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POSSIBILITIES OF HEATING AND AIR-CONDITIONING OF BUILDINGS IN THE MOUNTAIN AREAS[1]

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Summary

The mountain areas, due to their specificity, require special approach to issues concerning heating and air-conditioning of buildings. After presenting general information on demand for heat in a standard residential building, the forecasting of demand for final energy by particular branches of economy has been presented. Fossil fuels are most commonly used in heating buildings. In this kind of systems the heat is supplied to the consumer by means of heating pipes provided by heat power stations or combined heat and power stations or it is generated in boilers owned by the consumers. The remote heat source can also be energy from geothermal power station, as it is in the Podhale region. There is an alternative solution to these systems in the form of heat pumps that are often connected to borehole heat exchangers. Depending on the energy balance of the heating system and air-conditioning of a particular building the latter system can be additionally aided by solar collectors. This method requires only a power service connection, which is available almost in every building. Moreover, practical uses of the proposed system, which should be more widely applied in the mountain areas, have been described.

Keywords

heating and air conditioning of buildings • borehole heat exchangers • heat pumps • mountain areas • geoenergetics

1. Introduction

One of the most basic man's needs is to make sure that rooms in which he or she lives are warm enough. It is called more generally: the need of thermal comfort and involves the necessity of heating the interiors in winter and cooling them in summer.

Heating is needed in winter to keep suitable temperature in rooms and besides it is used all year long to heat, for example, tap water. Air-conditioning is used mostly in buildings such as hotels or offices, but it is more and more frequently applied in private houses.

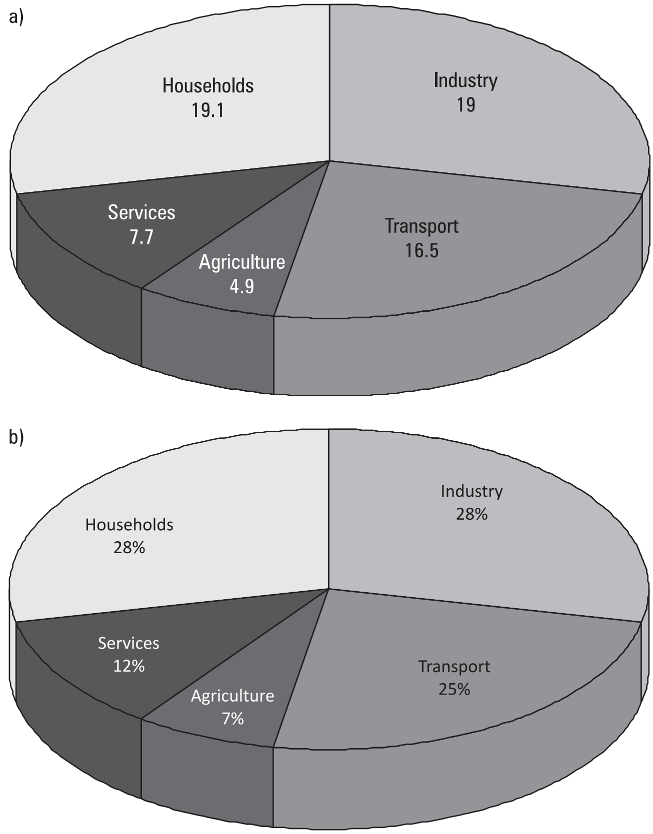
[1] The work was carried out as part of statutory research at AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Cracow, contract no. 11.11.190.555.

Heating or both heating and cooling devices are usually the greatest consumers of energy in civil structures. In Poland, including the mountain areas, fossil fuels are most frequently used to maintain the thermal comfort.

But some claim that heat as the final stage of energy transformation can and should be produced from other sources for heating purposes. Fossil fuels are too valuable to burn them only for generating energy to keep room temperature of 20°C.

2. Heat (and cold) supply

The average demand for heating capacity in central heating in new buildings (with good thermal insulation of dividing structures) is about 50 W $\cdot$ m^{-2}. Moreover, in order to have domestic hot water (with 25 dm^{-3} $\cdot$ d^{-1} $\cdot$ pers.$^{-1}$) the heating demand is 0.30 kW $\cdot$ pers.$^{-1}$. Thus the computational, peak demand for heating capacity in a single-family detached home of 150 m^2, inhabited by four persons, equals 7.5 kW.



