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Use of Solar Collectors on the Example of a Water-Park Part I: Technical Analysis

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Summary. The paper contains the technical analysis of the carried out modernisation of the facilities of a water-park consisting in fitting solar collectors for the heating of tap hot water and central heating system. The article includes information on the modernisation carried out with a particular emphasis on analysing the way in which the equipment has been selected and technical solutions employed.
Key words: solar collectors, technical analysis, swimming pool, modernisation.

INTRODUCTION

Every year, both in Poland and worldwide, the demand for energy increases due to, among other things, the development of the industry, technical and scientific development and the population growth. Excessive exploitation of non-renewable resources such as fossil fuels (coal, gas, oil) has resulted in a significant increase in the concentration of carbon dioxide in the atmosphere, causing global warming and high environmental pollution [1, 11]. This situation is slowly leading to the scarcity of resources. People noticing this problem have decided to look for alternative sources of energy, which has led to a rapid development of renewable energy sources (RES).

A source alternative to conventional heating systems based on non-renewable fuels is the use of solar energy, and the most popular method is to use solar collectors, especially useful in hot water heating systems [12, 22]. The collectors convert the radiation energy of the sun into usable heat through the change in temperature of a circulating medium [14, 16, 19]. The downside to the use of collectors is mainly that the maximum efficiency is achieved during the summer, when the energy demand is small [2, 15]. Another interesting way of obtaining renewable energy from the sun is the use of photovoltaic panels. They operate by converting solar radiation directly into electricity [5, 9, 18].

CHARACTERISTICS OF THERMAL TECHNOLOGIES USED IN THE EXAMINED WATER PARK – BEFORE MODERNISATION

The building of the analysed investment before the modernisation had one monovalent source of heat energy from the municipal heating system. Basic technical data required for the proposed modernisation option for the analysed facility are presented in Table 1.

Table 1. Technical data of the building [20]

Building construction/technology	Conventional
Number of storeys	4
Cubic capacity of heating	23273.32 m^3
Net area of the building	7386.78 m^2
Shape factor A/V	0.30 m^{-1}
Built-up area of the building	2885.14 m^2
Number of users	465
Hot water preparation method	Central heating + RES
Type of heating system of the building	Central heating + RES
Other building characteristics	A multi-storey building, with basement, detached; with heating substation of process heat, central heating and tap hot water.

The analysed building was fitted with a heating substation for central heating, process heat and tap hot water. The heating station was made with multiple circuits and the circuits of the substation were divided by their usage, parameters and technological characteristics. The substation made use of control and regulation concepts based on dedicated, versatile specialised microprocessor system of nano-programmable controllers for heating technology. It should be noted that prior to the execution of the investment, in the main pool hall a conventional heating system with water heaters making up a central heating system and a pool hall supply air heating system were used. Te duality of heating systems made it impossible to use a venting system with regulation based on temperature of exhaust air (with an averaged temperature). This is the best regulation system, which provides the most reliable information about the conditions in the hall [23]. The adjustment was made by maintaining the specific supply temperature, which is not optimal. Therefore, it was suggested to heat the pool hall only with supply air and provide regulation based on the temperature of exhaust air from the pool hall. Plate heat exchangers were used in the substation. One heat exchanger handled the low-parameter circuits for the processing and central heating, that is, the circuits:

– central heating circuit with a circulation pump and a three-way mixing valve,
– underfloor heating circuit, also with a circulation pump and a three-way mixing valve,
– supply circuit of the water heaters of the air venting units,
– circuit for preparation of the water supplying the swimming pools.

Another heat exchanger handled tap hot water preparation circuit. Hot water was stored in two heated hot water cylinders with the volume of 3000 litres each. The tap hot water circulation pump operated with a night break. High-parameter sides of both heat exchangers were supplied from high-parameter municipal network.

Automatic regulators for central adaptive regulation were used in the heat substation.

In the supply circuits of the venting units' heater, central heating and underfloor heating equipment, the automatic tracking control with an external temperature sensor, that is, the so-called weather control was used. The supply system of the venting units had a corrective task. All the circuits were controlled based on the external temperature, in accordance with the heating curve, and the specific temperature was controlled with a water temperature sensor. The tap hot water system was fitted with a fixed-temperature control. Both circuits were fitted with thermal energy meters (heat meters).

