

Article

# Technology Management Leading to a Smart System Solution Assuring a Decrease of Energy Consumption in Recreational Facilities

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**Abstract:** Improvement of the energy efficiency of public buildings appears to be one of the best ways to simultaneously reduce energy consumption as well as the negative impacts on the environment. The work is dedicated to the analysis of modernization process of the energy system in a sports facility in a way leading to design of smart energy system. The proposed solution, being a specific case study, offers optimal use of energy in the facility, significantly reducing the demand for energy derived from fossil fuels (heat providers and conventional power plants). The project, on its first step, consists of recovering energy from sewage that usually is irretrievably lost. This option allows to achieve the assumed goals simultaneously optimizing the investment costs. The proposed solution mitigates air pollution and harmful gas and dust emissions to the atmosphere, and contributes to an increase of both the attractiveness and competitiveness of the area in which the sports facility is located. The next step will be further automation of the system and intelligent synchronization of time-dependencies of the processes.

**Keywords:** renewable energy sources; technology management; CO<sub>2</sub> mitigation; modernization

## 1. Introduction

Water deficit along with the need of environmental protection coupled with ever-increasing civilization progress forces us to save energy, water and materials [1–4]. Results of scientific research and up-to-date industrial achievements in the area of the development [5–8] and implementation of intelligent energy systems based on renewable energy indicates that the use of primary energy may be important for achieving national and international goals [9–12].

Intelligent energy management systems are becoming increasingly popular [13,14]. Their attractiveness is due to the innovative perception of the energy sector, including issues related to monitoring, controlling, and collecting data. The purpose of their use is communication between all participants of the energy market, with the task of providing energy services, ensuring reduction of costs, and increase of efficiency as well as integration of distributed energy sources, including renewable energy. Intelligent networks give the opportunity to dynamize the development of energy technologies [15,16]. The smart systems integrate various resources and technologies in both generation and consumption.

Intelligent energy systems focus on an integrated inclusion of several sectors (electricity, heating, cooling) and allow for the identification of more achievable and affordable solutions in the transition to future renewable [17–19] and sustainable energy solutions [20,21].

Hybrid systems, which may include not only renewable sources but also conventional ones, are becoming increasingly popular [22]. Pioneering projects based on integrated energy systems using photovoltaic installations, heat pumps, and wastewater heat recovery are being implemented [23,24]. When waste heat is used, it is necessary to identify its sources and available resources [25–27]. When designing a wastewater heat recovery plant, the temperature and quantity of wastewater must be taken into account and it must be decided whether the process will be carried out before or after treatment with substances of a biogenic nature [28–30].

About 1 billion m<sup>3</sup> of wastewater water is recovered annually in the EU. As anticipated by EU bodies, the entry into force of the circular economy regulation can increase water recovery from wastewater by up to 6.6 billion m<sup>3</sup> by 2025 [31]. In accordance with the idea of a circular economy, it is assumed that maximizing the use of recycled water in swimming facilities causes maintaining for as long as possible the value of products, materials, and resources, while reducing the generation of waste. Promoting the idea of a circular economy aims at increasing the EU's competitiveness and protecting companies and, for example, utilities against resource scarcity and price volatility. The reuse of treated wastewater in safe and cost-effective conditions is a valuable but underused way to increase water resources and relieve over-exploited water resources in the EU.

These issues are particularly important for Poland, in which there is three times less water than the average in Europe, i.e., about 1600 m<sup>3</sup> per year per person, while in the European Union it is over 4500 m<sup>3</sup> [32]. EU member states have many years of successful experience in reusing water for various purposes. However, it should be emphasized that in Poland, such innovative solutions are only now being implemented and developed.

Considering the dynamics of development and technological advancement as well as the increase in the standard of living and consumer expectations, to ensure energy security, it is necessary to save energy in every possible area of life [33,34]. One of the examples of energy saving is the recovery of heat from rinse water in swimming pool facilities.

Regional and local energy systems and networks consist of locally and regionally available energy sources, built infrastructure, as well as user and consumer structures from various sectors. They serve ambitious goals for clean energy for specific communities and regions, as well as for the entire European energy system. They support security of supply, maximizing primary energy efficiency, and ensuring a high share of renewable energy in the energy balance. In Poland, in a situation where in August 2015 there were electricity restrictions caused by too low water levels for cooling commercial power plants with open cooling circuits, it became natural to develop and introduce solutions aimed at saving water and energy [35].

Saving electricity, materials, and heat is becoming more and more necessary [36,37]. Managers of swimming pools, water parks, hotels, and spas are looking for savings so that while minimizing expenses, they provide greater comfort to users. Maintaining proper water and air quality parameters in these types of facilities require ensuring huge amounts of energy supplied per year, and thus ensuring a budget to cover costs that can and should be reduced. In Poland, often too much emphasis on the purchase price of devices means that they work inefficiently or are simply of low quality. Often, a bad concept of a system that has not been optimized for the best possible ways of energy recovery also has a big impact on bad situations.

In the case of washings arising after cleaning the pool filter beds, the potential is hidden in their large volume and the possibility of using simple unit solutions of processes and devices, e.g., settling tanks, settling tanks, or combined settling tanks with a flocculant mixing chamber. With the appropriate quality of washings, their use for irrigating green areas, sprinkling pitches, tennis courts, and for flushing toilets is a simple solution that allows reducing the costs of water supply and sewage disposal [38].

One of the energy problems related to environmental protection is the loss of heat along with wastewater discharged into the sewage system—energy as well as heat is lost, among others in warm

washings intended for discharge into public sewers [39–42]. Some of this heat can be recovered using a wastewater heat recovery plant.

Energy recovery from wastewater is the subject of many scientific articles. Mostly, the works are concerned with energy recovery from municipal sewers [43,44]. Some works are concerned with energy recovery from residential buildings of various sizes [45–49] and also various industrial facilities [50]. A small number of papers deal with energy recovery from wastewater generated by sports facilities, including swimming pools. As an example, the works [51,52] give analysis of several Norwegian swimming facilities, coming to the conclusion that in each there is still room for improvement. The other paper [53,54] claims that the amount of recovered heat is much higher than energy consumption needed for powering the installation.

