Innovation possibilities of solar district heating systems with seasonal heat storage

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Abstract

The need for higher share of solar energy in the EU's energy mix shall lead to a more intensive use of heating systems working with seasonal heat storage in the near future. Such a system is usually extended with a boiler burning fossil fuels. However, a biofuel burning boiler could be an advantageous solution in several cases. The share of utilized solar energy in solar district heating systems based on a seasonal storage can reach 40 up to 70 %. These systems are in the initial phase of research and development, however, some experience from more demonstration projects are already available. A working group of the Faculty of Civil Engineering of Technical University of Kosice devotes its intellectual potential to this topic. Starting from the experiences of the recently operating district heating systems based on seasonal heat storage, its research focuses on innovation of these systems. An innovated system must be capable of covering not only the space heating demand of the buildings from renewable energy sources, but in a large amount or even completely the electric energy and cooling demand.

1. Introduction

At the beginning of the third millenium the development of the human civilisation entered into a critical phase. The danger of world-wide conflicts like the first and second world war demanding more than ten millions victims and causing enormous suffer and damages is decreased to a great extent in the 20. century. The increase of population with the extended demand for the better quality of life has accelerated the depletion of natural resources in such a measure that the sustainability of the development became like one of the biggest problems of the mankind. The concept of sustainable development became famous world-wide from the Brundtland report. As it is in the report sustainable development is a form of the development which beside satisfying the recent needs do not deprive the possibilities of the satisfaction of the needs of the future generation.

The major part of the materials originating from not renewable natural resources (i. e. metal, building materials, etc.) can be recycled after the use. Contrarily to that, the fossil energy sources cause environment pollution after utilisation beside the accelerated decrease of the reserve of the Earth. Consequently the rational use of fossil energy sources is one of the basic conditions of the sustainable development, however sustainability of energy supply is very limited also in the case of the most economic utilisation. The gas and oil resources will deplete in this century according to most of the scenarios. There are also more optimistic scenarios available but the fact can not be changed: the mankind has to face with the very inconvenient fact of the depletion of fossil energy resources. Their rational utilization can be understood also like replacement everywhere where it is technically utilised and economically accepted. The replacement of the fossil renewable energy sources can not happen from one day to the other. This is a long process through decades. We are now in the initiative phase where renewable energy sources - like the forms of solar energy and geothermal energy - give alternative solutions.

The competitiveness of renewable energies is relatively weak in the recent economic environment. Their utilization however have more advantages (decreasing the load of the environment, improvement of the external trade balance and the safety and reliability of energy supply, increasing the domestic employment rates) which can not prevail in the recent market circumstances effectively enough. Because of this its support through state- regional- and local energy policy is reasonable without any doubts. It is necessary to be very careful with the number and the selection of the beneficiaries in order to fulfil the EU 20-20-20 targets.

1. The energy use of buildings

In the EU primer energy use the proportion of the energy supply in building is the biggest with the 45 % (Fig. 1.). The energy demand of buildings means the use of end-energy in the complex system of energy supply. The electric energy demand of lighting, the household appliances etc. can be often neglected compared to the summarised yearly heat demand of heating and DHW supply and of the HVAC, but in the households or in exceptional cases like in shopping centres this proportion can be turned to the opposite.