DESCRIPTION OF THE MODERNISATION OF THE ENERGY SYSTEM OF THE ANALYSED WATER PARK

A study carried out on the swimming pool made it possible to determine the required daily amount of fresh water to dilute the pool water depending on the number of bathers. The value commonly recommended in the literature is 30 litres per day per one person whereas the consumption of water for taking a shower is about 55-60 litres per each visitor to the pool. Recovery of heat from the consumed shower water and the consumed pool water is a system used everywhere, where waste water is replaced with fresh water, for example, in swimming-pool facilities (water reservoirs, shower cabins).

The implemented solution covered the recovery of heat from the consumed shower water. In addition, the solution included the recovery of heat from the water from rinsing pool filters. With this solution, during downtime in the distribution of water to the showers, water for the pool is being prepared. Cleaning the installation of new bacterial flora and fat and soap sediments is made through pumping porous balls throughout the pipelines in regular intervals [21].

In the analysed water park the AquaCond Type 44 heat recovery from the waste water with recuperator and heat pump providing 2-level heat recovery was used. Waste water from showers and water rinsed from filters flows through the inner coil of the recuperator and then through the evaporator of the heat pump. At the same time, the same quantity of fresh water flows through the outer coil of the evaporator and then through the evaporator of the heat pump [8, 17]. When flowing through the recuperator, a significant amount of heat from the waste water stream is passed directly to the fresh water stream. As a result, fresh water can be heated up to the temperature of above 30 °C, without supplying external heat [3].

For the described pool facility of the water park, daily waste water capacity from rinsing the filters is 20.77 m^3/day and 5.14 m^3/day of tap hot water. Total discharge of waste water for the pool is 25.91 m^3/day with the average temperature of ~31 °C.

For the parameters defined, a perfect equipment is AquaCond 44.12.3, which is being used for waste water with aggressive properties (e.g. swimming pool water) – Cu-Ni-10Fe PVC and Cu. Target heat recovery from waste water is ~37 kW with 2.6 kW of the energy applied to drive the pump motor. Energy efficiency ratio (COP) is 11.6.

Considering the example of indoor swimming pools, warm waste water comes from showers, rinsing filters and draining water from the pools. Water temperature is, respectively:

– tap hot water – showers: 37 °C;
– rinsed water from filters depending on pool type: 30 °C.

Therefore, in the case of an indoor swimming pool we should expect waste water with the temperature of 30-37 °C, which is discharged into the sewer system.

In the case of an indoor swimming pool in the analysed investment, the amount of water from rinsing the filters is 21 m^3/day + 7 m^3/day of the tap water. With this consumption of the tap hot water the average demand for water at 37 °C is approx. 2 555 m^3/year. Water from the showers in the form of waste water drains into the sewer system and has the temperature of approx. 35 °C. To heat 1 m^3 of fresh water at the temperature of 10 °C to the temperature of water in the showers, that is 37 °C, 0.11 GJ of heat is needed. Annually, it is 281 GJ.

In the process of rinsing the filters the pool water is used, and the pool with bathers requires adding about 21 m^3 of fresh water per day. Therefore, 7 665 m^3 of waste water per year should be drained from the pools to the sewer system and the same amount of fresh water should be added. During addition of fresh water to the pool, water is drained from the pool in the form of waste water into the sewer system and it has the temperature of approx. 30 °C.

To heat 1 m3 of fresh water at the temperature of 10 °C to the temperature of water in the pool, that is about 30 °C 0.08, GJ of heat is needed. Annually, it is approx. 613 GJ.

The joint amount of waste water from showers and swimming pools drained into the sewer system is approx. 10 220 m^3/year, and assuming the pool operates 52 weeks a year, it means the discharge of 1.16 m^3/h warm waste water. The temperature of the waste water is approx. 31 °C.

For heating the water in the shower area, which is supplemented in the pool, and for filling the pools (apart from tap hot warm water) in the indoor swimming pool with the defined programme, the total amount of heat delivered over the year is approx. 894 GJ.

To heat 1 m^3 of water at the temperature of 10 °C to the temperature of approx. 31 °C, 0.09 GJ of heat is needed. Annually it is approx. 920 GJ. It was the heat lost during the year as warm waste water discharged into the sewage system. For the indoor swimming pool with a defined programme it was a huge amount of delivered heat needed to heat the water to the operating temperature. With the price of about PLN 60.90 per 1 GJ, it was a loss of PLN 56 028 a year as warm waste water from showers discharged into the sewer system.