Source: authors' study (based on data of Ministry of Economy 2009)

Fig. 1. Predicted demand for final energy by particular branches of economy a) Mtoe, b) percentage-wise

Seasonal demand for heat in new buildings can be defined by index method, assuming that 150 $kWh \cdot m^{-2} \cdot year^{-1}$ (0.54 $GJ \cdot m^{-2} \cdot year^{-1}$). In a single-family detached home described above the annual demand for heat in a central heating is 22.5 MWh (81 GJ) and for heating domestic water the demand is about 5.5 MWh (20 GJ). Total annual demand for heat equals 28 MWh (101 GJ).

The heat used in these conditions (so it does not apply to so-called passive houses) is generated from external sources. Heating needs play a significant role in states' energy balances. In Poland the heat mostly covers power needs of households and, in a smaller degree, of services and industry (Figure 1).

3. Sources of heat (and cold) supply

Fossil fuels are most commonly used for heating. It can be done in heating systems in which heat is supplied to a consumer by heating pipes. The remote source of heat can be a heating power station, where fossil fuels are burned, or by combined heat and power stations, where heat supplied to consumers can be regarded as waste heat. Moreover, the remote source of heat can be the energy from a geothermal power station.

The second heating method is based on heat produced at a consumer's house. The supplied heat carrier is fossil fuel, which is burned in a boiler working in a consumer house.

Both methods have its advantages and disadvantages. The first method requires construction of a distribution network and causes transmission heat losses. In the second, discharge system of combustion gases and a gas connection (in systems using system gas) are necessary.

Other ways of supplying heat to consumers are, for example, systems based on renewable energy sources, especially with solar collectors, and systems using electric heaters. Cold supply is essentially generated by air conditioners and refrigerating units powered by electric energy.

Most of the described methods require connection to a heat distribution network. It can be a problem in low-density housing areas and especially in mountain areas. Sometimes buildings or housing estates located far away from heat supply mains cannot be linked to pipelines for economic reasons.

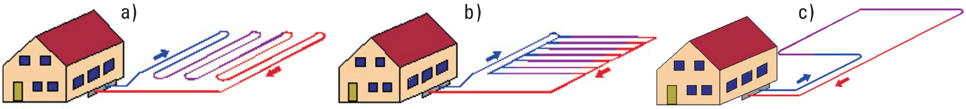
4. Proposed method of heat (and cold) supply

The more and more popular method of heating buildings are heat pumps. The objects heated (and air-conditioned) in this way require only a power service connection that is available in virtually every building. Besides, connection to a power source is cheaper (and easier) than constructing a pipeline.

Heat pump is a device that forces the heat flow. It draws dissipated heat from the surrounding environment that has low temperatures. It then transfers the heat, rising its energetic level to a higher temperature. Working in the opposite direction it absorbs heat from the air conditioned spaces, transfers it to a rock mass, in which it is stored.

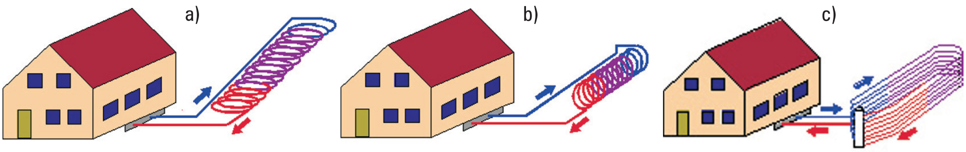
Treating rock mass as a thermal reservoir is becoming more and more popular, especially in countries in the temperate climate zone. Heat from natural and anthropogenic environment can be drawn from:

- surface waters (rivers, lakes, ponds, seas and oceans),
- groundwater (water-bearing strata, cooled thermal waters),
- rainwater (e.g. sewage treatment plant),
- the outside air,
- the waste air (e.g. from ventilation),
- rock mass, by means of horizontal (Figures 2 and 3) and vertical (Figure 4) heat exchangers,
- infrastructure, waste etc.



Source: Sanner 2004

Fig. 2. Ways of arranging horizontal ground-coupled heat exchangers: a) series connection, b) parallel connection, c) one loop connection



Source: Sanner 2004

Fig. 3. Ways of arranging horizontal ground-coupled heat exchangers in a confined space: a) spiral horizontal connection b) spiral vertical connection, c) several loops connection

The method, which is little dependent on morphological and geological factors, are borehole heat exchangers (Figure 4). And they have good coherence properties. Generating heat flow is not related with weather conditions (apart from heat exchangers working in shallow depths). Up to 20 metres of depth one can observe variability of rock mass temperature with the change of seasons.

