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SOLAR COLLECTOR INSTALLATIONS COMBINED WITH HEAT SUBSTATIONS

Piotr ZIEMBICKI*, Jan BERNASIŃSKI
Institute of Environmental Engineering
University of Zielona Góra
Szafrana st 15, 65-516 Zielona Góra, Poland

The paper presents the concept of combined heat production in solar collector installations supporting heat substations. In the first part, the systems of storing solar energy and typical solutions used in the integration of collectors with local gas sources of heat are discussed. Further on, the concept of technological solutions for heat substations using various forms of accumulating solar energy are presented.

Keywords: solar collectors, heat substations, energy storage, sources of renewable energy

1. INTRODUCTION

Limiting the negative impact of the increase in energy consumption at the global scale may be implemented by changing the structure of the use of primary energy and decreasing the level of its consumption. The realization of the former may be implemented by increasing the share of alternative energy (including solar energy) in the general energy balance and rationalization of use of existing methods of heat production and distribution.

The policy of the European Union promoting energetic efficiency and alternative forms of energy acquisition limiting the emission of pollution, certainly constitutes an additional stimulus triggering interest in the use of solar energy.

Systems of acquiring solar energy for heating utility water and supporting heating installations operating in combination with local sources of heat are well known and widely used. In case of smaller installations particular solutions are fairly typical and offered by various producers as ready-made systems.

* Corresponding author. E-mail: p.ziembicki@iis.uz.zgora.pl

On the basis of the analogy to solar installations operating in combination with local boiler houses, it could be argued that such solutions when combined with heat substations may reduce the consumption of primary energy for heating utility water by 40-60%.

There is however scarce information on the principles of integrating solar collector installations with heat substations supplied by municipal heat distribution systems. It has to be stressed that since heat distribution systems constitute the major source of heat in urban areas, the analysis of the forms of supporting them by renewable sources of energy seems to purposeful.

The analysis of publications concerning combined production of energy in heat production systems supported by solar installations indicates that, just like in Poland, all over the world there is a scarcity of studies indicating the solutions which would be correct both the energetic as well as technological point of view. Most studies focus on the issue of accumulation of heat in big storage tanks supporting entire heat production and distribution systems or selected elements of such systems [1], [2], [3], [9]. According to the authors combination of central heating with solar collectors supporting seasonal heat storage tanks guarantee a high level of the use of solar energy (50% or more).

Papers [1], [3], [4], [5], [12] and [13] present various seasonal heat storage tanks which were developed, tested, constructed and monitored in standard work conditions. In all cases the experience gained at the stages of construction and operation of both experiment and pilot objects led to the increase in the system efficiency and reduction of operating costs.

The basic problem related to the realization of such projects consists in high investment costs. The authors indicate that for the need of, among others, optimization of earth and construction work (e.g. heat insulation of the tanks), anti-moisture insulation etc. Furthermore it is particularly significant to increase the annual index of the tank use.

The conclusions resulting from the above mentioned publications specify major aims and directions for future research project which should focus on increasing the system efficiency, decreasing investment costs as well as the costs of solar heat in particular by means of the integration of various sources of heat and connecting them to storage tanks (e.g. solar or biomass energy) as well as combined production of useful heating and cooling.

The use of solar energy by means of the implementation of seasonal heat storage tanks in big, urban heat distribution systems is possible and justified from the technological point of view, yet in view of high investment costs it is significantly less economical. In this context it is vital to look for other solutions and among others integration of solar installations with heat substations, which is presented in the further part of the paper.

2. STRORAGE OF SOLAR ENERGY IN UTILITY HOT WATER INSTALLATIONS

The periods of higher demand for heat energy do not correspond to the periods of availability of sun radiation which results in the need to store energy. In order to meet the demands, once the energy stored has been used up and when the radiation is not available, supportive and conventional sources of heat have to be installed.

