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M.D. RABINOVYCH*

RENEWABLE ENERGY SOURCES FOR SUSTAINABLE DEVELOPMENT OF HISTORICAL CITIES

Renewable energy technologies in heating-supply systems in historical cities are most effective, provided that they are based on solar energy in solar hot-water and heating systems and heat-pump systems. In Ukraine today, over 50 experimental projects for solar hot-water systems have been implemented in different branches of national industry. Analysis of the sources of waste heat showed that heat produced in power stations, ventilation systems in buildings and underground constructions, industrial and municipal sewers is the most suitable for heat-pump systems.

Renewable energy technologies in heating-supply systems in historical cities are most effective, provided that they are based on solar energy used in solar hot-water systems (SHWS), solar heating systems (SHS) and heat pump systems (HPS).

In Ukraine, solar energy has been used recently for heat supply purposes, mostly due to the favourable climate conditions and extensive research in this technology. As a result, over 50 experimental projects have been implemented in different branches of national industry. Among them are hot-water supply systems for residential dwellings and public buildings, connecting solar collectors to fuel and electrical boiler stations, small self-serving units for private dwellings and various consumer services and many others. The laboratory-industrial complex "Geliotherm" (Krimea) is considered to be the largest centre equipped with several types of solar collectors for complex solar energy utilization in hot-water supply, heating and air conditioning. Simultaneously with the development of solar collectors some specific regulations governing their implementation and operation are put in force.

In the analysis of the equipment used in these systems and in preparation of their mathematical description, ε-NTU method was used. It allows the collectors and heat exchangers to be modelled. Due to development of the series of process models and

* Kiev National University of Construction and Architectures, Chair of Heat and Gas Supply and Ventilations of National University of Construction and Architectures, Kiev, Ukraine, 51b, B. Khmelnitskogo str., 01030, Kiev, Ukraine, e–mail: org@pinei.com

SHS units the system can be modelled as a whole. Mathematical models of systems ought to be used for their optimizing and finding long-term characteristics as well as developing experimental systems. However, in typical modelling and engineering practice, it is advisable to use the calculation methodology, which allows replacement of detailed mathematical methods with short simulation models (including regression equations which allow simplifying the process of solution optimization.)

The amount of the useful heat Q_u generated by the system during a given year (season) as a result of solar energy use can be presented as follows:

$$Q_u = \eta A q,$$

where:

η – the coefficient of efficiency;

A – the area of solar collectors, m^2;

q – gain in solar radiation, $kWh/m^2/year$.

In the systems under consideration, design characteristics were based on a changeable number of variables; calculations were made for 3 climate zones of Ukraine [1]. After statistic processing of the results, the target regression equations were found. They connected the parameters obtained with the input values. These equations are, de facto, the simulation models of the system and enable optimization calculations throughout the entire country. The table presents the calculation results for the systems mentioned above.

Table

Equations and their usage range for the systems tested and their estimated specific powers

Parameter	Main level	Interval of variation	Calculation equations
SHWS with sectional tank-battery and stand-in (1 GJ/day)			
$\overline{\mathbf{A}}$	100 m^2	50 m^2	$\eta = 0.360 - 0.085\overline{\mathbf{A}} + 0.042\overline{\mathbf{V}} + 0.019\overline{\mathbf{A}}^2 - 0.024\overline{\mathbf{V}}^2 + 0.004\overline{\mathbf{A}}\,\overline{\mathbf{V}}$
$\overline{\mathbf{V}}$	7.5 m^3	5 m^3	
SHWS with constant water consumption and heating up to two temperatures (1 GJ/day)			
$\overline{\mathbf{A}}$	100 m^2	50 m^2	$\eta = 0.396 - 0.093\overline{\mathbf{A}} + 0.046\overline{\mathbf{V}} + 0.021\overline{\mathbf{A}}^2 - 0.026\overline{\mathbf{V}}^2 + 0.004\overline{\mathbf{A}}\,\overline{\mathbf{V}}$
$\overline{\mathbf{V}}$	7.5 m^3	5 m^3	

Note: $\overline{\mathbf{A}}, \overline{\mathbf{V}}$ – normalized values of varying parameters.

