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Opportunities and Threats of Implementing Drain Water Heat Recovery Units in Poland

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Abstract: In recent years an increase of interest in usage of renewable energy sources as a substitution of fossil fuels is being noticeable. However, the waste heat potential, which can be used as an additional source of energy for heating water in buildings, is being omitted. The sources of this heat can be grey water discharged from such sanitary facilities as showers or washing machines. In response to this issue, we took on the task to define and analyze key factors affecting the development of DWHR (Drain Water Heat Recovery) systems using PESTLE (political, economic, social, technological, legal and environmental) analysis. The strengths and weaknesses of these systems were also identified. The studies were based on CFD (computational fluid dynamics) modeling tools. In the Autodesk Simulation CFD software environment, a DWHR unit was made, which was then analyzed for heat exchange efficiency. The obtained results were the basis for preparing the strategy for the development of Drain Water Heat Recovery systems. It was made using the SWOT/TOWS (strengths, weaknesses, opportunities and threats/threats, opportunities, weaknesses and strengths) method, which precisely orders information and allows presenting the project characteristic in readable way for a recipient. The results of the conducted analysis indicated the lack of acceptance on the part of potential users and the resulting need to promote the use of Drain Water Heat Recovery systems at residential level.

Keywords: CFD (computational fluid dynamics); drain water heat recovery; DWHR (Drain Water Heat Recovery) heat exchanger; PESTLE (political, economic, social, technological, legal and environmental) analysis; shower water; SWOT/TOWS (strengths, weaknesses, opportunities and threats/threats, opportunities, weaknesses and strengths) analysis

1. Introduction

A growing interest in the use of non-conventional sources of energy, which has been observed in recent years, is a natural consequence of both increased demand for energy, and the development of environmental awareness in terms of protecting environmental resources [1–3]. Research conducted in Germany has shown that a high level of knowledge about the possibility of using heating facilities that use renewable energy sources is one of the key determinants of their implementation in residential buildings [4]. The theory about a significant influence of environmental awareness of inhabitants on their perception of the energy efficiency of buildings is also confirmed by the results of research carried out in England [5]. In turn, Yaqoot et al. [6] pointed out that the lack of awareness is one of the main barriers to the development of decentralized systems based on renewable energy sources. The benefits of systematic education and promoting sustainable solutions of energy economy among the inhabitants of our planet are clear, especially since the increase in the share of renewable and waste energy in the total balance of energy can contribute to improving the energy security of the country [7], to the reduction of emissions from harmful substances into the atmosphere [8], and reduction of the risk of illnesses resulting from environmental pollution and climate change [9].

Despite growing public awareness and knowledge regarding issues related to sustainable energy, many countries still base their energy economy on fossil raw materials. Poland is an example of such a country, where the conventional sources of energy, mainly coal and lignite, cover more than 80% of total energy demand [10]. The consequence of such an approach is deteriorating geological conditions related to mining of fossil fuels and excessive emissions to the atmosphere of the products of fuel combustion, particularly carbon dioxide [11].

Buildings are particularly dependent on the availability of natural resources [12,13]. According to previously published data [14], it is estimated that the total energy consumption in residential and commercial buildings accounts for over 20% of global demand. For Poland, this participation is much higher than the world average, as the households themselves are responsible for the consumption of approximately 30% of the final energy [15]. Thus, the important issue is to enable the implementation of environmentally friendly energy systems intended for use by individual customers and promote their further development.

Creating a balanced approach to the problem of choosing an energy supply system in a building requires a comprehensive knowledge of the possibilities of alternative heat sources [16]. For this reason, the attention is focused on renewable energy sources, which include inter alia, solar energy [17], wind energy [18], and geothermal energy [19]. However, the significance of waste heat is marginalized, which means that most of it is unproductively discharged to the environment and lost for good.

A source of waste-to-energy that can successfully be used in buildings is wastewater [20,21]. The current development of technology allows recovery of heat deposited in wastewater both during transport and disposal, as well as directly at source [22,23]. Grey water discharged from sanitary facilities has a relatively high temperature, which in the case of showering oscillates at 35–40 °C. This allows the recovery of the heat deposited in them both by means of Drain Water Heat Recovery (DWHR) units [24] and using the heat pump [25]. The choice of the first of the presented methods of heat recovery is particularly recommended if the energy source is provided by drain water from the shower, because this sanitary facility is characterized by the simultaneity of water intake and wastewater discharge. This allows recovery of the heat contained in drain water to preheat water used at the same time without the supply of additional energy driving the DWHR unit [26]. It should also be noted that energy consumption for showering in residential buildings may even exceed 60% of water-related energy use [27]. The result is that by using a suitable heat exchanger both the amount of energy used for the preparation of hot water, as well as costs incurred for this energy are reduced [28].

The variety of devices dedicated to the recovery of energy contained in the wastewater allows their use in virtually any situation. However, there are no projects promoting this form of energy saving, making DWHR units unpopular among potential users and investors. Meanwhile, as indicated by Kretschmer et al. [29], raising awareness is crucial for the better identification of opportunities for utilizing wastewater for energy purposes. Moreover, in many cases, the supply of these devices on the market is not sufficient, which further impedes the expansion of drain heat recovery systems.

The above problems also occur in Poland, consequently wastewater heat recovery systems are applied very rarely. There is also no detailed analysis of the rationality of using DWHR units in residential buildings, and the scope of the published papers is limited to financial analysis [30,31].