The literature contains many detailed analyses from the energy and economic point of view concerning the possibility of optimizing the energy system efficiency of the indoor swimming pool center by means of solar collectors and heat pump technology integrated with the existing installation [55–58]. There are also original studies on the long-term operation of the pool heating system through the use of waste heat energy, which is discarded from the ice rink unit [59]. Energy-saving measures for sports centers of various sizes are analyzed [60–62]. In addition, control strategies that can be implemented in the building automation system and the HVAC (heating, ventilation, air conditioning) system of the existing indoor swimming pool complex are analyzed in order to minimize energy consumption [63]. The energy efficiency in public indoor swimming pools was also analyzed taking into account the concept of passive houses [64].

Recovery of heat from sewage is possible and also recommended in places where it is formed in large quantities, including in indoor swimming pools, industrial laundries, etc. which use significant amounts of heat or electricity in their technological processes. Heat recovery from sewage is based on recuperative systems, which consist of heat exchangers or heat exchangers cooperating with a heat pump [65–67]. The temperature of municipal sewage from households is in the range of 10–20 °C, while sewage generated in many industries has an even higher temperature—exceeding 40 °C. Lowering the temperature of 1 m<sup>3</sup> of wastewater by 1 °C results in 1.16 kWh of heat saving, thus heat recovery from wastewater is justified in terms of energy, environment, and economy [68].

In modern facilities, you can now meet various solutions implemented to optimize energy consumption, and thus reduce costs, such as solar panels, ventilation systems with various heat recovery methods, etc. Each of them is specific and should be justified by having a positive impact to manage energy and improve the financial condition of the facility [69,70].

At the global level, there are around 13 million pools, of which around 4.4 million (29%) are in Europe. North America accounts for 59% of the global market, while the rest of the world has only 1.65 million pools (12%) [71]. According to the European Union of Swimming Pool and Spa (EUSA) associations, France has the most pools in Europe (1.5 million, 34% of the total European number), followed by Spain (27%), Germany (20%), Italy (6%), and Great Britain (5%). In Germany, 250–300 million people visit public swimming pools every year. In Great Britain, 33% of children and 36% of adults visit swimming pools at least once a week, and 55% of children use swimming pools at least once a month. According to available statistics, a large city, such as Paris, has up to 38 public pools, and a public pool can have up to 1400 visitors on a busy Sunday in summer. Public swimming pools therefore have a great social impact, contributing significantly to the health and well-being of the European population, promoting active, healthy, and relaxing recreational activities for all ages and social classes.

In Poland, the total number of indoor swimming pools is estimated at 736, while the number of all pool troughs is estimated at 849. Among this type of sports facility there are Olympic pools, swimming pools, sports-type swimming pools, training, and recreational pools [72].

The temperature of the water supplied to the municipal indoor swimming pool is between 5 and 15 °C depending on the season. The analysis of technological possibilities and energy potential has become a premise for attempts to recover heat lost as a result of discharging hot sewage to the

sewage system in spot facilities such as a swimming pool. Wastewater generated in indoor swimming pools comes from showers, flushing filters, and discharging pool water. The water temperature in the indoor swimming pool ranges: showers: 38–40 °C, swimming pool: 25–27 °C, recreational pool: 26–30 °C, children's pool (paddling pool): 28–32 °C, pool for whirlpool: 34–36 °C, rinse water from filters: 25–35 °C. Wastewater temperature is practically constant throughout the year and is in the range of 25–41 °C (on average about 30 °C), so warm sewage in an indoor swimming pool throughout the year can be a constant source of heat [73–75]. It also can be observed that demand for heat and electricity is not constant, but undergo variations with maximum consumption during the daytime and sewage release during the night. The time dependences of both processes can be roughly approximated with rectangular shapes shifted with respect to each other.

In heat recovery systems from wastewater, the basic element is the heat exchanger between wastewater and freshwater. Its design should prevent the build-up of impurities such as hair, soap, and others. The presence of impurities could affect the intensity of heat exchange between wastewater and freshwater [76,77].

According to the currently recommended standard (DIN 19645-2006), the rinse water can be treated up to 80% and recycled to the pool water treatment system as freshwater, with drinking water parameters, directly to the overflow tank [78].

Sports complexes are an ideal place to enjoy the benefits of renewable energy [79–81]. The most commonly used methods are photovoltaic, geothermal and heat recovery from rinsing wastewater. These technologies are an innovative and ecological approach to the use of renewable energy [82]. Photovoltaic solar farms contribute to the lowering of sports complexes demand for electricity generated outside the facility [83,84]. Geothermal energy can be used to heat cold city water that goes to the facility in the same way as the central unit for recovering heat from rinsing sewage [85–87]. Both forms reduce the object's demand for heat generated from conventional energy sources, which are harmful to the environment and their limited amount is constantly depleting on the planet [88–92].

The market has a diverse offer of ready heat recovery equipment for single-family homes, for facilities that consume large amounts of hot water (e.g., laundries, swimming pools, hospitals, etc.) and for sewage treatment plants. On the local scale (heat recovery from the used shower water in the bathroom), there are e.g., ZYPHO (EcoMax, Bydgoszcz, Poland) recuperators using the heat from the used shower water to pre-heat cold water flowing into the battery (with a family of four, you can get 1200 kWh of saved energy per year).