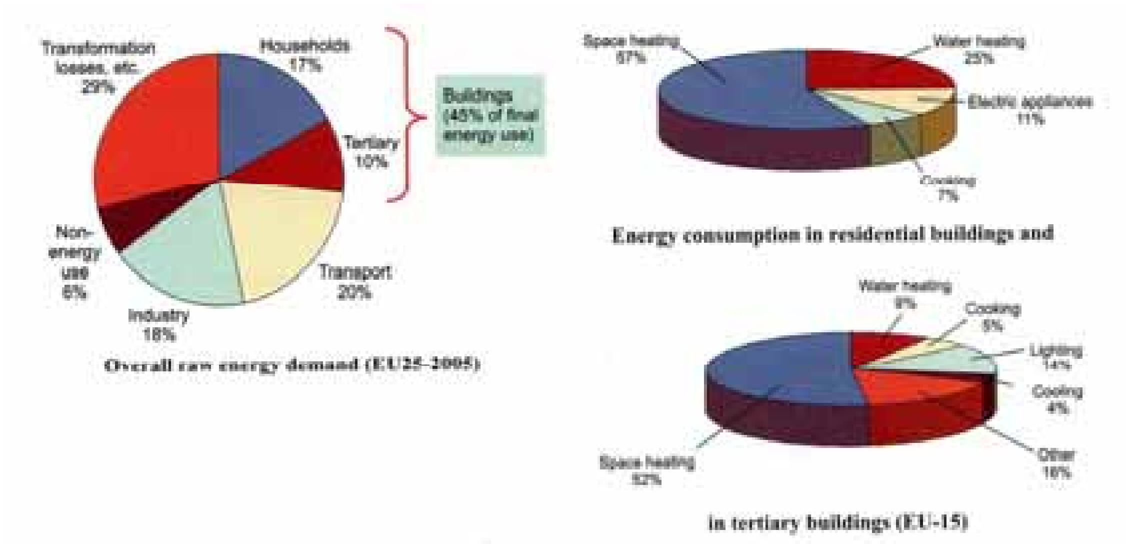

Fig. 1. Proportion of energy consumption of building [1]

The heat supply in residential buildings, like the heat demand of the heating and DHW is more than 80 %. This heat demand can be covered from low temperature heat sources (renewable energies, waste heat). In Slovakia the most expensive fossil energy (natural gas) is used in about 70 % with low effective direct heat production. This fact is even more worrying because in Slovakia almost 100 % of the natural gas demand is covered by Russian import. The last Russian-Ukraine gas conflict caused a big drop in the Slovakian industrial production and this shows that the high import dependency means a reasonable risk parameter for a national economy.

As it was mentioned before the biggest potential of decreasing the natural gas consumption is at the heat supply of buildings. The main two groups are:

- decreasing the heat demand of buildings with architectural and building service devices (DSM – Demand Side Management),
- the more effective heat supply with the traditional primer energies, mainly with natural gas and in an increased measure with renewable energy sources (solar, bio- and geothermal) (SSM – Supply Side Management).

For decreasing of the heat demand of buildings a wide scale of DSM measures can be applied i.e. isolation, change of windows and doors, regulation and modernisation of heating system, passive use of solar energy with the proper orientation at new buildings, etc. The available heat demand decrease can move on a wide scale (20-100 %). In certain cases very different results can be achieved. From the country's total energy utilization point of view the most significant is the average heat demand of the building.

The primer energy amount used for covering the heat demand of a certain building can move also in a wide range in the different heat supply system. The Fig. 2. supports also this fact with the comparison of some methods of the heat supply.