In order to increase the degree of acceptance for heat recovery from drain water discharged from the shower, as well as the degree of their implementation in residential buildings, the article presents the strengths and weaknesses of such a solution. These factors are defined based on the computational fluid dynamics (CFD) model of the DWHR heat exchanger, which allows visualization of heat flow in the device. The model created constitutes a basis for evaluating the efficiency of heat exchange in the first phase of the effluent from the shower. In addition, we describe the potential opportunities and threats arising from the operation of heat recovery systems from waste water in residential buildings, and set a strategy for their development. As a tool, PESTLE (political, economic, social, technological, legal and environmental) and SWOT/TOWS (strengths, weaknesses, opportunities and threats/threats, opportunities, weaknesses and strengths) analyses were applied to organize accurately information and present them in a clear way to the recipient.

2. Materials and Methods

2.1. Identification of Key Factors Using PESTLE Analysis

During the study, factors of key importance for the development of DWHR systems were identified. To this end, PESTLE analysis (Figure 1) was used, which is classified as a foresight study, and enables a context to be formed for further studies [32]. PESTLE facilitates identification and classification of external factors impacting the study subject into political, economic, social, technological, legal, and environmental issues. It is employed in many industries, including power engineering. For example, some papers present the results of studies concerning sustainable growth of renewable energy [33,34], while some analyses concerned waste incineration for energy production [35].

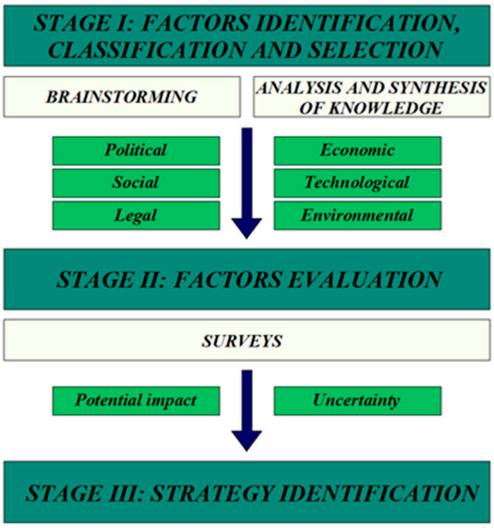

Figure 1. Research plan of PESTLE (political, economic, social, technological, legal and environmental) analysis.

The first stage of the analysis consisted of identifying factors that impact the development of DWHR systems and in the classification of these factors into six categories. The stage was based on a brainstorming approach following the analysis and synthesis of knowledge within an expert team. Subsequently, on the basis of guidelines identified in Reference [36], three factors of the highest importance for the development of the analyzed systems were identified in each group. Surveys were developed to assess the impact and uncertainty of each of these factors by the expert team, which comprised representatives of academic staff and contractors and exploiters of sanitary installations in building. The surveys were based on the 7-point Likert scale. The Impact/Uncertainty grid [37] was constructed on the basis of survey outcomes. The analysis of the grid facilitated identification of factors that are of the highest importance for the development of Drain Water Heat Recovery systems as well as the key areas of uncertainty.

Table 1 lists the most important factors, which are present in the system's environment. Political factors that affect the spread of DWHR systems include the sustainable development principle implementation strategy, as proper energy management is decidedly beyond the scope of care for fossil energy resource reserves. Waste energy recovery systems designed in keeping with these principles are considered one of the essential tools for combating the consequences of climate change [38]. A suitable support strategy for DWHR systems can also contribute to their growth, as political decisions and increased awareness of the relevant bodies may significantly alter the approach to the issue of responsibility for the natural environment [39]. Promoting the use of drain water heat recovery systems at different administrative levels in the country is materially important as well. However, particular attention should be paid to local governments, as it is at the city level that there is a possibility to apply the greatest number of programs dedicated to promoting sustainable solutions, such as financial subsidies.

Table 1. Factors taken into account in a PESTLE (political, economic, social, technological, legal and environmental) analysis.

P	Political
P_1	Strategy for implementing sustainable development principles
P_2	Strategy for supporting innovative solutions in energy management
P_3	Promoting the use of DWHR systems at a local government level
Ec	**Economic**
Ec_1	Capital expenditure levels
Ec_2	Public financing level and availability of other funds for building DWHR systems
Ec_3	Level of financial benefits stemming from the use of DWHR systems
S	**Social**
S_1	Society's inclination to using pro-environmental solutions in internal installations
S_2	Level of social acceptance of DWHR systems
S_3	DWHR system user safety and comfort levels
T	**Technological**
T_1	Supply of systems dedicated for heat recovery from drain water
T_2	Failure frequency and required maintenance frequency of DWHR systems
T_3	Experience in operating DWHR systems
L	**Legal**
L_1	Scope of requirements concerning the environmental impact of heating installations
L_2	Consistency and stability of legal regulations concerning waste energy use
L_3	Preferences concerning the use of sustainable technologies in public procurement
En	**Environmental**
En_1	Fossil energy resource reserves
En_2	Atmospheric air quality
En_3	Ability to reduce fossil fuel consumption and greenhouse gas emissions

The economic factors group, on the other hand, includes the capital expenditures incurred when applying DWHR systems. The price criterion is vital when selecting an energy source [40]. Expansion of these systems is also affected by the ability to gain financial benefits, which-as studies show [30] depend on a number of parameters related to the type of exchanger used and installation performance. Furthermore, the use of unconventional energy sources can also be supported by appropriate subsidies. In the case of Poland, emphasis is on renewable energy sources; however, with waste energy management marginalized, drain water heat recovery systems remain not in widespread use.

Another group of factors taken into account in the analysis are social factors. These include the level of social acceptance of unconventional solutions, which—as noted by Schumacher et al. [41]—depend on the type of energy source, previous experiences, etc. Society's inclination to use innovative solutions in internal building installations is also important. Their success is conditional on the society's readiness to be involved in the process of their implementation. The level of the warm-water preparation system user safety and comfort should also be considered. Roux et al. [42] noted that, regardless of the need to reduce water heating costs, consumers want to have guaranteed stable access to warm water. Cholewa et al. [43], on the other hand, emphasized the need to seek solutions that not only enable the reduction of energy consumption, but are also quick to install.