For facilities that consume large amounts of hot water, a heat recovery unit with a recuperator can be used. Wastewater flowing through the internal recuperator coil transfers a significant amount of heat to the freshwater stream flowing through the external recuperator coil. The cold water can be heated up to 30 °C without the use of other heat sources. Another solution is the use (installed in the vertical part of the sewer pipe) of the GFX (Gravity Film Xchange) flow coil. Wastewater flowing down the riser transfers heat to the cold water flowing counter-current inside the copper spiral that wraps the drain pipe. As a result, energy consumption is reduced by more than 7%, which saves 800–2300 kWh per year per apartment. There is also a method of recovering heat from wastewater not directly at the source but in the central collector. With this solution, wastewater flowing into the sewer pipe gives off heat to heat exchangers (built-in pipe segments installed in existing sewer collectors).

The aim of this work is to analyze a case study of an urban sports facility equipped with a modern heat recovery system. The manuscript focuses on demonstrating the feasibility of the investment under the assumed design conditions taking into account economic and environmental aspects. According to the design assumptions, the energy generated as a result of the investment will be used exclusively for the needs of the sports facility. In addition, the manuscript presents additional technological solutions to increase energy savings in sports facilities.

## 2. Materials and Methods

On the basis of the technical parameters of the analyzed building of the sports facility and the parameters of the thermal installation, a heat recovery system was designed to recover heat from sewage discharged from showers and from rinsing water from filters. The basis for the detailed discussion of technical parameters of the installation elements and calculation analyses was a pool installation scheme with heat recovery from rinse water. The control and measuring automatics system of the heat recovery installation was also analyzed.

### 2.1. Characteristics of the Analyzed Sports Facility

The analysis was based on materials provided by the investor, data provided by the investment contractor, information contained in manufacturers' catalogs, field inventories, and local visions of the analyzed object. Detailed specifications of individual devices included in the installation remain a trade secret of the investor.

The calculations were made for an investment located in a temperate climate zone, which is important information for the installation of buildings with hybrid heat sources.

The analyzed sports facility (Municipal Sports Center) from the architectural and construction side is characterized by the following technical parameters of the building (Table 1):

**Table 1.** Technical parameters of the sports facility building.

Technical Parameter	Size
Number of above-ground floors	2 floors
Number of underground floors	1 story
Length × width	52.35 × 37.10 m
Height	11.90 m
Building area	1994 m <sup>2</sup>
Usable floor area	5355.88 m <sup>2</sup>
Cubature of the underground part	9650 m <sup>3</sup>
Volume of the above-ground part	19,000 m <sup>3</sup>

The sports complex is equipped with central heating installation with a low-temperature pump with the following parameters: power  $Q = 110$  kW, rated thermal power range 50/40 °C. The source of heat is a cascade of two condensing boilers fed with gas GZ-50 type Viessman Vitodens 300 with a capacity of 60 kW. Boiler room power for the needs of central heating of the sports complex is a total of 120 kW. The process heat installation has been designed to supply technological devices for under-swimming pool and water heaters in ventilation centers: power  $Q = 850$  kW, rated thermal power range 80/60 °C. The source of heat is a cascade of two boilers, also powered with GZ-50 gas of the Viessman Vitoplex 200 type with a power of 440 kW with a gas blow torch. Boiler room capacity for the needs of technological heat is 880 kW in total. The gas system of the sports complex located in the boiler room consists of two 60 kW furnaces and two 350 kW furnaces.

The main source of pool water heating is a conventional source in this case natural gas furnaces. They heat the city's incoming water at an average temperature of 10 °C to domestic hot water at 55 °C. In order to reduce energy costs, waste heat recovery centrals were used, which heat the city water to a temperature of 35 °C using the heat from rinsing wastewater intended for sewage discharge. In the end, gas stoves heat the pool water only from 35 °C to 55 °C, which is a large and visible saving for heating the pool water by the sports complex.

## 2.2. Heat Recovery System Equipment

### 2.2.1. Used Water Tank

The heat recovery system equipment includes a wastewater tank which is used to collect shower waste and rinse water from filters. The capacity of the used water tank should be sufficient to collect the volume of shower wastewater during the day and rinse water from the filters during the night. There are two overflows, a valve for draining sewage into the sanitary sewage system, a sewage level indicator and an inspection hatch in the wastewater tank. A water meter is installed on the freshwater supply system. This tank is tightly closed. The tank parameters were calculated assuming that the swimming pool is used by 660 people per day and that the swimming pool is open 17 h a day (information obtained from the investor). On this basis, it was established that the volume of shower waste delivered during the day would be 40 m<sup>3</sup>:

$$660 \text{ people} \times 60 \text{ L/person} = 39,600 \text{ L} \quad (1)$$

The volume of shower wastewater delivered within 1 h will be:

$$40 \text{ m}^3 : 17 \text{ h} = 2.352 \text{ m}^3 / \text{h} \quad (2)$$

The project assumed the construction of an airtight tank for used water from modules made of grey polypropylene plates welded to walls reinforced with rims. This tank was assembled on the site of the investment and placed on the foundation.

### 2.2.2. Fiber Catcher

The hair and fiber catcher is a pre-filter which is used to trap impurities in the wastewater flowing from the rinse water tank to the heat recovery unit. It is installed in front of the sewage pump, which protects it from contamination or damage. A hair and fiber catcher made of corrosion-resistant materials type M-DN65 according to Menerga GmbH technology was used [93].

### 2.2.3. Sewage Pump

The wastewater pump should ensure the flow of wastewater through the hair and fiber catcher and the heat recovery unit. The minimum lifting height of the pump should cover linear and local losses in the pipe network, on the hair and fiber catcher, and the heat recovery unit. A BADU 90/7 wastewater pump by Speck Pumpen GmbH was used [94].

### 2.2.4. Heat Recovery Panel

There are many technologies and ways to recover heat from wastewater. Heat from sewage can be recovered in three zones of the sewage disposal system, i.e., directly at the source, in the sewage collector, and after the sewage treatment plant. In the solution under analysis, the heat accumulated in the discharged shower waste and rinse water from the filters is recovered in a heat recovery system. The sewage heat recovery unit is used where there are large amounts of warm sewage and there is a high demand for hot freshwater [95].