Heating and cooling systems based on heat pumps and borehole heat exchangers can substitute for more traditional heating methods. They can be an alternative for heat supply from heat and gas pipelines, as well as from liquid and solid fossil fuels, such as gas, fuel oil and coal.

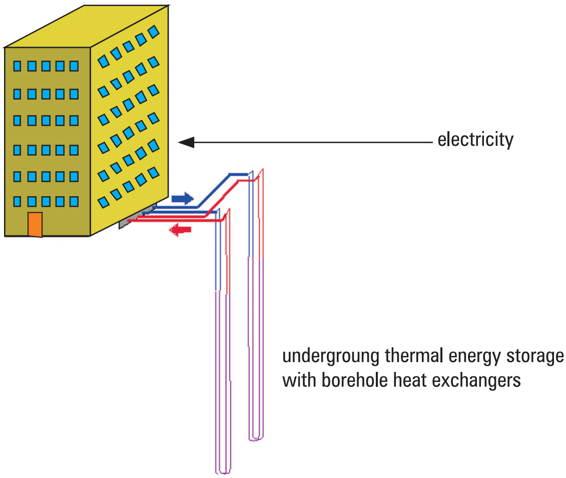


Fig. 4. Heating (heating and cooling) system based on heat pumps and borehole heat exchangers (heat from rock mass)

5. Economic analysis

Both operational (maintenance) costs and capital expenditures influence economic effectiveness of heat (cold) sources, such as heat pumps and boreholes heat exchangers, as well as all commercial investments.

5.1. Operational costs

The advantage of systems based on boreholes heat exchangers lies in increasing economic competitiveness during their operation. The efficiency of heat pumps that draw heat from rock mass by means of boreholes heat exchangers usually stays within 3–4. It means that the amount of thermal energy is 3–4 more times higher that the amount of drive energy. Drive energy for compression heat pumps is an electric current. Therefore heat costs are 25–33% of the costs of electricity.

The research carried out in The Laboratory of Geoenergetics at the Faculty of Drilling, Oil and Gas of The AGH University of Science and Technology, Kraków, shows that efficiency of heat generation from rock mass depends on type of borehole exchanger [Gonet and Śliwa 2008] and the technology of its exploitation. Operating technology of borehole heat exchanger it is mainly a volume flow of the heat carrier (usually monopropylene glycol) and its temperature. The influence of the type of heat carrier [Sapińska-Śliwa et al. 2014] and kind of sealing material [Śliwa and Rosen 2013] has also been confirmed. When the effectiveness of energy exchange with rock mass is concerned, the most important thing, if a borehole heat exchanger is correctly implemented (it applies in particular to a proper filling and/or sealing of exchanger), is thermal conductivity of rocks and hydrogeological parameters [Gonet et al. 2011].

5.2. Capital expenditures

The necessary capital expenditures are the fundamental problem in popularizing heat pumps systems with borehole heat exchangers. The investments are considerable because heat pumps (compared to boilers) and drilling are expensive. In case of dispersed objects, located in mountain areas, the opportunity costs must be taken into account. Such an alternative here are the costs of connection to or transport of fossil fuels heat carriers.

Various forms of financial support for this kind of systems have been developed. The basic form of aid are subsidies to capital expenditures. This method of support is a result of states' policies aimed at favouring the development of environment-friendly solutions in energy industry. Application of compression heat exchangers in Poland is an environment-friendly solution that can be a substitute for heat pump systems. The emission is moved to the place where electric energy is generated. However, in heat power companies (of large emitters) harmful substances are not let into the environment, thanks to systems of filters, which are not used in low-stack emission systems producing heat.

Another method of support are long-term contracts for electric energy supply to heat pumps. In the light of these contracts a heat pump user is not its owner. The costs of purchasing a device are covered by an electrical power distribution company, which later includes them in the price of electricity. This solution is implemented in France.

6. Energetic analysis

Investments in heat pumps and borehole heat exchangers are cost-effective, especially if the system is working in cycles: heating in winter and cooling in summer. This solution can be used in hotels and guesthouses located in mountain areas, far from heat and natural gas distribution networks.

Big advantage of using borehole heat exchangers in heating and cooling systems is an energetic balance. In the cooling mode the heat is absorbed from inside air and transmitted to rock mass. And so it is used in winter for heating. In a traditional air conditioning heat (waste heat) is irretrievably lost in the atmosphere.