Technological factors include the supply of systems dedicated to heat recovery from drain water. Limited number of available models of DWHR units in the Polish market causes a need to search for suitable facilities outside the borders of our country, which does not encourage their purchase. The possibility of excessive contamination of the surface of the heat exchanger is materially important as well. Creation of a thin layer of biofilm on the surface of the internal pipe leads to the intensification of the heat transfer from drain water to the heating water [44] but too much impurities on these devices may decrease their effectiveness. An additional barrier to the expansion of DWHR systems includes the potential lack of experience in operating them. Although the idea of using deposited heat in the wastewater is becoming increasingly common among exploiters of sewer systems, among individual energy users a way of obtaining it still raises many controversies. The consequence of a critical approach to the use of grey water to preheat the water is the lack of interest in DWHR systems, which causes that conventional fuels are a dominant way to prepare hot water for residential use.

The situation is not improved by the lack of any norms and regulations on the use of heat recovery systems from wastewater. Emphasis is placed on using renewable energy sources, while the potential of waste energy is ignored, especially at the level of individual households. As a consequence, the current legal regulations in Poland do not provide complete protection against the dangers arising from improper energy management. This issue is compounded by the necessity to recover energy from waste water not being considered at the public procurement level. This system is an important element of the state environmental protection policy due to the substantial role that public funds play in the economy.

The last group is comprised of environmental factors, which include fossil fuel reserves and the quality of atmospheric air. As is commonly known, fossil fuel reserves are not infinite, and their combustion results in material degradation of the natural environment. For this reason, it is necessary to use technologies that enable this process to be reduced, which also include waste water heat recovery technology.

2.2. *SWOT/TOWS Analysis of DWHR Systems*

SWOT analysis (strengths, weaknesses, opportunities and threats) is considered to be one of the strategic planning methods. It is commonly used to define development strategies of organizations and companies, but sometimes it is also used to assess people or investment projects [45]. It can also be used to evaluate power engineering investments. For example, Igliński et al. [46] used it to evaluate the opportunities of developing the wind energy sector in Poland. On the other hand, Kordana [47] focused on systems for energy recovery from drain water transported through sewage collector pipes.

The SWOT method systemizes information on the subject of research in four specific groups, and identifies the relationships between the elements assigned to each group. Strengths and weaknesses of the project assessed are classified as internal factors, while opportunities and threats—as external ones. Strengths (advantages) allow seizing new opportunities and overcoming potential threats. In turn, the weaknesses (disadvantages) heighten the risks and prevent achieving benefits from a favorable development opportunities [48].

On the other hand the TOWS analysis is a development and complement of SWOT analysis. In contrast to the basic method, which involves the study of interaction in the direction from the inside to the outside, TOWS analysis can assess whether the identified opportunities are able to enhance the benefits and reduce disadvantages and whether the potential threats will exacerbate the drawbacks and weaken the advantages [49].

SWOT/TOWS analysis, which was performed in this study, was carried out in accordance with the procedure shown in Figure 2. A particularly important step was an identification of factors, which are based more on the PESTLE analysis results, and the analysis and synthesis of the knowledge, but it was also supplemented by own findings from studies of a heat exchanger functioning. These studies were performed using the CFD software.

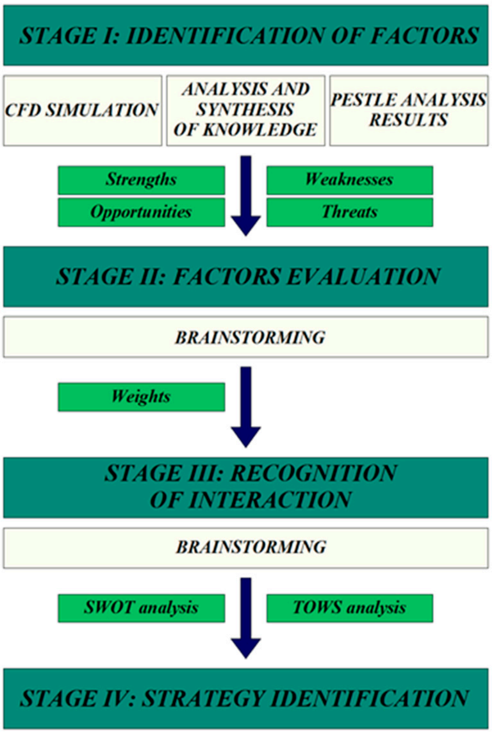

Figure 2. Research plan of SWOT/TOWS (strengths, weaknesses, opportunities and threats/threats, opportunities, weaknesses and strengths) analysis.

CFD modeling (computational fluid dynamics) is a computer method, which helps to analyze and solve problems connected with the flow of liquids and gases. Its calculation possibilities use the equations of fluid and heat flow and require a discretization of model research objects, since it is based on the finite element method [50].

CFD analysis has been used successfully for modeling of industrial processes as it allows the mapping of the phenomena occurring during the flow and heat transfer [51]. The procedure for the CFD analysis is based on the following stages:

- Provision of a simplified geometric model of the analyzed object, which is related to the flow of heat or liquid,
- Digitization of the geometric model,
- Determination of initial and boundary conditions,
- Solution of the model equations, and
- Visualization, validation and verification of the results.

A significant barrier in widespread use of this tool was the need to dispose of computational tools for high computing performance. An increase availability observed in recent years has resulted in a growth in interest in the use of CFD techniques. Following this, a number of computer programs were developed, which allow a complete calculation of the flow dynamics of the liquid.

For the purpose of this study, the Autodesk CFD was applied. A geometric model of the DWHR heat exchanger (Figure 3) of the parameters listed in Table 2 has been implemented into the software environment. In the examined object there were separated two spaces for the fluid volume. The first one is the flow of grey water, while the second is the flow of water. The two spaces are separated by a structural part (solid) as a copper pipe. An outer casing of a heat exchanger, which allowed us to obtain a water jacket for water, is a PVC (polyvinyl chloride) pipe.