In the analyzed solution, the heat recovery unit was equipped with: a tubular counter-current heat exchanger enabling heat exchange between hot sewage and cold freshwater; a system of automatic cleaning with balls from sponge of those exchanger pipes through which sewage flows; a control panel with electrical protection, power supply, and control systems; automation with complete software; a display showing water and sewage temperatures, operating time of the unit, messages about the operating status of the unit and interference alarms; sewage level sensor; heated water temperature sensor.

The AquaCond unit has been designed to recover heat from wastewater intended for sewage discharge [96–98]. It is intended to heat cold city water with an average temperature of 10 °C to 35 °C. (for this purpose a heat exchanger with 80/60 °C network parameters is used and provides 30 kW of heat; the heat recovery coefficient expressed as the ratio of the required heat to the supplied energy is 1). When the water reaches this temperature, it is heated by a gas oven to 55 °C. Rinse water, i.e., used water, is understood as water drained from showers, washbasins, and water from rinsing the filtering devices located in the Municipal Sports Center. Wastewater has an average temperature of 31 °C and is a free source of heat. The path of sewage discharged by installations leads through a recuperator and then through a heat pump. The municipal water flows counter-current through the recuperator and continues to the heat pump condenser. The recuperator is the first place where municipal water receives heat from the rinse water (in the wastewater/freshwater recuperator, the wastewater is cooled to 14 °C). The heat recovery occurs counter-current, thanks to which this process has a low demand for external energy. The next place for heat collection is the evaporator (cooling to 8 °C). At the same time, freshwater is heated in the recuperator from 10 °C to 27 °C, and then in the heat pump condenser from 27 °C to 35 °C. In this system, the heat recovery coefficient expressed as the ratio of the heat demanded to the supplied electricity is 10.

In order for both water flows to be equal (heat dissipation could be carried out all the time), a buffer tank is used. From the economic point of view of the investment, it is necessary to secure the drainage of all the water consumed to the central unit (with the exception of back-flushing water). The water level in the tank should be set so that, on the one hand, the pumping pumps can suck while showers are not in use, and on the other hand, that when showers are used the water does not flow unnecessarily through the bypass circuit directly into the sewage system.

The proposed solution provides for the following basic technological processes: collection of shower and rinsing water from filters in the wastewater tank; removal of mechanical impurities in the form of hair and fibers contained in the wastewater by means of a hair and fiber catcher; flow of warm wastewater from the wastewater tank through the heat recovery unit; flow of cold freshwater through the heat recovery unit; heating of cold freshwater in the heat recovery unit by warm wastewater; cooling of warm wastewater in the heat recovery unit by cold freshwater; flow of heated freshwater from the heat recovery unit to the heated water tank, swimming pool overflow tanks and domestic hot water exchanger; flow of cooled wastewater from the heat recovery unit to the sanitary sewage system.

Pipes in which sewage is discharged have the same diameter, which enables purification of the installation. Purification must occur regularly to prevent contamination inside the pipeline, as this is used water that is not necessarily clean. An innovative idea is to use cleaning balls in the installation that move inside the installation and prevent deposits.

The control panel with a programmable microprocessor PLC (Programmable Logic Controller) is used to automatically control the processes of rinsing water treatment, touch screen displaying current operating parameters (pressure, flow, filtration and flushing time, position of each valve, alarms, historical data). By connecting to the Internet, using the Internet portal, there is full control of the process of purifying rinse water and the guarantee of a remote service. To reduce chloramines, the system has been equipped with an additional module utilizing the excellent sorption properties of activated carbon, which means that the output parameters of water are such as freshwater with a lower chlorine concentration than water from tap water. The UltraEcoSwim system was used to treat swimming pool rinse water and reduce chloramines. The guidelines for connection and design as well as parameters and equipment are presented in [99].

An example of a swimming pool installation with heat recovery from rinsing water is shown below (Figure 1).



Table 2. Cont.

Parameter	Description
Water evaporator—used water	
Refrigerant	R407C
Refrigerant mass flux	0.091 kg/s
Temp. coolant carrier outputs	7.7 °C
Cooling medium volume flux	1.8 m <sup>3</sup> /h
Refrigerant pressure drop	0.14 bar
Water heat exchanger—recuperator	
Cooling medium volume flux	1.8 m <sup>3</sup> /h
Heat carrier volumetric flux	1.8 m <sup>3</sup> /h
Temp. coolant carrier outputs	15.5 °C
Temp. refrigerant supply	10 °C
Temp. heat carrier outlets	25.5 °C

Table 3. Technical specification of wastewater heat recovery unit.

Parameter	Unit	Value
Max. water flow	m <sup>3</sup> /h	1.2
Thermal efficiency	kW	37
Power consumption—pump	kW	2.6
Heating capacity coefficient		11.4
Available pressure: freshwater	kPa	105
Flow resistance: used water pump	kPa	90
Supply voltage 3/N/PE 50 Hz	V	400
Max. power consumption	kW	6.4
Connections		
Used water PVC (Polyvinyl Chloride)	mm	32
Freshwater Cu/PVC	mm	22/32
Dimensions		
Width	mm	1210
Depth	mm	890
Height	mm	1530

The installation described in Table 2 due to combination of the recuperator with the heat pump enables such savings of energy that only about 10% of the amount of energy is required as compared to that the conventional heating would consume. For wastewater burdened with pollution, the device is equipped with an automatic cleaning system that uses cleaning balls inside the installation.

### 2.2.5. Hair and Fiber Catcher Washing Station

The hair and fiber catcher of the sewage pump must be periodically cleaned and washed. Therefore, a hair and fiber catcher and a sewage pump should be installed in the washing station. In the analyzed case, the hair and fiber catcher washing stand has dimensions of 180 × 100 cm (placed at a depth of 2 cm in the base, it has a sewer inlet).

### 2.2.6. Control and Measuring Automatics

The sewage heat recovery unit is equipped with a complete automatic station control system controlling the freshwater supply to the overflow tank of the swimming pool, swimming pool, and the flow of sewage and freshwater through the heat recovery system.