The following systems supporting the heating of utility water can be distinguished:

- passive (termosyphon) using the difference in water density (fig. 1a) or the working medium in the collector or storage tank,
- active in which water (fig. 1b) or the working medium (figs. 2a, b, c) circulation is forced by a circulating pump,
- no water or medium circulation, i.e. energy is stored inside the collector (so called storing collector).

A storing collector is a collector covered with a selective coating and transparent insulation on the side exposed to solar radiation while the remaining sides are insulated with typical materials.

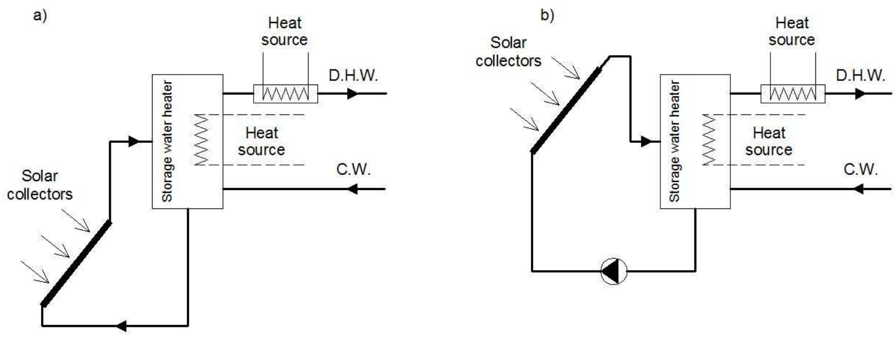

Fig. 1. A flow-chart of the passive system of heating utility water: a) with a natural direct flow of water through the collectors (termosyphon), b) with a forced, direct flow of water through the collectors.

At present systems using antifreeze media prevail and the exchange of heat between the medium and heated water may take place in storage water heaters (fig. 2a) or external heat exchangers (fig. 2b). In case of larger installations systems storing solar energy in buffer heating water tanks are used and the additional heating of water usually takes place in external heat exchangers (fig. 2c). Additional heating of the utility water from the external source of heat as well the configuration and the number of storage tanks can be organized in various ways.

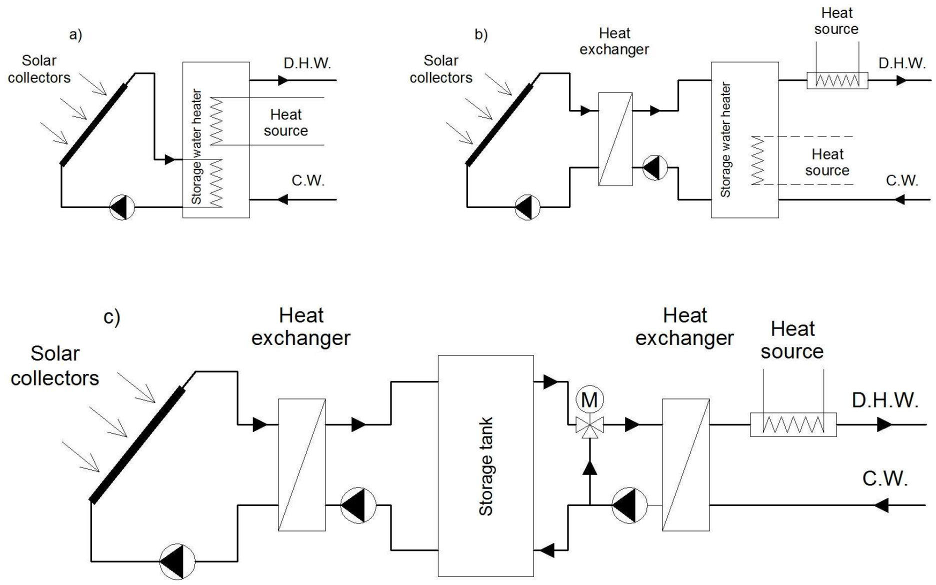

Fig. 2. Active heating systems: a) with a separated collector circulation and the system of heating water in a bivalent heater, b) with a separated collector circulation and the system of heating water in an external heat exchanger, c) with a separated collector circulation and direct heating of utility water by means of heating water.