MODERNISATION OF THE WASTE HEAT RECOVERY SYSTEM FROM THE VENTING SYSTEM OF THE POOL HALL

In the analysed facility before thermal upgrading, venting units with partial recovery of the heat lost associated with the stream of air removed from the facility had been used. A component serving for recovery of part of the heat energy was cross-flow exchanger with metal membranes with declared capacity of 40%. The largest unit was the unit handling the pool hall located in the underground of the pool hall. These units had both the supply and the exhaust functionality. They were fitted with radial fans powered with squirrel-case induction electric motors, without speed regulation. The motors were not fitted with any device to fluent or step rotation control. The fans were powered with single-stage belt transmission. There were no inverters to adjust the rotation. Exhaust and supply sections were fitted with filter pockets with replaceable inserts. The units were not fitted with automatic measurement and regulation systems. As a result, the airflow was not constant and depended on the parameters of the whole system; flow resistance, set points and regulatory data of diffuser and expansion boxes, dampers and, in particular, it depended on dirtiness of filter pocket inserts. Energy consumption was much greater than in case of electronic tracking and adaptive automation systems. Particular emphasis was put on the fact that simple cross-flow exchanger used without the active heat recovery section, e.g. heat pumps, and without an air humidity regulation functionality also led to higher loss. In addition, it was found that the main venting unit worked in a mode quite contrary to the concept of operation of air supply and exhaust venting units [7]. Due to the incorrectly selected parameters of heat recovery and air heating devices, the venting unit does not allow heating the air to a defined temperature, especially at low external temperatures. Upon detecting many above-mentioned errors, it was decided to carry out a modernisation consisting in the use of venting unit fitted with:

– highly efficient exchanger made of plastic,
– regulated bypass,
– active heat recovery and humidity regulation systems,
– system of fluent regulation of the supply and exhaust airflow.

MODERNISATION OF THE AIR SUPPLY AND EXHAUST VENTING SYSTEMS IN OTHER ROOMS OF THE WATER PARK

Due to the poor technical condition of the existing air supply and exhaust venting systems, the existing units have been completely replaced with new units with highly efficient heat recovery with at least 85% recuperators. The previous units had declared heat recovery of 40%. For offices and technical rooms the option with central air conditioning and local central fan-coil unit was considered. This made it possible to divide the conditioned rooms by function and distribute the operating cost of potential users.

A modernised system, which handles the rooms such as: entrance hall, administrative space, changing room hall and changing room, staircase hall, main hall, corridor, rehabilitation room, gallery, hairdresser and beauty salon, sollux, rehabilitation rooms, gym, projection room, club room and other rooms, has been fitted with air supply and exhaust venting units with heat recovery based on high efficient VS-180-R-PHC rotary heat exchanger with the efficiency of: Vn=18 000 m^3/h; Vw=19 100 m^3/h.

The systems for water treatment station, hypochlorite storage and H2SO4 storage are fitted with VS-30-R-H air supply unit and VS-30-R-V air exhaust unit with the efficiency: Vn/w=3 600 / 3 200 m^3/h.

The third unit handles men's cabinet changing room, women's cabinet changing room, rental room and hydrotherapy room and operates with air supply and exhaust venting unit with heat recovery based on VS55-R-PH cross-flow exchanger with efficiency of: Vnw=4 850 / 5 335 m^3/h.

For these venting systems an air conditioning unit has been installed with the cooling capacity of 110 kW – generator: KOMPAKT ZR250x2 R407C/73AG.

SOLAR INSTALLATION PROVIDING ENERGY FOR HEATING THE POOL WATER, PROCESS WATER, SHOWER WATER AND TAP HOT WATER

The modernisation consisting in installing flat solar collector system along with all accessories (e.g. circulation pump, regulator, expansion vessel, piping with insulation, structure for fixing the collectors) with tap hot water storage cylinder with capacity of 6 x 1000 l. [4]. The priority of the system is tap hot water.

The collectors are laid out in a southerly direction at an angle of 40 °. The conducted analysis of the preparation of tap hot water in the solar installation in the Water Park shows that the solar collectors are a reasonable method of obtaining energy to prepare tap hot water, but the condition of profitability of the investment is to get financial support from external sources [9].