During the start-up of the sewage heat recovery system, a heat recovery unit is started up, taking into account the cooperation with the pool water treatment plant technology.

During the system operation, the following parameters are measured and displayed on the digital display of the unit: freshwater temperature-inlet; freshwater temperature-outlet; sewage temperature-inlet; sewage temperature-outlet; unit operation time.

The sewage heat recovery unit controls the sewage pump and freshwater solenoid valves. It is controlled by a sewage level sensor located in the wastewater tank and freshwater solenoid valves located near the overflow tanks.

In order to control the heat recovery unit, cables from the sewage pump, sewage level sensor, freshwater topping up solenoid valves and from the water topping up system in the water treatment plant are connected to the electric control and switchboard. In order to monitor the operation of the air handling unit, sewage heat recovery units were connected to the air handling units. Activation of any electro-valve of freshwater heated at the overflow tank will switch the unit on. Overflow tanks are filled with water heated by the control unit. At the same time, when the control panel is switched on, the freshwater solenoid valves close. If there is no sewage in the wastewater tank, the level sensor switches off the unit. Switching off the unit opens the freshwater valves. This allows the water to be topped up to the overflow tanks via freshwater solenoid valves.

### 3. Results

Heat recovery from rinsing wastewater realized due to the application of the AquaCond installation is an innovative treatment method for wastewater intended for sewage discharge. The use of this method is important for the Municipal Sports Center not only due to the reduction of swimming pool water heating costs but also due to the reduction of CO<sub>2</sub> emissions resulting from the reduction of fuel consumption.

#### 3.1. Generation of Warm Rinse Wastewater by the Municipal Sports Center

For heat recovery from wastewater in sports facilities of the city pool type, systems (installation schemes) such as: heat exchanger, with recuperator and heat exchanger, either/with heat pump, or with recuperator and heat pump can be used. Analyzing freshwater heating systems, it was found that taking into account heat recovery from wastewater, the freshwater heating system with a recuperator and heat pump is the best. In this system, the ratio of the amount of heat required to the heat (electricity) supplied was 10 (Table 4). This means that for heating freshwater with a temperature of 10 °C to 35 °C, 10 times less electricity should be supplied than in a system with a heat exchanger. This system also has the largest cooling of wastewater.

**Table 4.** Comparison of installation schemes for freshwater heating.

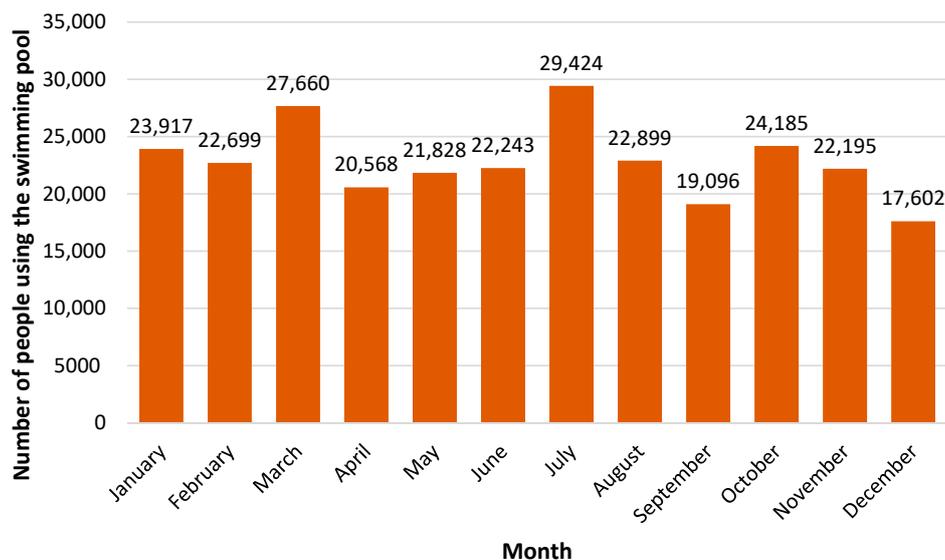
Parameter	Heat Exchanger	Recuperator and Heat Exchanger	Heat Pump	Recuperator and Heat Pump
Heat demanded [KW]	30	30	30	30
Delivered heat (electricity) [KW]	30	10	7.5	3
Heat (electricity) recovery factor	1	3	4	10
Freshwater temperature (inflow) [°C]	10	10	10	10
Freshwater temperature (drain) [°C]	35	35	35	35
Wastewater temperature (inflow) [°C]	-	31	31	31
Wastewater temperature (outflow) [°C]	-	14	12	8

The analyzed swimming pool is open seven days a week from 6 a.m.–11 p.m. excluding holidays and periodic technical breaks on average every three years of use (a technical break lasts about 2 weeks). The pool was made of acid-resistant steel, what reduces the needs for a technical pool break as compared to classic pools that need this break every year.

Due to public holidays, during the calendar year, the Municipal Sports Center is closed six times all day and three times half day, and open 356 times for all day and three times half day. This gives the number of hours of wastewater production:

$$(356 \text{ days} \times 17 \text{ h}) + \left(3 \times \frac{1}{2} \text{ days} \times 17 \text{ h}\right) = 6052.0 + 25.5 = 6077.5 \text{ h/a} \quad (3)$$

During the year, the Municipal Sports Center produces warm rinse sewage within 6077.5 h, and the amount of sewage depends upon the number of people using the municipal swimming pool, that varies depending on the season. The number of people using the swimming pool in each month is shown in Figure 2.



**Figure 2.** Summary of the number of people using the swimming pool based on 2018.

The average production of warm rinsing sewage per 1 person using the swimming pool is 10 L, therefore the amount of sewage generated by users is:

$$274,316 \text{ people/year} \times 10 \text{ L} = 2,743,160 \text{ L/year} \quad (4)$$

Consequently, during the year, the Municipal Sports Center generates warm rinse wastewater by people using the swimming pool at the level 2,743,160 L.