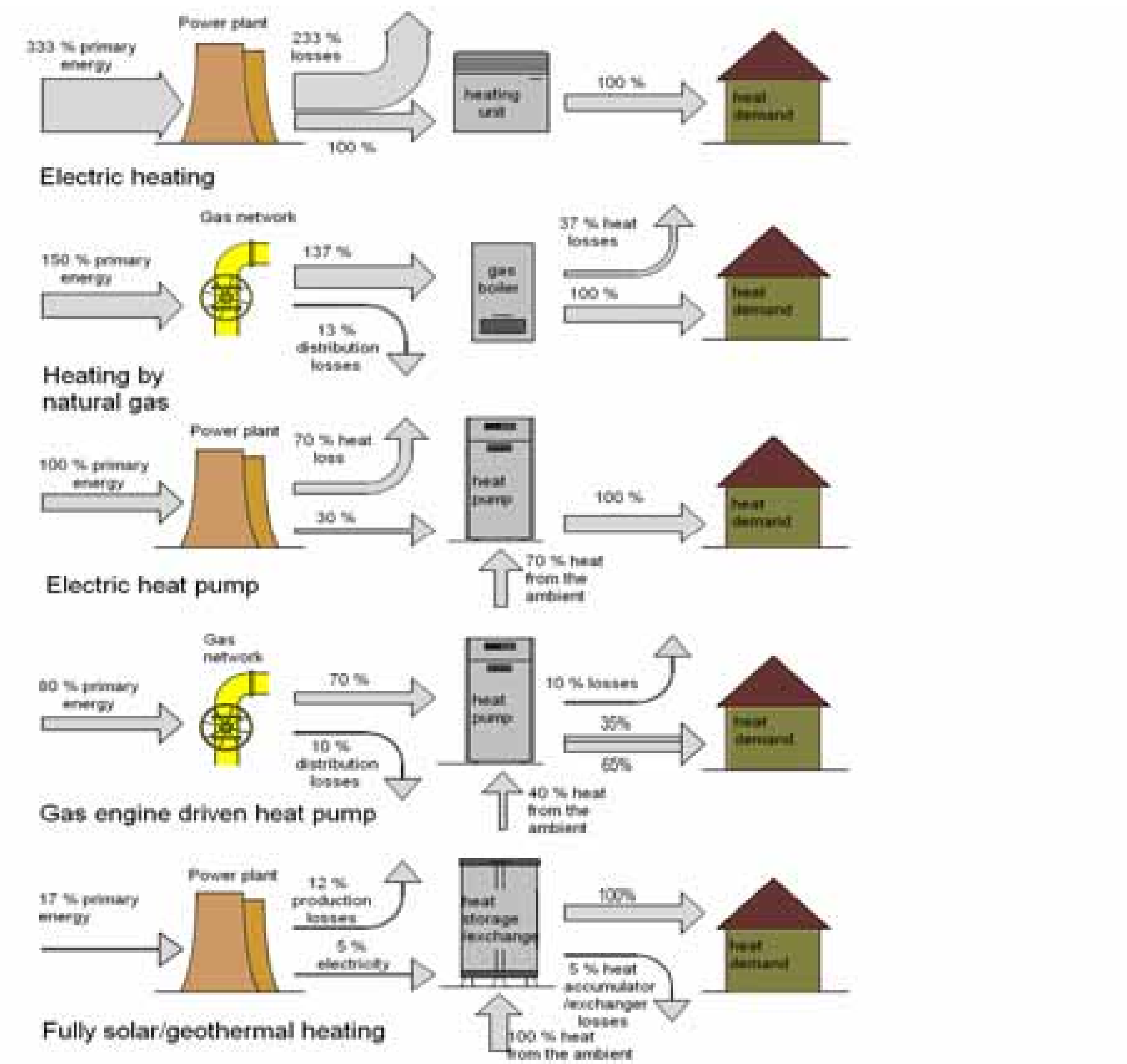

Fig. 2. Comparison of some methods of heat supplies of building

Although the use of low efficiency electric energy produced for heat supply of a building is very consumer friendly and is considered also as environment friendly very often but in the reality it is the strongest environmental pollutant and its application has to be limited only for exceptional cases.

The possibilities to increase the efficiency of heat supply of buildings through direct heat production based on natural gas can be only covered with condensation boilers. More decrease in the primer energy utilization can be resulted by non traditional heat supply systems based on coupled energy production or heat pumps.

The natural gas can theoretically substituted simply with solid biomass in the heat supply of buildings. This can be realized easily in the case of direct heat production, but the consequence is a decrease in energy efficiency and an increase in the emission of pollutant materials. The quantity of the biomass which can be used for energetic purposes is limited.

The substitution with biogas is more advantageous from the environment aspects, but its production increase the costs and the quantity is limited like in the case of solid biomass. The environmental load caused by the primer-energy consumption in the building's heat supply is the lowest by using solar- or geothermal energy.