Practically all the SHWS described were designed, constructed and tested after completion of the research described. Figure 1 shows the schematic diagram of solar hot-water supply system with solar water heaters and photoelectric elements for the multifunction production of heat and electrical energy in the city of Simferopol. In figure 2, technical and economical parameters of the system are presented.

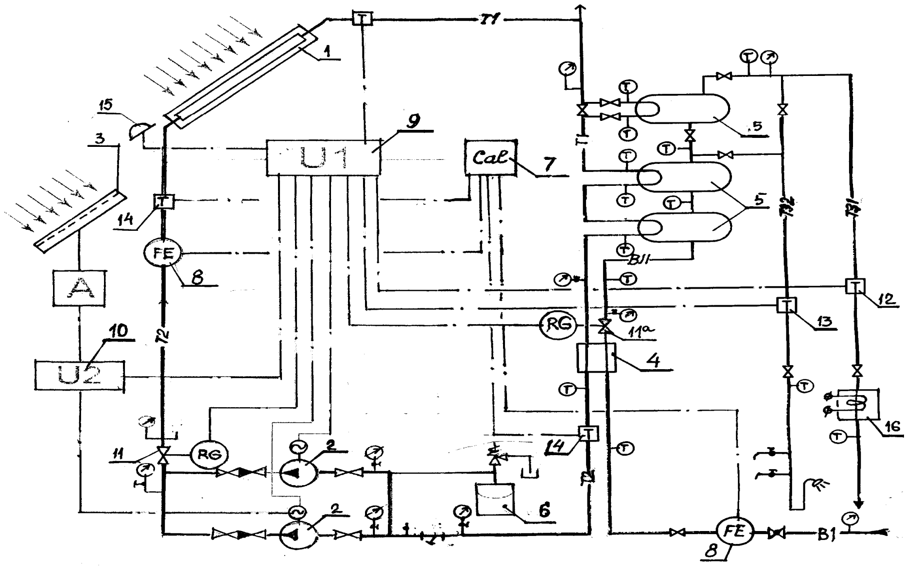

Fig. 1. Schematic diagram of autonomous energy-supply system deployed
in a kindergarden of the city of Simferopol:
1 – solar collector; 2 – circulation pumps of heat supply system; 3 – solar photoelectric module with the reverser; 4 – high-speed heat exchanger; 5 – capacitive heat exchanger; 6 – tank stretcher; 7, 8 – heat-meter with two flow-meters; 9,10 – electronic regulator; 11, 11a – regulating valve with drive; 12, 13, 14 – sensors of temperature; 15 – solar radiation instrument; 16 – electroheater

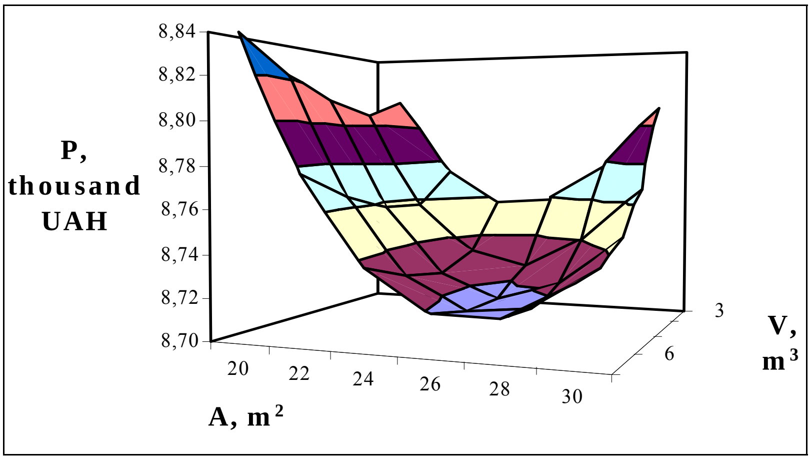

Fig. 2. Expenseses (P) to implement the system at different variants of area of solar collectors and volume of sections capacitive heat exchanger.
Optimum: area of solar collectors, 26 m^2; volume of sections capacitive heat exchanger, 6 m^3.
Paying back period of systems, 6.89 years