Every day of the year, to maintain the highest quality of pool water, it is subjected to a filtration process. In the City Sports Center, water filtration takes place every day in 5 out of 8 gravel-sand filters (with an additional filter layer applied from anthracite). During hours when the swimming pool is not used, the filters are rinsed. The average amount of water used for rinsing per day is a total of 40,000 L, so the amount per year will be:

$$40,000 \text{ L} \times 365 \text{ days} = 14,600,000 \text{ L/year} \quad (5)$$

During the year, the Municipal Sports Center consumes 14,600 m<sup>3</sup> for flushing filters. Therefore, the total rinse sewage generated in 2018:

$$2,743,160 \text{ L} + 14,600,000 \text{ L} = 17,343,160 \text{ L} \quad (6)$$

Consequently, during the year, the total sum of generated rinse sewage supplied to the heat recovery installation is 174,43.160 L, as per 2018, and it is the sum of sewage generated by users using the swimming pool and the water used for flushing filters.

Hence, of the entire amount, as much as 84% of the water that goes to the heat recovery center comes from filters flushing, and only 16% of the water from warm rinsing sewage generated by pool users, i.e., from showers and washbasins.

### 3.2. Economic Analysis of Investment

It is seen therefore, that during the year 2018 at the Municipal Sports Center the amount of 17,443.160 L of warm rinse sewage were produced. By passing through heat recovery centers, they heated the city water coming to the sports complex from 10 °C to 35 °C, then cooled were discharged to the sewage.

To heat 1 L of freshwater from 10 °C to 35 °C the following amount of heat is needed:

$$Q = 104,750 \text{ J} = 0.000105 \text{ GJ} \quad (7)$$

Therefore, the amount of heat saved by the Municipal Sports Center in 2018 was:

$$17,343,160 \text{ L} \times 0.000105 \text{ GJ} = 1821.0318 \text{ GJ} \quad (8)$$

At a fixed price of 2017/2018, PLN (Polish Zloty) 40.75 for 1 GJ of heat from natural gas was paid according to the contract issued by PGNiG (Polish Oil and Gas Company), the savings obtained throughout 2018 are:

$$1,821,0318 \text{ GJ} \times 40.75 \text{ PLN} = 74,207.045 \text{ PLN/year} \quad (9)$$

The electricity consumption of the heat recovery device is 26,043.96 kWh per year, and its cost after taking into account that 1kWh costs PLN 0.54 is:

$$26,043.96 \text{ kWh} \times 0.54 \text{ PLN/kWh} = 14,063.74 \text{ PLN} \quad (10)$$

To sum up, the annual savings obtained by the heat recovery central unit in relation to the expenditure incurred for its electricity consumption is:

$$67,196.07 \text{ PLN/year} - 14,063.74 \text{ PLN} = 53,132.33 \text{ PLN} \quad (11)$$

With an average annual saving of PLN 53,132.33 (based on 2018), the investment cost assuming its initial value was PLN 170,000.00 will pay for:

$$170,000.00 \text{ PLN} \div 53,132.33 \text{ PLN/year} = 3.2 \text{ year} \quad (12)$$

The initial value of the investment was provided to the authors of the manuscript by the investor. The authors verified the given investment amount on the basis of interviews with other investors [101].

In the case of a heat recovery system from wastewater equipped only with a central unit with a recuperator with assumed parameters (Table 5), the cost analysis looks as follows:

**Table 5.** Assumptions for the analysis of investment profitability (wastewater heat recovery center with recuperator).

Description	Size	Unit
Operation time of the heat recovery plant from wastewater	6077.5	h/year
Heat output	32	kW
Sewage inflow temperature	28	°C
Freshwater inlet temperature	10	°C
Electric power consumption (sewage pump + automation)	0.4	kW
The cost of 1 kWh	0.54	PLN
Cost of the waste heat recovery system with heat recovery central unit with recuperator	170,000	PLN

The estimated payback time of the investment will be (Table 6):

**Table 6.** Cost analysis (heat recovery plant from wastewater with a recuperator).

Description	Size	Unit
The cost of electricity consumed by the system	312.74	PLN/year
The cost of recovered heat	37,806.912	PLN/year
Amount saved (difference between the cost of recovered heat and the cost of electricity consumed)	36,494.172	PLN/year
Estimated return on investment incurred	4.66	years

### 3.3. The Effect of Environmental Protection

In the analyzed Municipal Sports Center during the year 2018, the amount of 17,443.160 L of warm rinse sewage were produced. The amount of heat saved by the Municipal Sports Center during the year under analysis was around 1821GJ (fed from the municipal heating network, in which hard coal is the main source of energy). This allows to evaluate the annual avoidance of carbon dioxide emissions to the atmosphere depending on burning fuel or obtaining energy from various sources (Table 7) [102,103]:

**Table 7.** Avoided CO<sub>2</sub> emissions to the atmosphere.

Fuel Type	Calorific Value MJ/kg	CO <sub>2</sub> Emission Factors kg CO <sub>2</sub> /GJ	Avoid CO <sub>2</sub> Emissions to the Atmosphere Mg CO <sub>2</sub>
Coal	21.42	93.74	170.70
Lignite	8.99	110.55	201.31
Hard coal briquettes	20.7	97.5	177.55
Brown coal briquettes	20.7	97.5	177.55
Petroleum	42.3	73.3	133.48
Firewood and wood waste	15.6	112	203.96
biogas	50.4	54.6	99.43
Industrial waste	10	91.7	166.99
Municipal waste—biogenic	11.6	100	182.10
Other oil products	40.2	73.3	133.48
Coke and semi-coke (including gas)	28.2	107	194.85
Liquid gas	47.3	63.1	114.91
Motor gasoline	44.3	69.3	126.20
Gasoline	44.3	70	127.47
Diesel fuel (including light heating oil)	43	74.1	134.94
Heating oils	40.4	77.4	140.95
Semi-finished products of crude oil processing	44.8	73.3	133.48
Refinery gas	49.5	57.6	104.89
Coke oven gas	38.7	44.4	80.85