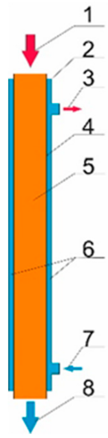

Figure 3. Model of the heat exchanger: 1, drain water input; 2, outer PVC (polyvinyl chloride) pipe; 3, outflow of heated water; 4, internal copper pipe; 5, inside of the vertical drain; 6, water jacket; 7, inflow of cold water; 8, outflow of drain water.

Table 2. Parameters of the analyzed DWHR (Drain Water Heat Recovery) unit.

Parameter	Unit	Value
Length of DWHR unit	mm	2000
Diameter for inner copper pipe (for the flow of grey water)	mm	50
Diameter of outer PVC pipe (for the flow of water)	mm	60
Diameter of cold water inlet connector	mm	15
Diameter of hot water outlet connector	mm	15

The geometric model was subjected to discretization using the built-in mesh sizing software tools, which by default creates a tetrahedral mesh. The model is divided into 1,154,043 elements.

The next step was to determine the initial and boundary conditions [52]. In the analysis, in terms of boundary conditions, the grey water inflow rate was 40 °C at 9 L/min and the same was the volume flow of cold water of 10 °C. The outflow of grey water from the heat exchanger was provided by setting the outlet pressure of 0 Pa.

In terms of initial conditions one assumed that the cold water temperature in the water jacket of the heat exchanger is 10 °C.

For the analysis the solver was applied which allowed calculations for free surface. The analysis allowed visualizing and verifying the efficiency of heat exchange in the first phase of the heat exchanger functioning.

3. Results and Discussion

3.1. Potential Impact and Uncertainty of DWHR Systems

In order to increase the environmental awareness of the public regarding the possibility of the use of heat recovery systems from drain water discharged from the shower, the average potential impact and uncertainty values of factors assigned to individual groups were determined (Figure 4). The orange line indicates the global average for all elements, while the green line indicates the average values within individual factor groups. As shown in the study, economic factors were found to play a key role in the development of DWHR systems as assessed by the expert team. The potential impact of these factors was estimated at 5.7 (Figure 4a). Social factors (5.2) and environmental factors (4.8) were also above the average value (4.4). The lowest importance was ascribed to legal factors (3.2). The differences were also observed in relation to the uncertainty of the elements (Figure 4b). The highest notes were ascribed to political (4.6) and social factors (4.4). Technological factors were judged most certain as evidenced by the uncertainty score of 3.0, with global average of 3.8.

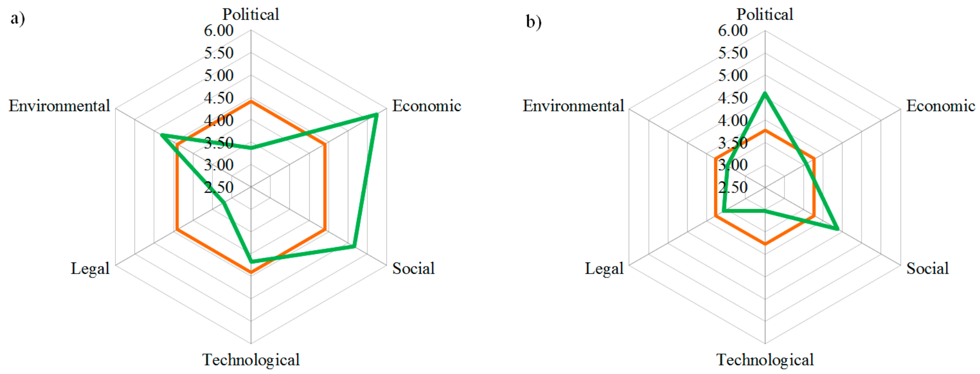

Figure 4. The averaged assessment of factors: (**a**) potential impact, and (**b**) uncertainty.

Figures 5 and 6 show the results of surveys regarding the potential impact of individual factors on the development of DWHR systems and their uncertainty within a time framework of the nearest 20 years. Grey horizontal lines illustrate the ranges of responses obtained for the factors, while green and red dots indicate arithmetic means. Red dots are used for factors with the highest scores within particular categories. Vertical orange lines show the global averages for all elements included in the study.

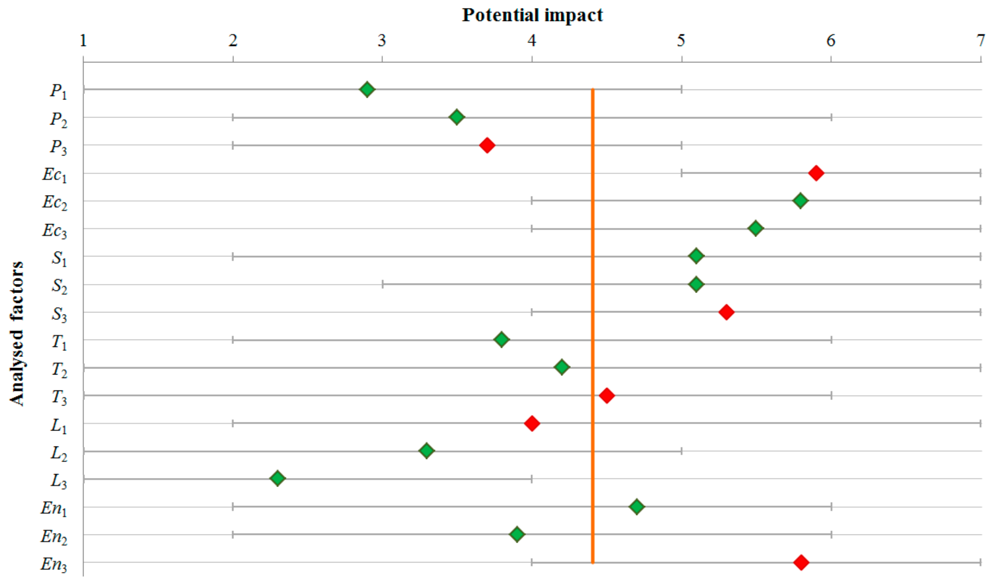

Figure 5. The results of surveys regarding the potential impact of the analyzed factors.