In the conditions of the Polish climate separating the collector circulation containing an antifreeze mix enables the operation of the installation throughout the year.

Two groups of energy storage containers can be distinguished:

– with full mixing (water temperature is almost identical within the whole volume of the tank) ,
– with thermal stratification, i.e. with a vertical gradient of temperature (in case of a well insulated tank the radial gradient of temperature is almost insignificant).

Thermal stratification is more advantageous in view of the efficiency of the installations and storage of heated water which has a high temperature at the outlet of the tank and low temperature at the collector intake, which increases the efficiency of the tanks.

It also depends on the geometry of the tank, i.e. its shape and volume as well as location of stub pipes and other elements which may disturb stratification such as heat exchangers (coils) and electric heaters.
It is suggested that the ratio of the height to the diameter of tanks should range between 3:1 and 4:1 [8].

Some solutions such as the systems with direct flow and external exchanger are supportive of stratification, whereas other such as tanks with built-in exchangers hinder stratification. Tanks should be made from materials of low level of thermal conductivity (ideally plastics), should be well insulated and should not contain elements of high thermal conductivity.

In well designed and operated tanks stratification is spontaneous and lack of stratification means that such containers are inappropriately designed and have inappropriate operating parameters.

In case of tanks with heat exchangers, spiral exchangers to the least extent disturb stratification. Spiral coils should divide the cross section into two identical areas and the recommended heat exchange surface should amount at approx. 0,45 m^2/ m^2 of the area of the absorber [8]. If the exchanger is located at the bottom part of the tank, full mixing of water occurs only above the exchanger, while if it is located only in the upper part, the active volume of the tank is in practice limited to the area in which it is localized.

Similarly, a wrongly located heater may eliminate stratification. It should be placed in the vicinity of hot water intake stub pipe, above the collector intake or above the exchanger. The best solution consists in using flow-through heating systems localized outside the tank.

3. CHARACTERISTICS OF TYPICAL UTILITY WATER HEATING SYSTEMS

Solar collector installations are used mainly for heating hot utility water, water in swimming pools and to a lesser extent for supporting central heating systems. Boiler houses are used as additional sources of heat. The principles of combining boiler houses with solar collectors installations, i.e. technological systems and control automatics are widely known and in case of smaller installations (for detached or semi-detached houses) are offered as standard systems.

Appropriate selection of solar collector installations requires the familiarity with a wide range of data characterizing the system of water heating and in particular:

- daily and annual demand for hot utility water,
- of the demand for hot utility water.

While defining the demand for hot water it is suggested that the predicted and normative water consumption is taken into account i.e. (80dm^3/(person/day) in detached houses and 40-60 dm^3/(person/day) in multi-family buildings [1]. The assumption of inflated levels of demand for hot water may result in overrating the installation – the heating medium may be overheated and the efficiency of the installations falls.

In case of smaller installations (up to approx. $10m^2$ of the area of the collectors) it is possible to meet the annual demand for energy at the level of approx. 60% while in case of bigger installations it is suggested that the level of 40% should not be exceeded [1]. The area of the collectors should be specified on the basis of the annual demand for energy and the characteristics of the collectors.

The choice of the elements of solar collector installations depends on the area of the collectors and should be made in accordance with product specifications. The selection of major elements securing the operation of the installation i.e. the safety valve and the diaphragm tank should be made in accordance with the principles specified in the PN-EN-12976 norm. Technological systems of the installation of solar collectors depend on the area of the surface of the collectors and the profile of demand for hot utility water.

In smaller installation mainly bivalent heaters are used, yet their volume depends of the profile of demand at the level of $1.5 \div 2.0$ of daily consumption of hot utility water.