In addition, the use of a heat recovery installation avoids other emissions to the atmosphere when burning fuel or obtaining energy from (Table 8):

**Table 8.** Avoided SO<sub>x</sub> (Sulphur Oxides) and NO<sub>x</sub> (Nitrogen Oxides) emissions to the atmosphere.

Fuel Type	SO <sub>x</sub> Emission Factors kg SO <sub>x</sub> /GJ	Avoided SO <sub>x</sub> Emissions to the Atmosphere Mg SO <sub>x</sub>	NO <sub>x</sub> Emission Factors kg NO <sub>x</sub> /GJ	Avoid NO <sub>x</sub> Emissions to the Atmosphere Mg NO <sub>x</sub>
Coal	820	1483.24	209	380.6
Lignite	247	449.79	1680	3059.33
Firewood and wood waste	10.8	19.67	81	147.5
Heating oils	485	883.2	142	258.59

#### 4. Discussion and Research Limitations

The manuscript analyzes variants of potential systems for freshwater heating and sewage heat recovery. Based on the financial possibilities and available technologies, a variant based on the AquaCond heat recovery unit was selected. The amount of heat saved in a sports facility during the analyzed period was the basis for calculating the annual avoided emissions of CO<sub>2</sub>, SO<sub>x</sub>, and NO<sub>x</sub> to the atmosphere when burning fuel or obtaining energy from various sources.

The analyzed sports facility is an urban facility. In accordance with the legal regulations in force in Poland, this type of facility does not and cannot generate any income from the investment, it is a budgetary unit (DNR = 0, DNR—Discounted Net Revenue), the energy produced as a result of the investment is used exclusively for the facility [104,105].

The concept analyzed in the manuscript is based on the synergy of technological solutions. The authors' assumption was to select possible solutions as a function of financial constraints aimed at increasing energy savings in the sports facility under analysis. The basic concept is based on the recovery of heat from rinse water. Next, the system will be supplemented with a solar kit and modern ventilation systems. Thanks to the modularity of these technologies and their universality, it is possible to build larger investment projects from them.

Sustainable energy policy is most often implemented through the use of renewable energy sources such as solar, wind, and ground energy. The disadvantage of devices such as solar collectors, photovoltaic panels, or wind turbines is that their efficiency depends on changing climate conditions. This disadvantage is not present in the equipment for recovery of waste heat from wastewater generated daily in residential, commercial, or industrial buildings.

Energy in the form of heat, which is generated by other processes and which is not received and used (energy lost irreversibly) is called waste heat. One effective example of its development is cogeneration. In Poland, energy efficiency is about three times lower than in Western European countries [106]. The need to save energy is an impetus for the use of renewable energy sources and the recovery of waste heat is a response. The problem of using waste heat is very important because many of its sources are unused. New, more efficient, effective, and economical solutions are being sought. The criterion for selecting the method of heat recovery always depends on the specificity of the facility, its geographical location, and investment opportunities. Equally important is the architecture and structure of the building, which should be characterized by low heat losses in the cold period and heat gains in the warm period. There are installations using waste heat from car engines, waste heat from air conditioning, heat from server rooms, waste heat from industry, waste heat from sewage treatment plants, waste heat from the sun. Nevertheless, there are still obstacles to the development of waste heat recovery technologies. Strategically, the fact that the heat used cannot be transported over long distances limits where waste heat can be used.

The recovery of waste heat from sewage in internal sewage systems of buildings requires a dual system in which black sewage will be discharged directly into the external network, while grey sewage, mainly from the shower, bath, washbasin, and sink, will be directed to the heat recovery system. This is due to the fact that grey wastewater is much less polluted than black wastewater and has a relatively high temperature of 30–35 °C. This allows for their use as an energy source. The energy recovered from wastewater is mainly used to preheat water. Suitable devices such as heat exchangers and heat pumps are used for this purpose.

Energy savings in swimming pool facilities can be achieved not only by using high-performance equipment but also by using equipment to recover heat from rinsing water, exhaust air, or renewable energy. In swimming pool facilities used year-round, it is difficult to talk about a complete replacement of conventional heat sources by renewable energy systems. Swimming pool water heating requires careful selection of the system to achieve the highest possible thermal comfort expected by the users and the purpose of the pool, with the lowest possible operating costs. For comfort of use and stable pool water temperature, an air-to-water heat pump can be an advantageous solution. Independently

from the sun, it ensures any long working time and thus reaching the required pool water temperature. The solar system will ensure low operating costs.

Comparative calculation analyses can be carried out on the basis of comparative variants or adopted design assumptions. Calculation tools are available (e.g., Menerga Designer server), which enable the design of complete systems e.g., air conditioning for averaged weather conditions for temperature:  $-20, -15, -10, -5, 0, 5, 10, 15, 20, 25, 30$  °C [107].

In the case of the object analyzed in the manuscript, the investment return time is about 3 years or in the case of a sewage heat recovery system only with a recuperator, with assumed parameters about 5 years. Of course, other, perhaps more effective solutions can be proposed. Nevertheless, the authors focused on their chosen solution, which will be enriched in the near future with additional energy-saving schemes (an agreement to support investments from European Union funds was signed). These reflections will be the subject of future authors' manuscripts.

The concept presented in the manuscript will be complemented by a solar kit for the energy purposes of pool water heating, technological water, shower water, and domestic hot water. For modernization, a system of flat-plate solar collectors will be used (Vitosol 200-F type SH2 collectors with min. 83%) (Viessmann, Allendorf, Germany) together with all additional equipment (e.g., circulation pump, regulator, expansion vessel, insulated pipes, collector fixing structure) with a  $6 \times 1000$  L hot water tank [108]. The priority of the system will be domestic hot water, the installed solar power is to be 422 kW. From the analysis of domestic hot water preparation in the solar system in the sports facility under analysis, it can be seen that solar collectors are a rational way of obtaining energy for domestic hot water preparation, but the condition for the profitability of the investment will be obtaining financial support from external sources.