Slovakia have high geothermal potential eligible for heat supply of buildings however for that purpose it is used only in a small scale. The interest for utilizing of that heat is always growing especially because of the gas crises; however only in some region can be taken into account as a realistic approach. The solar energy can be used everywhere in smaller or bigger scale and in an unlimited time scale because the hourly incoming solar radiation to the Earth is more than the annual energy demand for more than 4 milliard years. The supply covered only by solar energy is theoretically possible and practically can be realized but it has high investment cost. The research of the possibilities of the effective heat supply based on the combination of solar energy and biomass is very important. Principally all of them is solar energy as the biomass is also solar energy stored in a chemical form.

3. The quasi fully solar heat supply system of buildings with seasonal heat storage

The active use of solar energy is mostly about producing DHW or water heating for swimming pools. Only ca. 15 % of the yearly heat consumption can be covered by solar energy in the DHW systems. The heat demand is the higher in winter when the heat produced by solar energy is the lowest, and the proportions are the opposite for summer. The support of space heating from solar energy is also very limited in time – just in the very short time in the beginning of the spring and autumn period – also in the dedicated systems if the solar heat can be stored only for short time for several days. In this systems only 30 % of the yearly heat demand can be covered. This proportion can be extended with a consequent system-planning however the real development is the seasonal storage.

In the solar district heating systems based on a seasonal storage the proportion of the utilised solar energy can reach 40-70 %. These systems are in the initial phase of the research and development but good experiences from more demonstration projects are already available. These projects have been realised mainly in Germany, in Denmark and in Sweden. The scheme of the system is illustrated in the Fig. 2. with the main parameters of the Friedrichshafen project in Germany.

The useful heat energy is produced from the solar energy in the solar collectors. This heat energy captured in antifreeze liquid is transported through pumps and heat exchanger in a seasonal heat storage tank in the summer period. In the heating period in winter the heat consuming elements of the building are supported with the heated water from the storage tank through heat exchanger and pumps. The system normally is extended with a fossil fuel boiler.

Under the market conditions of a reliable and secure natural gas supply the traditional heat production in buildings by solar energy is not enough tempting for the owner or operators without financial support although with proper planning and implementation the additional cost pays back long before the lifetime of the system. One of the positive rezult of the near past is that the government supports also the biomass fired boilers beside the solar collectors. This would hopefully help the spread of the combined powered (solar and biomass) boilers and especially in the cases of the individual heat production can allow the use of renewable energy instead of natural gas.