In medium installation (up to approx. 40 m^2 of the area of the collectors) systems comprising two standard heaters can be used [1].

It has to be stressed that as the area of the collectors increases the bigger capacity of hot utility water heaters is necessary ($30 \div 50$ dm^3/m^2 in case of flat collectors and $70 \div 100$ dm^3/m^2 in case of vacuum collectors).

In view hygiene (periodical heating of water up to $t_{min} = 70^oC$) and economics (with the increase of the capacity of heaters the efficiency of installations drops), in larger installations of above 50 m^2 of the area of the collectors, only buffer tanks for hot water are used [1].

4. HEAT SUBSTATIONS SUPPORTED BY SOLLAR COLLECTORS

In multi-family housing mainly serial and parallel heat substations are used and in view of the size of the buildings, large installations with the area of collectors above 50 m^2 have to be used. Hence for the purpose of accumulation of energy the installations will need buffer tanks for heating water or vessels for hot utility water. The size of such tanks constitutes the main obstacle preventing the use of collector installations in existing buildings (sub-stations).

The analyzed initial concept variants of technological systems combining serial-parallel substations with solar collector installations are presented in figs. 3-6.

For the sake of clarity all basic elements of heat substations and solar collectors installations including control automatics and water circulation systems are not presented.

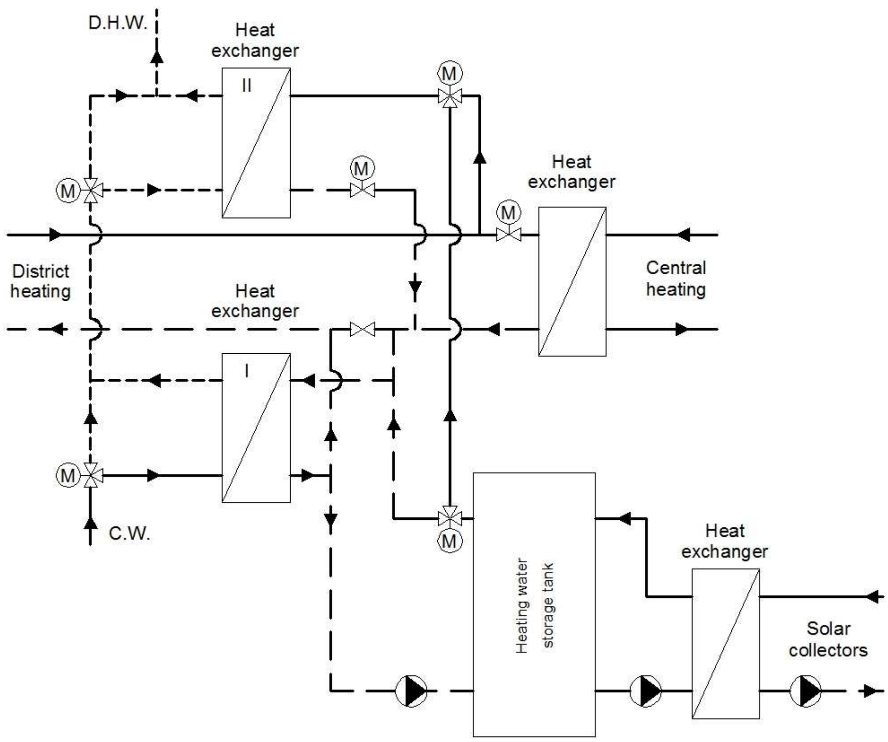

Fig. 3. The concept flowchart of the serial-parallel heat substation and the installation of solar collectors – Variant 1.

Since the presented systems are treated as initial in view of further analysis, the solutions do not include the forms of conducting thermal disinfection of installations.