In addition, due to the poor technical condition of the existing supply and exhaust ventilation systems, the units will be completely replaced with new units with high energy efficiency of heat recovery with recuperators at the level of min 85%. The current units have a declared heat recovery of 40% (cross-exchanger with metal membranes). For office and technical premises, a variant with central air conditioning and local Fan-Coil Units (FCU) (three ventilation systems) is planned [109]. This made it possible to divide air-conditioned rooms by function and to share the operating costs of potential users.

The system serving such rooms as entrance hall, administration, cloakroom hall and hanging cloakroom, hall with staircase, main hall, corridor, rental room, and others is to be equipped with the supply and exhaust air handling unit with heat recovery on a highly efficient rotary heat exchanger VS-180-R-PHC (Ventus, Opole, Poland) with supply and exhaust air capacity  $V_{n/w} = 18,000/19,100$  m<sup>3</sup>/h. The system serving the water treatment room, a hypochlorite warehouse, is to be equipped with the supply air handling unit VS-30-R-H and extract air handling unit VS-30-R-V with supply and extract air capacity  $V_{n/w} = 3600 \times 2F; 3200$  m<sup>3</sup>/h. The third system serving the men's cloakroom, the women's cloakroom, is to cooperate with the supply and exhaust air handling unit with heat recovery on the VS55-R-PH cross-exchanger with supply and exhaust air capacity  $V_{n/w} = 4850/5335$  m<sup>3</sup>/h. For the above-mentioned ventilation systems an air handling unit with the cooling capacity of 110 kW is to be installed—KOMPAKT ZR250x2 R407C/73AG unit [110].

The air handling unit ensures proper temperatures and humidity in the pool hall and in the wet areas of the swimming pool in each period of the year. It is also important that the heat recovered from the air in the pool hall, including the heat of evaporation of the pool water, will be directed to the place where there is demand in each period of the year. This place is used to heat swimming pool water and drinking water.

The calculations included in the manuscript were made on the basis of information provided by the investor. The costs of the main elements of the analyzed system were also verified on the basis of documents available on the Internet on the implementation of energy investment audits. The investor did not agree to include in the manuscript detailed information on the plans of the sports facility, hydraulic schematics, and photographs taken on the facility.

## 5. Conclusions

In the manuscript, the authors proposed the use of a system for recovering heat from sewage discharged from showers and rinsing water from filters in a city sports facility. All the project objectives related to the reduction of harmful gases and dust emissions into the atmosphere, increasing the energy balance of the facility through the use of renewable energy have been achieved. On the basis of studies, analyses and discussions on design limitations of heat recovery installations in an urban sports facility, conclusions were drawn and recommendations for the future were formulated. The manuscript presents future directions of work on increasing energy savings that can be applied in the analyzed sports facility.

### 5.1. Implications

The plant for heat recovery from the rinsing wastewater located in the Municipal Sports Center is not a fairly popular device but it has been ideally designed for this type of processes:

- Analysis of the heat recovery, realized due to transfer of heat to the fresh municipal water coming to the facility taken away from the wasted water intended for sewage discharge, shows that it is a good solution for this type of facility from both the ecological and economical side.
- Heat recovery central units should be connected in places where hot utility water in large quantities is necessary for the functioning of the facility, e.g., swimming pools, laundries. New devices, which were created for renewable energy sources in recent years have been quite dynamically developed and more and more are being used. The proposed solution has contributed to reducing the demand for energy produced from conventional sources (1821.0318 GJ the amount of heat saved by the Municipal Sports Center in 2018) and to reducing the costs of media consumption at the Municipal Sports Center (costs incurred on gas bills per year by 67196.07 PLN). This is a substantial amount of saved energy within one facility. Consideration of the global scale gives large amount of energy that can be saved.
- Renewable energy is a non-expensive source of electricity as well as heat, and with relatively short payback times and low operating costs, it is a growing and significant competitor to conventional energy sources. The rate of return on costs incurred for the construction of a heat recovery center for the proposed investment is 3.2 years.
- The applied solution assured reducing emissions of harmful gases and liquids released into the atmosphere.
- Introduced technology is the first step that can be followed by computerized synchronization of time dependencies of the processes of energy generation from alternative sources (thermal solar and PV) with recovery from sewage, assuring sustainable activity of the whole system.
- The work indicates that substantial energy savings shown in the studies substantiate the statement that wider application of such installations in other similar facilities will provide a huge impact if realized in a countrywide or global scale. This impact is related to both: the amounts of energy recovered as well as economic savings.

### 5.2. Further Development

One of the classical approaches to the theory of management is Kaizen [111] realized by stepwise improvement of the processes and technologies being used.

The case study performed on the sports facility shows the following. The main characteristic of the energy consumption in such a facility is time-dependent periodic alternation of consumption and recovery of some amount of energy. Such a system seems to fit nicely to the idea of integration with e.g., photovoltaic electricity generation and eventually solar thermal collectors. Intelligent coupling into a smart energy system together with computer control would provide good synchronization of time-dependent functions of demand for energy and its generation, and therefore assure sustainability of the solution. The results also show that the amount of recovered energy is substantial, and brings

also substantial economic benefits. Both energetic as well as economic advantages estimated for individual facility indicate feasibility of similar investments to be done in other similar facilities. Such investment made in a country scale would have an important impact on a countrywide scale, and moreover on the global scale. The present studies also indicate perspectives for further improvements through more and more intelligent solutions.

Modern swimming pools and their equipment are part of a technological revolution. There are a number of smart solutions that can be used, for example, to connect the pool with a mobile application for monitoring pool water quality (Insta-Link Home), control the safety of professional swimmers and children in the pool (The Seal Swim Monitoring, The Pool Guard Alarm System) [112].

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