Below there is a summarised technical variant of use of solar installation in the swimming pool in the Water Park in Ełk. The Vitosol 200-F collectors type SH2 with minimum optical efficiency of 83% and thermal power of approx. 421 kW were located above the shelter of the car park of the water park. The main component of the solar collector Vitosol 200-F is copper plate with the Sol-Titan coating. It ensures maximum absorption of solar radiation with minimum emission of thermal radiation [13]. The absorber plate is fitted with a meander copper tube, through which heating medium flows. This way heating medium receives heat from the absorber through copper tube. Cover of the collector, in which the absorber is placed, has very good thermal insulation, which ensures minimisation of the heat loss. Thermal insulation is resistant to high operating temperatures of the collector. The collector is covered with a glass pane made of special solar glass. Such glass panes are characterised by a reduced content of iron oxides, which minimises number of reflections of sun rays coming to the collector. Temperature sensor of the medium should be mounted at the exit of the collector battery, along with immersion collars.

When deciding to thermal upgrading through installing solar collectors, heating for tap hot water purposes was taken as a priority (Table 2).

USE OF PHOTOVOLTAIC CELLS TO POWER THE WATER PARK

The project assumes the use of photovoltaic power plant with nominal capacity of approx. 50 kW. The photovoltaic power plant operates in parallel with the electricity network without discharging energy to the network. In case of the power flow in direction of the network, the meter of network parameters sends a signal to switch on charging receivers and to switch off the solar plant (controlled by the plant automation system). Photovoltaic cells operate to satisfy the demand of the internal network (possibility to switch to conventional electricity network should be provided in case of excess energy). In order to integrate the proposed Renewable Energy Sources into the control system and to make it possible to perform advanced visualisation and access via Ethernet, a solution based on a system of devices from SMA was employed [6].

All operating parameters of the mains-connected inverters of the wind turbine and of inverter of photovoltaic batteries related to the produced, collected and consumed energy are collected and sent to the PC. The adopted solution allows connecting all devices into the network via RS485 and linking them to Sunny WebBox Ethernet module.

The collected data related to the RES system operating parameters and the operating information are shown on a plasma TV set. These data are collected and archived and can be displayed in numerical and graphical form.

The system handling the inverters and controllers of the solar plant, which collects measurement data and perform visualisation, is based on the equipment by SMA. Communication system is based on Ethernet communication module – Sunny WebBox with Ethernet-Interface. Diagnosis and communication is preformed via the network, radio connection and a wired connection (RS232 or RS485) [10].

CONCLUSIONS

The modernisation of venting system of the swimming pool hall has enabled:

1. Increasing the recovery of heat from ventilation to more than 85% from less than 50%;
2. Adjusting the ventilation pool hall to current standards and technical requirements;
3. A significant improvement in sanitation and hygiene of the pool hall and other rooms;
4. Use of heat pump in the venting unit, which will increase the efficiency of waste heat recovery and provide for simultaneous dehumidification of the pool hall;
5. Reduced emissions of harmful gases, e.g. CO_2 and dust into the atmosphere.

Table 2. Selection of the collectors with the priority of tap hot water [20]

Installed power of solar collectors	421.34 kW	
Total radiation on solar collectors	664.72 MWh	1 190.23 kWh/m²
Total energy produced by solar collectors	211.83 MWh	379.3 kWh/m²
Energy produced by solar collectors	186.29 MWh	333.57 kWh/m²
Energy for heating of tap hot water	114.9 MWh	
Energy from solar collectors for heating tap hot water	65.01 MWh	
Energy from solar collectors for heating swimming pool water	121.29 MWh	
Energy from the external heat supply company	292.1 MWh	
Savings of heat energy	210.2 MWh	
Prevention of CO_2 emissions	45 407.62 kg	
Share of energy from solar collectors for heating tap hot water	53.7%	
Share of energy from solar collectors for heating swimming pool water	34.0%	
Share of total energy from solar collectors	38.9%	
System efficiency	28.0%	

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WYKORZYSTANIE KOLEKTORÓW SŁONECZNYCH NA PRZYKŁADZIE PARKU WODNEGO CZ. 1: ANALIZA TECHNICZNA

Streszczenie. Praca dotyczy analizy technicznej przeprowadzonej modernizacji obiektów parku wodnego z wykorzystaniem kolektorów słonecznych na potrzeby podgrzewania ciepłej wody użytkowej i centralnego ogrzewania. W artykule zawarto informacje na temat przeprowadzonej modernizacji ze szczególnym naciskiem na analizę sposobu doboru użytych urządzeń oraz wykorzystane rozwiązania techniczne.

Słowa kluczowe: kolektory słoneczne, analiza techniczna, pływalnia, modernizacja.