In Variant 1 utility water is heated in heat exchangers which constitute the basic element of the heat substation. Depending on the temperature of the hot water in the buffer tank, heating in level-I and level-II exchangers utilizes network water only or the water from the buffer tank in the parallel mode i.e. water from the buffer tank is directed to the Level-I exchanger and utility water is heated by network water in the Level-II exchanger.

The switch of heating circulations is controlled automatically by the valve trim.

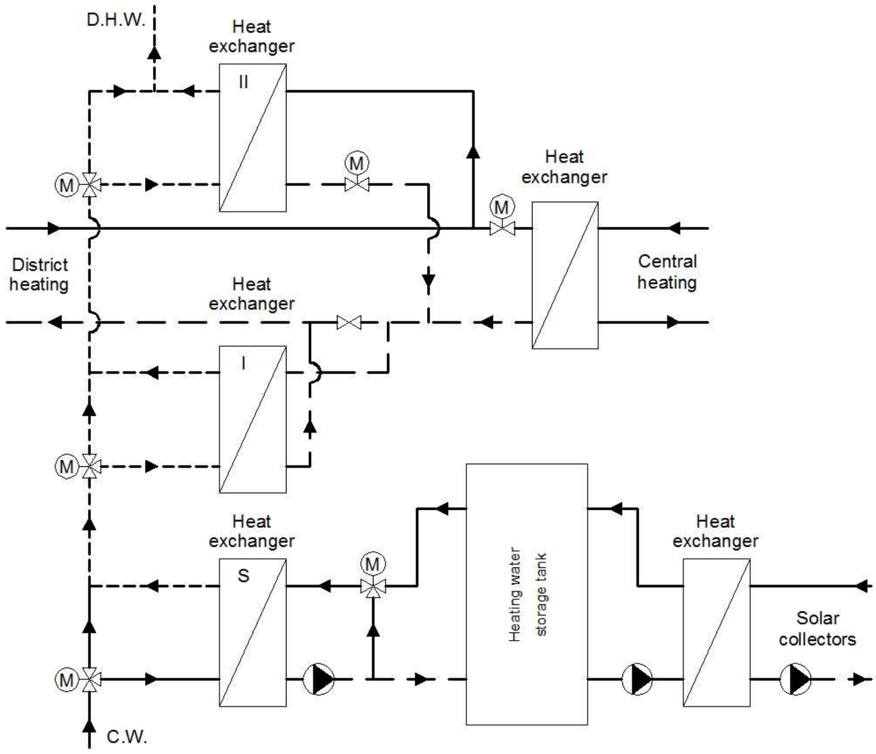

Fig. 4. The concept flow-chart of the serial-parallel heat substation and the installation of solar collectors – Variant 2

The basic drawbacks of the solution include:

- connecting the circulation of network water and hot water from the buffer vessel,
- limiting the recovery of solar energy in transitory periods (hindered control of the functioning of the pump forcing the flow through the buffer vessel and the control automatics in different cycles of the system operation).

The drawbacks can be significantly eliminated by the solution presented in the second variant in which utility water is heated by the solar energy accumulated in the buffer tank and takes place in the auxiliary heat exchanger only. The size of the exchanger has to guarantee the heating of utility water up to the required temperature (in case of multi-family housing 55-60^{o}C) in the summer season and in the periods when installations of solar collectors cover the whole demand for heat. The water heated in the exchanger is directed to the utility water installations. During other periods, depending on the temperature of the utility water at the outlet from the auxiliary exchanger, the water flow is directed to the Level-I or Level-II exchanger of the basic heat substation.