In general, the tests and their results have shown the expediency of the decisions taken; the data calculated corresponded to the practical one. The average efficiency of the decisions made during the operation period ranged from 30 and 45%; a specific daily output (average and maximum) varied between 26.8 and 31.4 MJ/m^2; a total average specific output per season was 1.9 GJ/m^2; and annual thermal energy generation ranged between 500 and 600 kWh/m^2; the specific fuel savings ranged from 0.03 to 0.15 t oil equiv./year. The period of paying back for the installed solar heat-supply units is 3 to 10 years, organic fuel replacement ratio is between 25 and 40%.

An analysis of the possible sources of waste heat in the industrial and municipal sectors of a city available for heat pump systems was conducted under conditions similar to these in the city of Kiev. Among these heat sources the following were recognized as the most promising: electric power stations, ventilation of buildings and underground constructions as well as industrial and municipal sewers.

The biggest share in waste heat generated in power plants is connected with the systems of water cooling [2]. A heating potential of the cooling water being heated depends upon the type of a cooling system, the regime of work of heat and power generating plant (HPGP), meteorological conditions and other factors, which all display a seasonal variability but are sufficiently constant from year to year. The calculations have shown that the available resource of the heat disposed of Kiev's HPGP approaches 100 MW.

An original source of a low-potential heat can be the reverse flow of heat in heat distribution network in the vicinity of heat and power generating plants. Its monthly average temperature during a heating period of a year is practically stable and ranges from ca. 45 to 50 ^{o}C which gives a high transformation factor (4.5–5.0). It is considered positive that the cooling of reverse network water would allow to increase heat and electrical power of HGPG without changing the hydraulic regime of working heat network.

Restrictions in the usage of the heat reverse network water in the existing HPGP are imposed because of an insufficient ability of turbogenerator to withstand the overloads due to flowing water (110–125%). However, replacing an old equipment with a new one allows us to solve this problem.

The waste heat from underground railway is the most available of all the types of ventilation waste heat, and seems to be the best for using in the city HPGP. The ventilation system of an underground is connected with the atmosphere through a network of air suction and exhaust ventilation shafts. They are installed at every underground station and at each section between stations. The average consumption of ventilation air in the shaft varies depending on the time of year and in the cold period it ranges between 17 and 30 m^3/sec at a temperature of ca. 16 °C. Technically available heat power of each duct of a ventilation system varies between 170 and 300 kW. Average total waste heat of a ventilation system during the heating season, for instance, in the city of Kiev, is estimated to be 13–15 MW.

It is best to use the above methodology for air heating systems, offices and public buildings, such as department stores, movies, theatres, sport gyms and music halls.

The transformation factor of air heat pumps (HP) for the underground waste heat is sufficiently high, i.e. it ranges from 4.2 to 4.4. Besides, such heat pumps allow us to use the air conditioning system in summer time. Due to these facts, the underground ventilation waste heat is considered to be very promising.

The above sources are also easily available because of their frequent presence in built-up areas, where an infrastructure should be developed and where it is not possible to reconstruct the existing heating systems.

Certain opportunities for installation of local HPGP depend upon the usage of waste heat of laundries, swimming pools and other sport facilities, whose hot water consumption is very high.

One more big source of heat for HPGP are sewers. Municipal centralized heat-supply systems for housing and public facilities in Ukraine consume annually more than 100 mln Gcal. The temperature of water in sewers is always by 3 to 5 °C higher than the temperature of cool water, which makes its usage possible and technically attractive all year round. In Ukraine, implementation of this technology is difficult because different types of sewers are not separated. For this reason making use of heat from municipal and public sewers is possible only after water treatment.