The highest potential impacts were ascribed to: Ec_1 (capital expenditure levels), Ec_2 (public financing level and availability of other funds for building DWHR systems), En_3 (ability to reduce fossil fuel consumption and greenhouse gas emissions). The average scores of these factors were above 5.8, and none of the experts considered them to be insignificant. The lowest scores (below 3.0) were ascribed to factors L_3 (preferences concerning the use of sustainable technologies in public procurement) and P_1 (strategy for implementing sustainable development principles). The latter, however, was characterized by the highest uncertainty score (5.7). The same score was also ascribed to the social factor S_2 (level of social acceptance of DWHR systems). The highest certainty was, in turn, ascribed to the technological factor T_1 (supply of systems dedicated for heat recovery from drain water), reflecting the broad scope of available solutions for DWHR systems. This diversity allowed us to choose the optimal solution taking into account the size of the installation, the efficiency of devices and their prices, as well as the availability of space for development of the system.

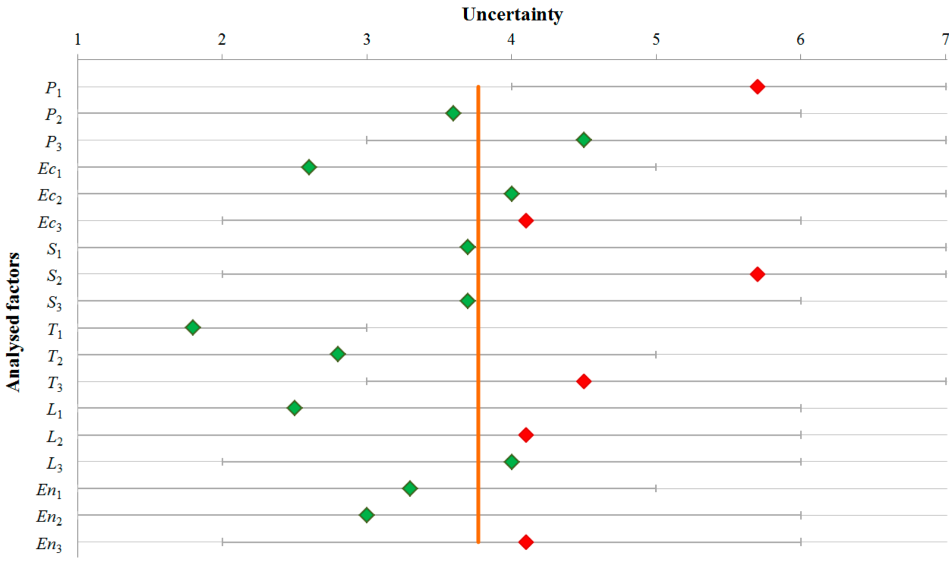

Figure 6. The results of surveys regarding the uncertainty of the analyzed factors.

The results of the impact and uncertainty surveys were placed within the Impact/Uncertainty Grid shown in Figure 7. The factors that are marked in red, including Ec_2 (public financing level and availability of other funds for building DWHR systems), Ec_3 (level of financial benefits stemming from the use of DWHR systems), En_3 (ability to reduce fossil fuel consumption and greenhouse gas emissions), T_3 (experience in operating DWHR systems), and S_2 (level of social acceptance of DWHR systems), are critical uncertainties. The remaining elements located above the horizontal line corresponding to the average global impact of factors may be considered predetermined elements as defined in [37]. Factors located below the horizontal line are secondary elements [37].

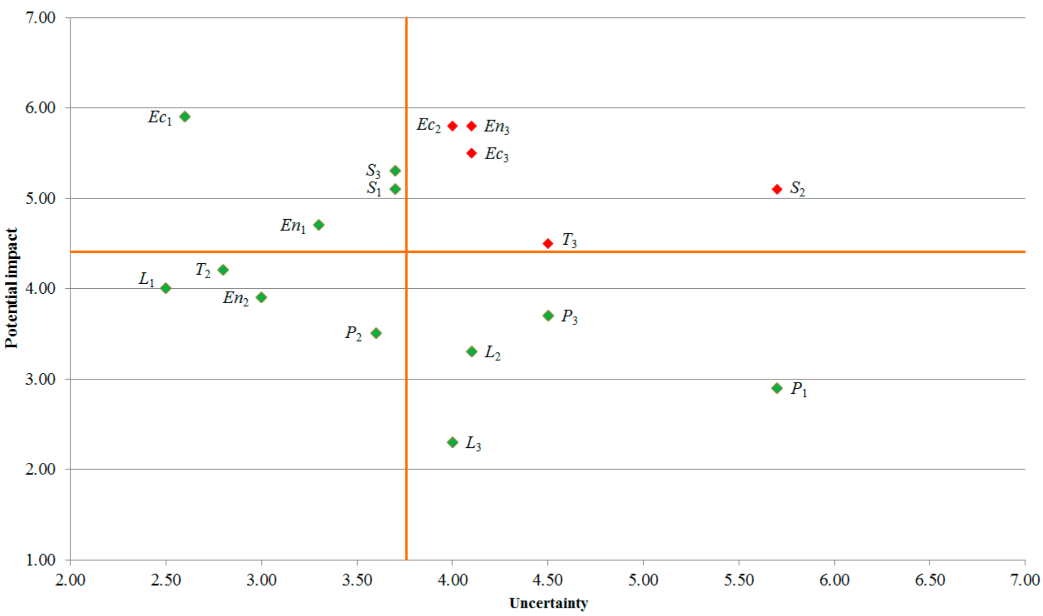

Figure 7. The Impact/Uncertainty Grid.