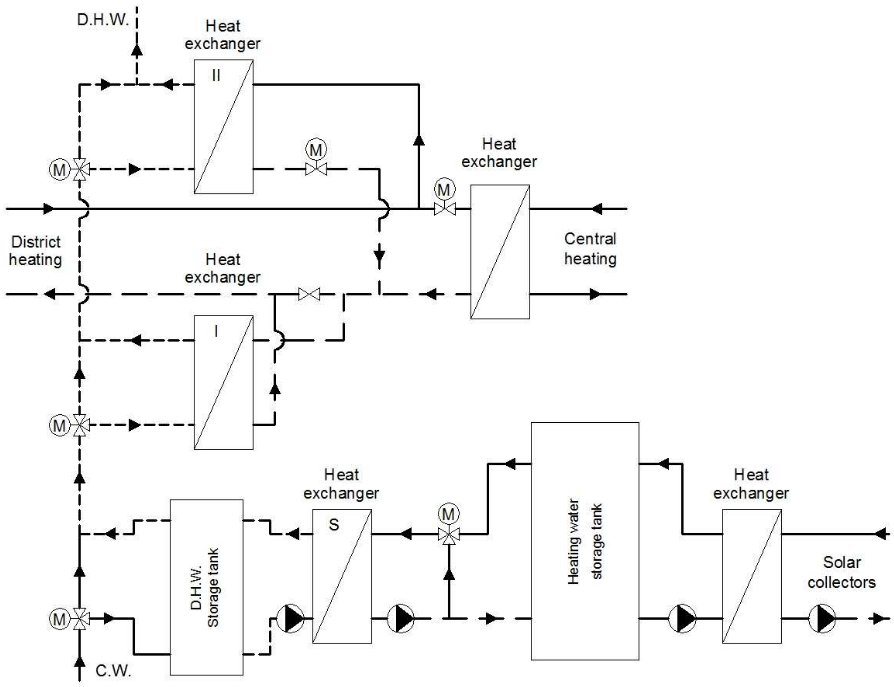

Fig. 5. The concept flow-chart of the serial-parallel heat exchanger and the installation of solar collectors – Variant 3.

This solution in view of the required size of the auxiliary exchanger and the control of the flow of hot water by the exchanger is not suitable for buildings with varied demand for utility water. In case of such buildings Variant 3 is recommended which in comparison to Variant 2 uses a utility water vessel. The system requires installation of a much smaller heat exchanger, loading the vessel in the periods of lower demand for the utility water and simplifies the control and operation of the loading pump.

In the presented solution, the tank stores hot utility water only in the periods of the operation of solar collectors. In case the tank is used throughout the year, the solution requires modification.