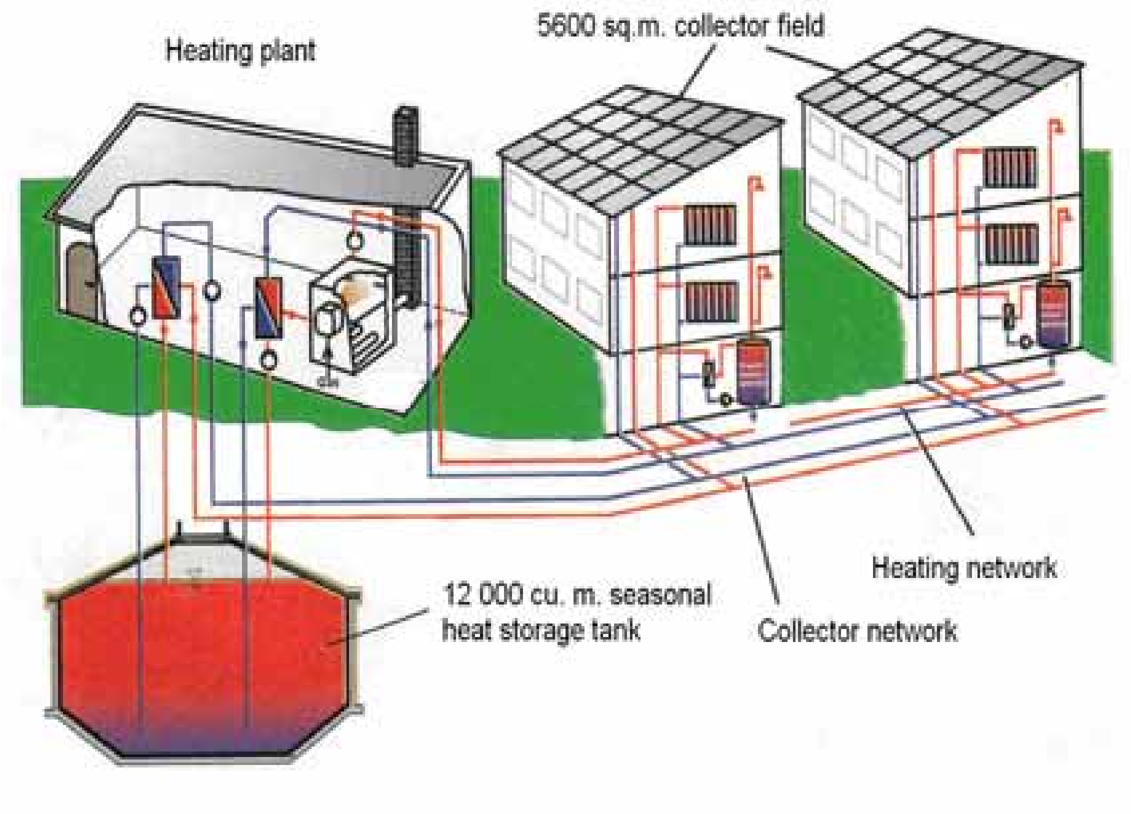

Fig. 3. The principle of the solar district heating system based on the seasonal heat storage [5,6]

In these systems only short term heat storage can be taken into account. This means that the proportion of the solar energy will be much behind the biomass one depending on the system planning. More advantageous would be the opposite from sustainability point of view. This can happen with the application of a seasonal heat storage which can be effective in the solar district heating.

Seasonal storage is possibility in the development a new generation of solar and biomass based combined systems which can be a transmission between the biomass based solar supported individual heat production and the biomass supported solar district heating. Research and development of that systems are reasonable in Slovakia because of the total lack of the experiences.

Starting from the experiences of the recently functioning district heating systems based on seasonal storage there are more type of innovation possibilities:

- In the additional heat source the usage biomass instead of natural gas in order to have a system only based on renewable energy source.
- the use of biomass in the coupled energy systems instead of in direct heat production. This can work also in summer because the produced heat can be fed in the storage and as

a consequence the collector area can be decreased.

- Increase of the capacity of the heat storage with a heat pump; its cooling capacity can be also used as a consequence of the temperature layer.

Taking into account these innovation possibilities the principle of the object of the research, the solar district heating system based on a seasonal storage is shown in Fig. 4. This system is able to cover not only the space heating demand of a building from renewable energy sources but in a big amount or even totally the electric energy and cooling demand.

4. Energy balance model alternate of system

In order to analyze the possible realization of quasi-fully solar centralized heat an alternative solution according to principal scheme shown in Fig. 4. is assumed. Consumer system with a maximum 1 MW heat loss close to locality of Kosice in Eastern Slovakia is assumed.