The analysis showed that factors that are often marginalized or completely neglected are of key importance for the development of Drain Water Heat Recovery systems. Although the importance of economic factors has been known for a long time, the importance of such factors as level of social acceptance of DWHR systems or experience in operating them is usually disregarded. These factors are considered at a later stage of the study.

3.2. SWOT/TOWS Analysis Results of DWHR Systems

In order to increase the environmental awareness of the public regarding the possibility of the use of heat recovery systems from grey water discharged from the shower, the SWOT analysis of such a solution was conducted. Table 3 lists the three most important factors describing the strengths and weaknesses of the systems under consideration, as well as the potential opportunities and threats associated with their implementation. On the basis of the opinion of the same expert team, there were assigned the following weights. They are included in the further part of the analysis, the results of which are described in this paper.

Table 3. SWOT (strengths, weaknesses, opportunities and threats) analysis of Drain Water Heat Recovery systems.

Strengths	Weight	Weaknesses	Weight
1. Low energy consumption for hot water heating	0.60	1. Dependence of the system efficiency on the flow and the temperature of the water and drain water	0.40
2. Independence of heat source from atmospheric conditions	0.30	2. The heat recovery delay relative to the start of taking a bath	0.20
3. Possibility of combined use of waste and renewable energy	0.10	3. Relatively high investment costs	0.40
Opportunities	**Weight**	**Threats**	**Weight**
1. Improvement of environment condition by reducing fossil fuel consumption and greenhouse gases emission	0.40	1. Unforeseen period of investment payback	0.30
2. Providing safe and comfortable operation of the system	0.30	2. Lack of acceptance on the part of potential users	0.50
3. Providing funding for environment-friendly internal installations	0.30	3. Lack of experience in operating DWHR systems and guidelines for their use	0.20

The strengths of heat recovery systems from grey water included the ability to clearly reduce consumption of fossil fuels in comparison to the situation when installations are operated conventionally. The application of DWHR units allows recovering about 30% to over 60% of the energy carried by wastewater [53]. The highest benefits are noticeable in the case of vertical heat exchangers, which have the largest surface area of heat exchange between the discharges of wastewater from the shower and heated water. This is due to the fact that the wastewater introduced into the vertical pipe does not fill the entire cross-section, but flows down the walls. This has been verified by performing simulations of fluid flow in the DWHR unit using the software for modeling fluid dynamics Autodesk Simulation CFD 2016. The results of the simulation are shown in Figure 8 where the space occupied by the flowing sewage has been marked in red.

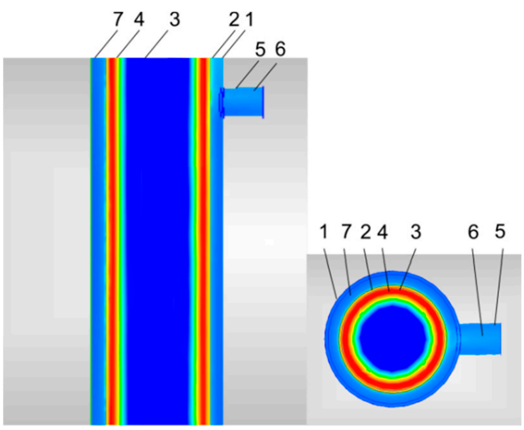

Figure 8. The visualization of water and drain water flow inside the DWHR (Drain Water Heat Recovery) unit obtained using CFD software: 1, outer PVC pipe; 2, internal copper pipe; 3, the interior of waste pipe; 4, drain water; 5, water outflow; 6, water; and 7, water jacket.

CFD analysis indicates a significant energy potential of grey water flowing through the heat exchanger. As part of the study conducted, the temperature on the outer plane of the copper pipe at a height of connecting the outlet of the heated water was determined. The temperatures obtained in the initial phase of the device operation are presented in Figure 9.

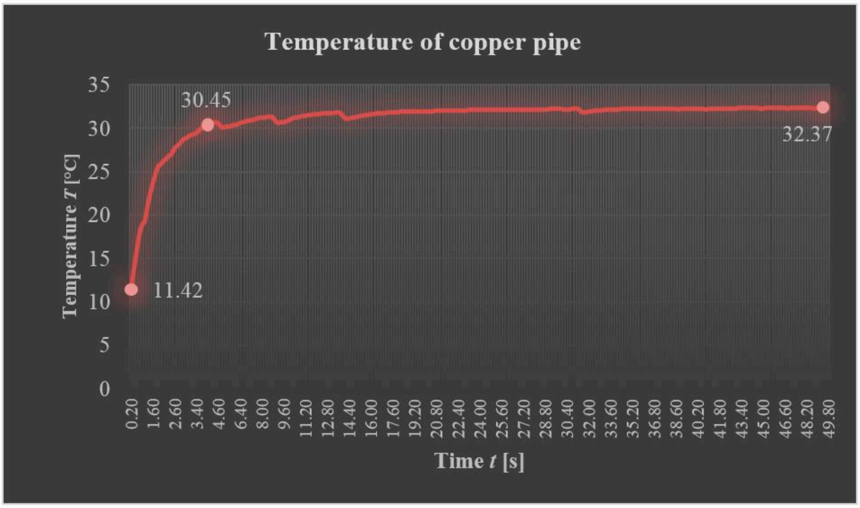

Figure 9. The temperature registered on the outside plane of copper pipe.