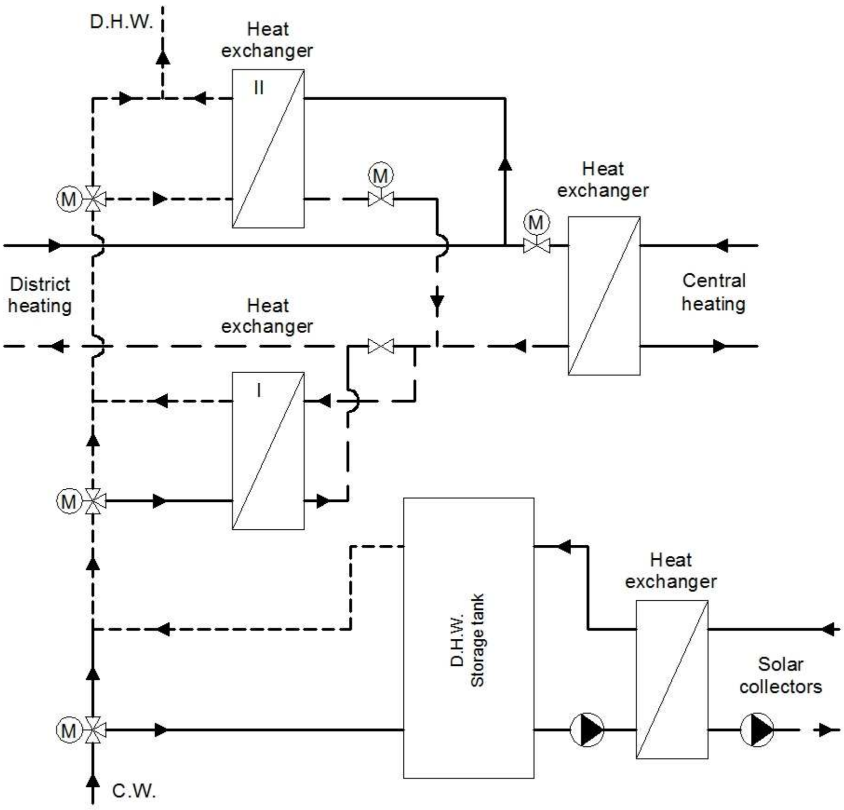

Fig. 6. The concept flow-chart of the serial-parallel heat substation and the installation of solar collectors – Variant 4.

The concept flow-charts of technological systems presented in figs. 3-6 should not be treated as construction specifications since they present merely initial solutions enabling the use of solar energy for heating utility water in heat substations.

It needs to be stressed that the capacity of utility water tank is significantly smaller compared to the buffer tank. By analogy to technological systems of solar installations combined with boiler houses it can be assumed that the capacity of the tank should not exceed 15% of the daily demand for utility water. The solution presented in Variant 3 may be simplified by the use of a tank performing the function of a storage water heater (with an in-built coil) which in turn would be disadvantageous from the point of view of water stratification in the tank and in case of larger installations also from the point of view of the intensity of heat exchange. Such systems can be possibly used in buildings with high peak demand for utility water, provided a heater of the appropriate size is used.

The need to install high volume utility water tanks eliminates the usefulness of accumulating solar energy in hot water buffer tanks. The system in which solar energy is stored in a utility water tank is presented in Variant 5 (fig. 6). In the periods of intensive exposure to the sun, utility water in the tank is heated to 60^{o}C, whereas in other periods it is heated just like in Variants 2 and 3. The size of the tank could be reduced if utility water was heated up to above 60^{o}C in the summer period (in such case Variant 4 has to be modified).

5. SUMMARY

High parameter heat distribution network remains the basic source of heat in urban areas. The use of renewable sources of energy, including solar energy, may limit the consumption of network heat. The choice of appropriate solutions enabling the integration of solar collector installations with basic heat substations, including their automatic control, exerts a fundamental impact on the extent to which solar energy is used in the total balance of heat consumption. Integration of solar collector installations should not disturb the operation of basic heat substations hence the heating media from the network and from the installations of solar collectors should not flow through the same units. Hence the solution presented in Variant 1 has to be excluded.

The introductory analysis presented above indicates that the system presented in Variant 3 seems to most advantageous, yet in case of low consumption of utility water and a relatively even profile of demand, the solutions presented in Variants 2 and 4 are worth consideration.

In case of the systems in which solar energy is accumulated in buffer hot water tanks, a relatively limited volume of utility water is stored, which in view of hygiene and economics offers a favorable solution. Thermal disinfection in the systems with large volumes of hot water, significantly lowers the efficiency of installations. Hence it is suggested that a computer simulation of the operation of the systems in buildings with diverse characteristics of central heating and utility water consumption as well as profiles of demand for hot water is conducted.

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INSTALACJE KOLEKTORÓW SŁONECZNYCH WSPÓŁPRACUJĄCE Z WĘZŁAMI CIEPŁOWNICZYMI

S t r e s z c z e n i e

W artykule przedstawiono koncepcje współpracy instalacji kolektorów słonecznych wspomagających podgrzew c.w.u. w wymiennikowych węzłach ciepłowniczych. W pierwszej części omówiono układy magazynowania energii słonecznej oraz przeanalizowano typowe rozwiązania integracji kolektorów z lokalnymi gazowymi źródłami ciepła. W dalszej części artykułu przedstawiono koncepcję schematów technologicznych dla węzłów ciepłowniczych różniących się sposobem akumulacji energii słonecznej.