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Energy integration and performance evaluation of a new concept of advanced solar district heating/cooling networks for energy supply in buildings

Kane M., Grosjean S., Kaempf J.

Laboratory for Thermal Energy (LTE), Mechnical Engineering Department at the University of Applied Sciences and Arts of Western Switzerland, HES-SO, Pérolles 80 ▪ PO BOX 32 ▪ CH-1705 Fribourg, Switzerland, tel +41 (0)26 429 68 42 (direct), malick.kane@hefr.ch

District heating (DH) networks are becoming an energy-saving and cost-effective alternative to conventional conversion systems (boilers, killers, combined heating and power systems) and appear as a vector of the energy transition because of the diversity of the energy sources that can be used for their operation. They are increasingly used in cogeneration and more efficiently when operating with lower temperature levels. Indeed, many previous works, carried out in several European countries, notably in Switzerland, Great Britain but also in countries such as Denmark and Sweden were able to demonstrate the application of renewable energy sources such as biomass, solar thermal and geothermal energy and / or waste heat recovery for DH energy supply. These works were carried out on traditional networks (eg steam, superheated water and/or hot water with temperature levels in general above 60°C), hence relatively high temperature levels compared to ones required for heating new and high-performance buildings (below 30°C). In addition to the linear thermal losses related to the high differential temperature between the networks and the environment, the heat transfer processes that occurred on the substations (decentralized heat exchangers connected to the network system to supply heat to buildings) are clearly inefficient with significant exergy losses.

Recent developments have led to so-called "anergic" networks operating at low temperature levels (~ 8/12 °C), which use decentralized heat pump (HP) substation units for heating and domestic hot water production. These HPs make it possible to raise the temperature to approximately 30°C for space heating and 55°C for the preparation of hot water. Such advanced networks have the advantage of being able to serve both for heating (in winter) and cooling (in summer). The performance of these heat pumps depends strongly on the temperature of the network. The high differential temperature between the DH network and the level of energy supply for heating and hot water process in the building corresponds to an important consumption of electricity in the decentralized HP units.
The proposed study concern a new concept of advanced heating/cooling networks that operates with optimal temperature levels, using an intelligent centralized energy conversion unit able to integrate and manage different renewable and residual energy sources (solar thermal, geothermal and waste heat). In winter, the temperature of the DH network could be chosen higher than 30°C, thus enabling simple heat exchangers to be used for heating purposes. Compared to an "anergic" low-temperature network, only hot water production requires the use of decentralized heat pump units. The latter operate even more efficiently to raise the temperature up to more than 55°C (low temperature differential between sources of the heat pump). In summer, the temperature of the DH network could be reduced to a lower value (around 15°C), allowing to use the same heat exchangers for free-cooling the buildings.

A typical application for a set of high performance buildings in the BlueFactory district (Fribourg, Switzerland) has been considered. The demands for heating, cooling and electricity as well as the temperature of the required

hot water are first estimated for each building. It allows to determine the key parameters for the design and operation of the advanced heating/cooling network such as the pinch temperatures of heating and cooling, the nominal capacity of the network and the range of the working conditions (flowrates, minimum heating/cooling capacity). Hydraulic and thermodynamic models have been developed for all components in order to simulate different structures of advanced thermal networks where the performances in term of pressure drop and thermal losses on the pipes and exergy losses on the substations (heat exchangers and heat pumps for space heating and domestic hot water preparation) are determined in function of the temperature of the network. A general energy/exergy modelling have also been performed in function of the temperature to evaluate the various options of the substations in term of exergy efficiency. These different model results have then been applied: first to simulate the performance of a reference system based on an "anergic" low-temperature (8/12°C) advanced heating/cooling network; then to evaluate the influence of different local heat sources on the temperature of the network (solar thermal and geothermal contributions, waste heat recovery from the residual hot water); and finally to evaluate the required heat from the centralized EC unit to control the temperature of the network. Results show that an exergy efficiency of the substations units of more than 55% can be achieved for the proposed concept, reducing electricity consumption of about 20% compared to the "anergic" DH network.