During analysis of the DWHR heat exchanger operation, it was observed that the temperature increase on the wall of the copper pipe at the point of contact with water took place in the first seconds of operation of the device. After ~4 seconds, this temperature exceeded 30 °C, and in a further simulation time it was followed by its stabilization.

Another strong point of the project is the fact that in contrast to renewable energy sources the availability of grey water is completely decoupled from the prevailing weather conditions. Preferences regarding the temperature of mixed water do not change throughout the whole year. As a result, fluctuations in temperature of grey water discharged to the sewer system are insignificant, which ensures stable operation of the system.

The final strength of the systems in question, which was included in the analysis, is a possibility to integrate heat recovery system from drain water with installation that uses renewable energy sources. For example, in [54] cooperation between a DWHR heat exchanger with solar collectors has been described. It is also noteworthy that the recovery of thermal energy contained in the grey water may be carried out together with its recycling [55].

The weaknesses of the DWHR systems include the dependence of the system efficiency, and consequently the costs of savings achieved, on the operating parameters of the installation such as the flow rate of mixed water from the tap and the usage time of water of the defined temperature. Meanwhile, wastewater outflow from the buildings (especially detached houses) is unpredictable and uneven [56]. Furthermore, the configuration of a heat recovery system is of great importance as it determines the share of the water flowing through the heat exchanger in its total energy consumption [57]. Accordingly, the clear identification of cost-effectiveness of such a system is not possible, which results in the need for the respective detailed analysis of technical and financial potential solutions.

A critical parameter for the heat exchange process in the heat exchanger is the velocity of water in the water jacket. The consequence of failure to obtain the water velocity ensuring a turbulent flow is the reduction of the possibility of waste energy recovery. This weakness of the project was also analyzed using the CFD modeling software. During observation of the hydraulic parameters of the model of the heat exchanger, it was noted that this velocity was correlated with the thickness of the water jacket. The greater layer thickness of water around the inner vertical, the lower water velocity.

Velocities of water in the heat exchanger discussed are summarized in Table 4.

Table 4. Velocities of water in the heat exchanger obtained in the course of CFD (computational fluid dynamics) analysis.

Location of Measuring Point	Unit	Velocity
Axis of the connector at the inlet to the heat exchanger	m/s	1.0
Centre of water jacket in the middle length of the heat exchanger	m/s	0.3
Axis of the outlet connector at the outlet of the heat exchanger	m/s	1.0

For the obtained hydraulic conditions of the flow of water and grey water, a graph was drawn which shows the change in temperature of heated water in the outlet connector. The registered temperature variation over time is presented in Figure 10.

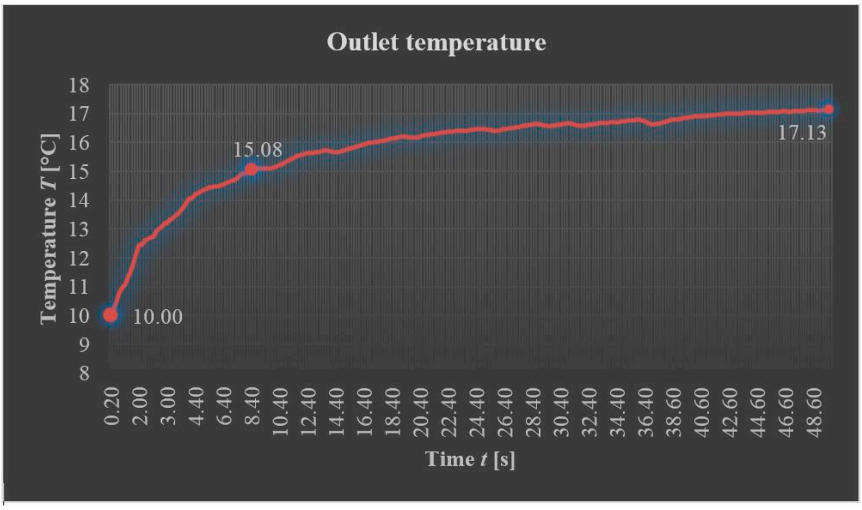

Figure 10. The temperature of heated water in the outlet connector of the heat exchanger.

During the analyzed period of time cold water was heated from 10 °C to 17.13 °C. The temperature rise of 7 °C obtained within 49 s is negligible, which is due to the low velocity of water in the water jacket, equal to about 0.3 m/s. In the present case, it would be advantageous to change the heat exchanger to another one, which is characterized by a smaller cross-sectional area of the water jacket. It would result in an increase in water velocity, and thus also give a greater degree of energy recovery. However, it is worth noticing that obtaining the velocity at the required level often requires the use of a water jacket of thickness of 2 mm or less, and making a device with such a high precision increases production costs significantly.

In addition, the attention should be paid to the fact that the shower length is not identical with the duration of heat recovery from drain water. Although the recovery of heat from grey water takes place in the first seconds of operation of the device, as shown in Figure 6, it should be noted that the water temperature at the outlet of the heat exchanger reaches the desired level only after 60–90 seconds [58]. Very often, this phenomenon is not taken into account in the analysis of the profitability of the use of these devices.

Objections from potential users are enhanced by the relatively high investment costs to be incurred for the purchase and installation of a suitable device. Depending on its design and efficiency, the cost of buying a heat exchanger designed for use in detached houses can vary widely from less than €450 to more than €700. In many cases, the price of the device, in addition to the cost of installation, does not include the cost of transport from another country.

In addition to internal factors, the article also examines external ones on the use of heat recovery from grey water discharged from the shower. Opportunities for DWHR systems include the possibility of improving the environment conditions associated with the reduction in demand for conventional fuels. As a result of the reduction of fossil fuels consumption, the emission of combustion products into the atmosphere is reduced as well. The use of Drain Water Heat Recovery systems will not solve the problem of the devastating impact of the energy sector on the environment on a global scale, however, it may be a small building block in building a sustainable energy policy.