The heat charged into rock mass is a form of artificial recovery of energy resources in rock mass. Systems with more number of holes (of greater power), working only in a mode of heat absorption from rock mass, can be characterized, especially in first years of their work, by systematic fall of heat carriers temperature. It results from incomplete natural recovery of energy resources from the surrounding rock mass, which means lower effectiveness of the system. A good solution in such situations is an artificial recovery of these resources. As the research shows [Śliwa 2012] the method can be supplemented, with positive effects, by solar collectors. The solution is being implemented in The Laboratory of Geoenergetics (Figure 5).

Recovery of energy resources can also be carried out by means of fan heaters. If the temperature of heat carrier in the system is lower than the temperature of the air, than it is possible to warm it up. The system is cheaper to install than solar collectors [Poniedziałek and Śliwa 2013].

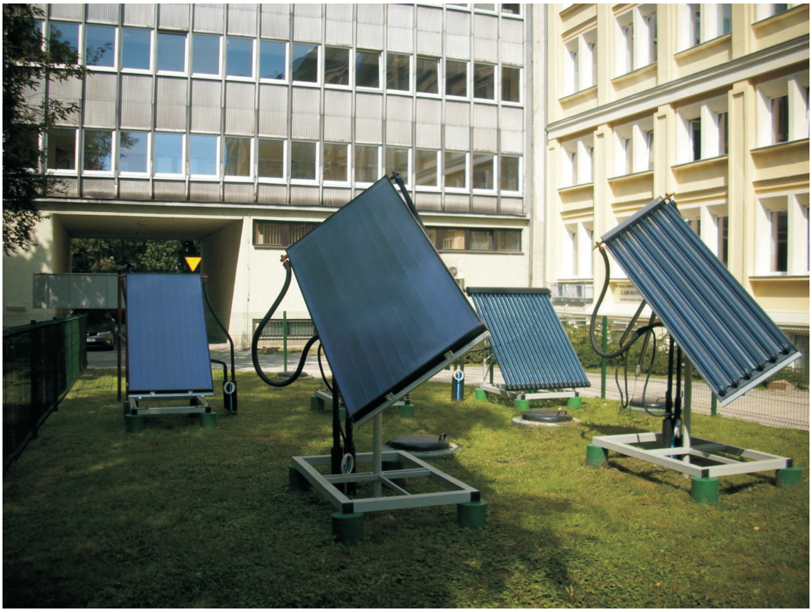


Photo by T. Śliwa

Fig. 5. Solar collectors used to recover heat resources in rock mass – in between: chambers of borehole heat exchangers (The Laboratory of Geoenergetics at the Faculty of Drilling, Oil and Gas of AGH University of Science and Technology)

Another way of complementing heat in rock mass can be a system of snow-clearing. In winter heat from the pipes embedded under roads, car parks, pavements can melt, de-ice and dry the surfaces. In summer the same system can be used to recover heat from hot surfaces and charge it into rock mass. It has been confirmed by the research carried at The Laboratory of Geothermal Energy [Śliwa et al. 2014].

Application of systems of snow removing and de-icing by heat are frequently used in Japan, Sweden and Switzerland. Thus pavements, car parks, crossroads, bridges and uphill roads in mountain areas are cleared of snow. The use of heat from rock mass is an interesting solution. The heat in winter can be used even with bypassing heat pumps. Especially when in summer heat from such a system is charged into rock mass. Experiences of other countries (e.g. Japan) show that application of such systems, financed by insurance companies, is cost-effective.

It is important too that heat pumps are powered by electricity from Polish energetic resources, whereas only limited amount of gas used in Poland comes from our own deposits. In the most part gas is imported from abroad.

7. Conclusions

1. Connection of dispersed buildings in rural areas to heating distribution networks and gas mains considerably increases capital expenditures. For this reason borehole heat exchangers, potentially more advantageous than system networks, are more and more popular.
2. A good and safe way of maintaining thermal comfort inside buildings is an application of heat pumps and borehole heat exchangers. They absorb low-temperature heat contained in rock mass.
3. Compression heat pumps are driven by electricity, which is available in every building. It is usually transferred through connections to power network, sometimes by means of power generators (e.g. in mountain hostels).
4. Compression heat pumps and borehole heat exchangers are effective when they work alternately in heating and cooling mode. Therefore they can be used in hotels and guesthouses distant from heat and gas networks.

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