are designed for a high heating capacity in the range 0.5 - 10 MW. The heat pumps may to be connected in series in order to reduce the losses caused by irreversibility, and save energy. The irreversible losses decrease and the investment costs increase as the number of heat pumps used increases.

One device which can make a significant contribution to energy conservation is the heat pump. By raising low grade (or low temperature) heat to a more useful temperature, “new” sources of heat become available, for example outdoor air, and also, sources of waste heat which previously were considered unsuitable for recovering, because of their temperature is low. The heat pump therefore can vastly increase the potential use of low grade energy, albeit with the expanditure of proportion of high grade energy to achieve this.

A preview of geothermal waters advantage for space heating by heat pumps in spa locality in Slovakia is in Tab. 3.

Tab. 3. Preview of geothermal waters advantage for heating by heat pumps

	Locality of spa	GTW temp. [^oC]	Heatig capacity [kW]	Heat pumps number	COP [$kW.kW^{-1}$]	Utilization time [h/year]	Utilized heat [TJ/year]
1	Podhájska	40	20	1	3,8	3 360	0,153
2	Bojnice	38	40	1	4,2	4 350	0,273
3	Vyšné Ružbachy	19	778	2	3,7	11 390	6,845
4	Gbeľany	9	23	1	4,0	4 550	0,115
5	Rajecké Teplice	34	489	3	4,5	7 600	4,725
	Summary	-	1 350	8	-	31 250	12,111

Use of Heat Pumps in Vyšné Ružbachy Spa

This project of use heat pumps was realized in years 1997-98. Formerly the preparation of hot water was solved by accumulation electric boilers (5 pieces with installed power of 400 kW), net power 2 000 kW. Accumulation of hot water was solved by 5 pieces of reserviors with volume of 200 m^3. Exploitation of geothermal borehole Izabella with thermal water temperature of 2 ^oC. In consequence of unfavourable physical and chemical properties of geothermal water it was necessary to aply separational water circuit with Alfa-Laval plate heat exchangers. For the achieving of 10 $l.s^{-1}$ water quantity it was build pumping station for geothermal water.

The advantage of 2 pieces of water-water type heat pump equipment was from Ochsner (Austria) with installed heating capacity of 2 x 389 kW, with the predicted COP of 3,9. The secondary side of heat pumps was switched with existing water heating system after some modifications. Heat pumps are suply for heating, for air condition and for preparation of hot water of basins in building objects of Balneoterapia and spa house Dukla.

The bivalency point for heat pumps is at -5 ^oC. In the case of lower outdoor temperature than -5 ^oC, during 100 days in the year the heat pumps collaborate with electric boilers for heating and air conditions. Heat pumps are exploited for preparation of hot water continously.

The basic technological data of realized project :

- characteristic outdoor temperature	- 18 ^oC
- average outdoor temperature during heating season	+ 1,5 ^oC
- number of days of heating season	255 days
- number of days of hot water demand	340 days
- basic temperature drift on heating systems	70 / 50 ^oC
- temperature drift of hot water and geothermal water	50 / 30 ^oC
- input temperature of geothermal water	19 ^oC
- quantity of geothermal water	20 $dm^3.s^{-1}$
- quantity of geothermal water	- 5 ^oC

Heat demands of building objects:

- heating	at - 18 ^oC	740 kW
	at - 5 ^oC	450 kW
- air condition	at – 18 ^oC	450 kW
	at - 5 ^oC	300 kW
- for preparation of hot water		120 – 230 kW
- for the gbasins (evening filling)		800 kW

The goals after advantages of heat pumps in this case are,

Energy savings (redusing of brown coal consumption)	2 306 ton/year
Reduction of hard material emission	11,3 ton/year
Reduction of SO_2 emission	42,7 ton/year
Reduction of NO_x emission	6,7 ton/year
Reduction of CO_2 emission	2,3 ton/year

6. CONCLUSION

Low-temperature combined heating represents progressive systems for sustainable low-energy buildings using the advantages of both kinds of heat transfer e.g. by radiation and convection too. The experience with heat pump technology in Slovak Republic so far is excelent. An important factor, related to the further development of eletric heat pumps systems in general, is the current process of deregulation in Slovakia. The energy sector, and especially the eletric utility companies, is currently under deregulation and privatization. This affects not only the producers but also the customers. The deregulation process may affect the heat pump market in two ways. At first the heat pump economy might be influenced by changes in the energy price structure and at second, the heat pump market might be stimulated or hindered, depending on changing utility market strategies.

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