The opportunity of a properly designed and constructed drain water heat recovery system is also its safe and convenient operation, as the DWHR units operate unattended and their construction prevents contact of waste water and heated water. In addition, reducing the difference in temperature of water at the inlet and outlet of the instantaneous water heater the heat exchanger operates with can increase the efficiency of water heating.

The reduction of energy used for the preparation of hot water is also accompanied by a clear reduction of costs for energy supplies in a building. The savings achieved are greater the higher the price of energy, which is why the use of the DWHR system will protect the family budget in case of a significant increase. However, this is an insufficient incentive for citizens. It is therefore vital to acquire an additional source of funding that would enable increasing the financial benefits gained.

The factors threatening the implementation of DWHR systems include, in turn, the inability to clearly identify the period of return on investment, because it depends on several factors such as the characteristics of the use of the shower installation or type of fuel used. For example, unexpected change of operated hot water heater from electric to gas will result in a significant reduction of achieved financial benefits in relation to the expected values.

Another threat for the analyzed systems is the lack of acceptance on the part of potential users, which is a natural consequence of insufficient knowledge about the rationality of the use of DWHR units and negligible experience in their using. In addition, the negative external factors include the lack of experience in operating DWHR systems and guidelines for their use.

In further research the occurrence of interaction between the elements assigned to groups of internal and external factors was analyzed. In order to ensure comprehensiveness and credibility of the study, the occurrence of interactions was tested both by SWOT and TOWS analysis. Based on the guidelines described in [59], eight subsidiary tables were developed, which determined the total number of interactions and the products of the interactions and the weights assigned to each factor. The combination of quadrants for which the highest sum of products was obtained determines the development strategy of DWHR systems. Products of weights and interaction, which were set for individual elements of the quadrants, also allowed the identification of factors with the highest importance. The results of analysis are summarized in Tables 5–7.

Table 5. The summary of SWOT analysis result.

Quadrant Combinations	SWOT Analysis Results	
	Sum of Interaction	Sum of Products
Strengths/Opportunities	**16/2**	**5.40**
Strengths/Threats	12/2	4.30
Weaknesses/Opportunities	12/2	4.10
Weaknesses/Threats	**16/2**	**5.40**

Table 6. The summary of TOWS analysis result.

Quadrant Combinations	TOWS Analysis Results	
	Sum of Interaction	Sum of Products
Strengths/Opportunities	12/2	3.90
Strengths/Threats	12/2	4.10
Weaknesses/Opportunities	10/2	3.10
Weaknesses/Threats	**18/2**	**6.00**

Table 7. The summary of SWOT/TOWS analysis result.

Quadrant Combinations	SWOT/TOWS Analysis Results	
	Sum of Interaction	Sum of Products
Strengths/Opportunities	28/2	9.30
Strengths/Threats	24/2	8.40
Weaknesses/Opportunities	22/2	7.20
Weaknesses/Threats	**34/2**	**11.40**

The results of the SWOT analysis ("from the inside to the outside") showed a significant advantage of the interaction occurring between the internal and external positive factors. This suggests that the DWHR systems have significant growth potential, and it is important to aim to maximize the use of favorable opportunities with the shares held by these systems strengths. However, the number of interactions occurring between the internal and external negative factors are the same. Furthermore, the results of the TOWS analysis ("from the outside to the inside") suggest that potential threats for grey water heat recovery systems heighten substantially the weaknesses of these systems. Therefore, one should try to reduce the impact of weaknesses and threats, the impact of which can prevent the expansion of the DWHR systems. In case of a comprehensive SWOT/TOWS analysis, the highest sum of products was also achieved for the combination of weaknesses and threats.

Products of weights and interactions designated in the following combinations, which were set for individual elements of the quadrant, also helped identify the factors that have the greatest impact on the analyzed systems. In the case of negative external factors the highest scores in each of the four lists were obtained for the threat associated with the lack of acceptance on the part of potential users. This confirms the need to promote sustainable management of the energy deposited in drain water, since the elimination of the negative attitude of the residents is the key to increasing utilization of DWHR systems. Systematic education and the promotion of sustainable technologies among the residents may lead to greater acceptance for unconventional solutions. Especially important in this regard is the ability to use computer tools that, based on an appropriate algorithm calculation, help to reflect the migration processes of heat. In addition, they allow the implementation of parameters the specific device would operate within, which can significantly increase confidence among potential recipients who themselves can assess the work of the device. The results described can be achieved, among others, using CFD modeling software.

4. Conclusions

The analysis results indicate a high susceptibility of the systems to the threat in external environment, among which the lack of acceptance on the part of potential users plays the dominant role. Weaknesses of DWHR units are also not without significance. They include, among others, the dependence of the system efficiency on the installation parameters.

The CFD analysis shows that the selection of a precise model of the heat exchanger is very important. The most important issue in this field was the thickness of the water jacket, which affects the water velocity in the heat exchanger. Using inappropriate devices results in considerable deterioration in the heat exchange process. In addition, studies show that it is advantageous to perform numerical analyzes, e.g., through the use of CFD tools, in order to validate the operation of the selected device. This allows the analysis of the liquid velocity and temperature distribution in the full cycle of operation of the heat exchanger.

The obtained results of the points to the need for further analysis, where the objective is to assess the effectiveness of drain water heat recovery systems. An important issue is also a need to promote the use of sustainable energy systems and to educate the public, as only such an approach will ensure the diversified development of a considered systems and an increase in the degree of their implementation in residential buildings.

In addition, attention should be paid to the fact that the obtained test results refer only to DWHR systems and rationality of their use in residential buildings. In the case of other wastewater heat recovery systems, as well as buildings for different purposes, for example, industrial facilities, the research results described in the article will not apply. In such a situation, the PESTLE/SWOT analysis can be used as a tool for assessing the system.

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