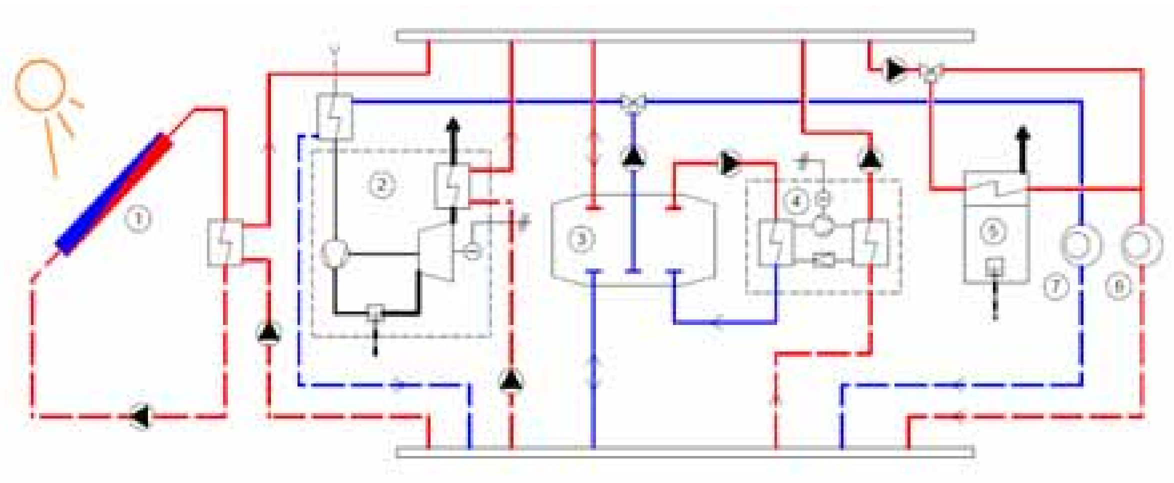

Fig. 4. An innovated alternative of the solar district heating system based on the seasonal heat storage

1-solar collectors, 2-cogeneration unit, 3-seasonal heat storage tank, 4-heat pump, 5-boiler, 6- heat consumers, 7-cold consumers

In an effort to increase the efficiency of producing cogenerated energy, a hybrid cogeneration system is considered, which generates heat and electric energy from biofuels and solar energy. The crucial condition for economic effectiveness of a cogeneration unit is the highest annual operating time possible. Therefore, a microturbine 2 with a 70 kW power output is proposed, the heating capacity of which is 108 kW and is used for domestic hot water production all year long. Biogas can be used for driving the microturbine. If biogas is not available, natural gas is the most convenient. However, liquid fuels can be utilized as well.

The heat demand would be covered by solar energy and by boiler for burning biofuel. The heat produced by the solar collector field 1 of about 2000 m^2 absorption surface in summer period is accumulated in the water of about 10 500 m^3 volume present in the seasonal heat storage tank 3. The water is then charged to 85 °C. Solar collectors are used to meet the heat demand in the heating season directly in cooperation with storage tank for short time accumulation (that is not displayed in the Fig. 4.). Seasonal heat storage tank is discharged to 35 °C approximately until the end of December. Since the beginning of January, a heat pump 4 would be fully utilized and would discharge the water present in the seasonal heat storage tank to about 5 °C. The supplementary heat source is a biomass boiler 5 with a 700 kW heating capacity (therefore, a better solution is the combination for example 500 kW + 200 kW). The structure of meeting the heat demand in the course of a year is shown in Fig. 5.

A heat pump integrated into the structure of system significantly contributes to the increase in efficiency. It increases the accumulation potential of the seasonal storage tank by further subcooling the water. The investment costs of the seasonal storage tank could then decrease by similar extent. Moreover, this subcooled water can be utilized for cooling purposes.