At sewage disposal plants in large cities sewage is precipitated due to fermentation in methane tanks, and as a result a biogas is produced [3]. The content of methane tanks can be heated in few different ways in order to maintain its constant temperature. In Ukraine, a direct steam heating is most commonly used. Steam is introduced directly into methane tank and mixed with the sediment. Thereby, a large part of the biogas produced must be spent on fermentation. In order to reduce this consumption, the author has designed the installation where solar energy enables this process of fermentation.

Today the biogas in Ukraine is utilized in two cities only, i.e. in Kiev and Kharkov, where it is used in sewage disposal plants. Nowadays biogas is widely used all over the world for multifunction production of heat and electrical energy for enterprises, e.g., diesel generating stations. Many companies produce energy installations with energies for internal gas combustion whose power ranges from 25 to 1100 kW. Their general coefficient of efficiency, due to the utilization of waste heat, reaches 80–93%.

However, this case scenario does not take into account the possibilities of using sewers as a source of low-potential heat. The biogas used as a fuel for internal-combustion engines, which in turn ensure drive of heat pump, allows us to increase a total energy produced by such a system up to 160 and 180% with respect to heat produced by gas. From the viewpoint of heat engineering such an association is quite efficient, because it allows two-stage water heating: first, in a heat pump up to 35 and 40 ^{o}C, which ensures its work with high transformation factor; second, heating the necessary amount of water up to the temperature of 65 and 85 °C due to the system of an engine cooling (figure 3). The calculation of cost-efficiency of such a technology, even if we take into account approximation and estimation of this calculation, testifies to its evident feasibility compared to a direct usage of biogas instead of natural gas for heat technological processes in sewage treatment plants. The period of paying back for capital investments does not exceed 2 years.

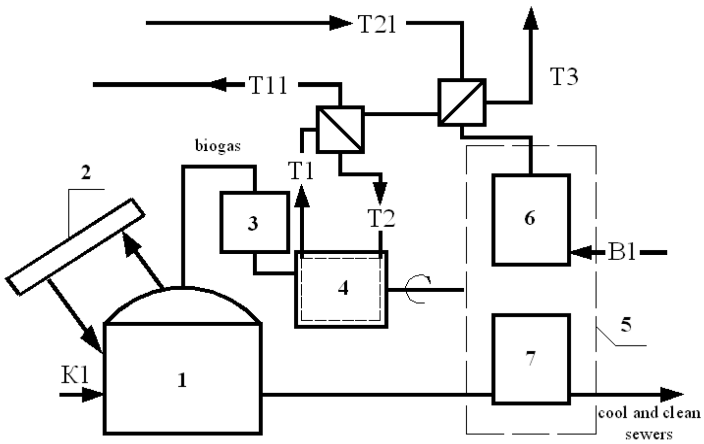

Fig. 3. Scheme of installation which uses biogas and heat of sewage for the heat supply system: 1 – methane tank; 2 – solar collectors; 3 – block of biogas cleaning; 4 – internal combustion engine; 5 – heat pump plant; 6 – condenser; 7 – evaporator; T1 - water from cooling system of internal combustion engine; T11 – water in heating system, t = 80–85 °C; T21 – water from heating system, t = 55–60 °C; *T*3 – hot water in hot water supply system, t = 50–55 °C; B1 – cool water from the plumbing; K1 – sewage

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ODNAWIALNE ŹRÓDŁA ENERGII
W ZRÓWNOWAŻONYM ROZWOJU HISTORYCZNYCH MIAST

Technologie oparte na odnawialnych źródłach energii zastosowane w systemach grzewczych w historycznych miastach są najbardziej wydajne pod warunkiem, że źródłem energii jest promieniowanie słoneczne wykorzystane w systemach grzania wody i pomp ciepła. Obecnie na Ukrainie wdrożono ponad 50 eksperymentalnych projektów ogrzewania wody energią słoneczną w systemach grzewczych. Projekty te dotyczą różnych gałęzi przemysłu. Analiza źródeł ciepła odlotowego pokazała, że ciepło wytwarzane

w elektrowniach, systemach wentylacyjnych budynków i metra, przemysłowych i miejskich systemach kanalizacyjnych jest najbardziej odpowiednie dla systemów pomp ciepła.