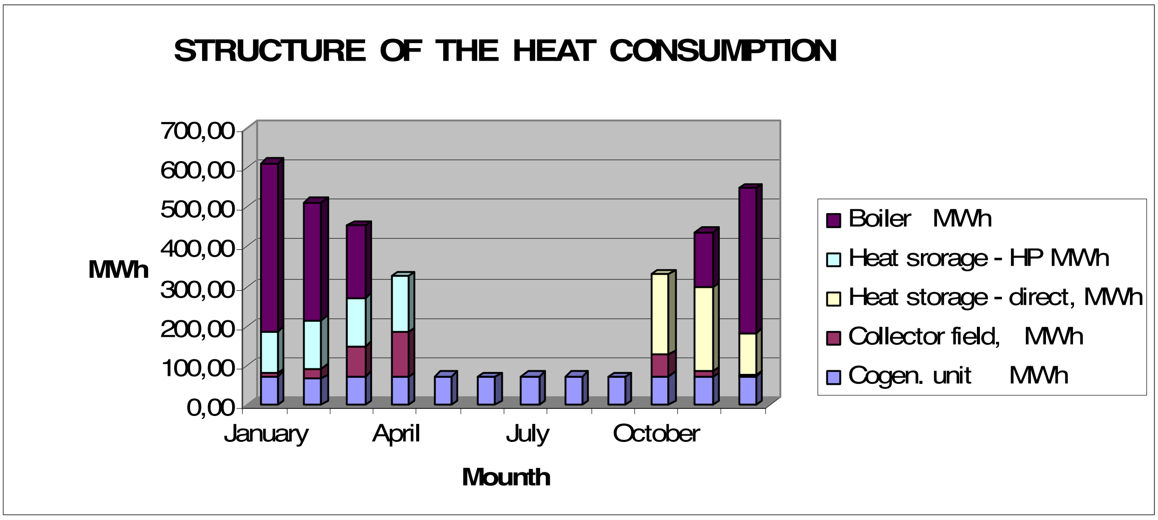

Fig. 5. Structure of heat consumption

Except of using this subcooled water for meeting the demand of cooling energy consumers, the air at the inlet of the cogeneration unit's compressor could be cooled as well. The decrease of power output of the cogeneration unit at high ambient temperatures can then be avoided. The water in the cooling energy consumers can be heated up to 20 °C. This consequently means that the solar collectors would operate with higher absorber temperature when charging up the seasonal storage tank, and thus at higher efficiency.

The unique feature of the heat pump is the high temperature difference when generating either heating or cooling capacity. In order to increase its efficiency, applying a multi-stage design is necessary. The overall COP can in our case be assumed at 3.5. The required power input is then about 60 kW. In the case if also cooling capacity is utilized (with a time delay).

At a 30° slope angle and southern orientation of the solar collectors, the consumption structure would be as follows:

• from the cogeneration unit: 851,5 MWh/a,
• from the collector field directly: 304,0 MWh/a,
• from the storage tank directly: 519,7 MWh/a,
• from storage tank supplemented by the heat pump: 490,8 MWh/a,
• from boiler: 1413,9 MWh/a.

180.8 MWh of cooling energy is produced when charging the seasonal storage tank. Besides the energy of solar radiation also the heat of heat consumers is utilized, which is also an accumulated form of solar energy. If 180.8 MWh cooling energy would be generated by a vapor compression chiller , the electric energy consumption would equal 42 MWh.

When meeting the heat demand for providing with domestic hot water, the cogeneration unit would generate 551.9 MWh/a electric energy. Its part is used for covering of own demand on electricity, mainly for running the heat pump. Therefore, approximately 410 MWh/a electric energy can be fed into the electric grid at advantageous cost.

If the overall efficiency of generating electric energy fed into the grid is assumed at 37 %, feeding 410 MWh/a of electric energy into the grid and a saving of 42 MWh/a of cooling energy by operating the heat pump results in a 1291.4 MWh/a decrease in primary energy consumption.

5. Summary

The Ukraine-Russian gas crises in the near past – and the stopping of the gas supply in the middle of the heating period as its consequence – did not influenced the gas supply of the residential individual heating system however most of the district heating systems as big scale consumers were in danger and some of them had to decrease the production.

Theoretically the natural gas can be simply and totally substituted with biomass in the residential heat supply. In the practice this could cause reasonable environmental damages. Because of this the heat supply based on the combination of biomass and solar energy can be everywhere taken into account seriously.

The mainly individual heating systems supported with solar energy based biomass are more and more popular. The disadvantage is that the solar proportion in the yearly heat demand supply is relatively low, in general below 30 %. As the directly used solar energy is the most clean energy the proportion of this has to be increased. This could be achieved with the seasonal storage of the heat produced by the collectors and which could be rentable at higher capacities. The solar proportion in these systems can reach 40-70 % so the solar district heating supported by biomass can be eligible.

The biomass supported solar district heating based on seasonal storage is a new generation of the utilisation of the solar energy. In the Central Europe it has no tradition until now. Initiating a common research and development on the Faculty of Civil Engineering of Technical University of Kosice, Slovakia and the Faculty of Mechanical Engineering of the Szent Istvan University, Godollo, Hungary is to overcome this lack of technology.

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