Experimental Study for the Analysis of the Potential Energy Conversion of Wastewater Discharged from Installations and Equipment’s of the Civil and Industrial Buildings

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Abstract. Even though the science and technology in the field of energy production for buildings has reached an advanced stage of development, there is still a considerable part of the population who do not have access to electricity. Currently, renewable energy (Solar, Wind, Geothermal, Hydro, Wave energy, Biogas), are considered sources that will meet future energy requirements, but have geographical limitations, are not available throughout the territory and are difficult to integrate into energy systems due to of the unpredictable character, their functioning being determined by the weather conditions. Also, the power and efficiency of renewable energy systems are still limited. Given that gravity (the fundamental forces of nature) is available everywhere, regardless of the climatic conditions, it represents an inexhaustible source of energy. In the context of apocalyptic scenarios or cyberattacks on energy systems, gravitational electrical systems can offer solutions for restoring electricity supply from simple to most complex solutions. The article explores the conversion of potential energy from wastewater of the technological processes, into electricity. The study was performed on an experimental stand designed to be connected to the drainage system of a water-to-water heat pump. The efficiency of potential energy conversion for applicability to wastewater discharging systems of equipping civil and industrial buildings was analysed.

1. Introduction
The use mode of energy in buildings has been one of the main topics in Europe with the implementation of the European Parliament's directive on the energy performance of buildings. Achieving the energy efficiency targets set for buildings requires that energy efficiency measures be implemented in the existing building stock [1-2]. The maximizing energy efficiency is one of the main priorities not only for buildings, but for all market sectors. Rising utility costs have recently led to innovations in the building services industry, and today there are many opportunities to use a variety of energy recovery solutions [3].

The energy recovery systems for heating, cooling and ventilation, which are well designed, are able to maintain the proper temperature and air quality of the building, while reducing energy losses.

On the other hand, it can be said that the main sources of heat loss in a building are the air discharged through the ventilation systems and the hot water discharged through the sewerage systems.
The temperature of the air and water discharged through these systems is often so low that it is difficult to use a passive heat recovery system and for these reasons, an active system using a heat pump is an interesting concept [1]. Wastewater discharged from technical systems that equip buildings, for example in the case analysed from a water-water heat pump, can be a source of energy by converting potential energy, as a measure of gravity, into electricity.

The world needs technologies that can generate clean and renewable energy, and especially those that are cheap to exploit.

A proven source of clean and renewable energy is the gravitational energy of water. It is known that water produces a large amount of energy, for example, in the form of hydroelectricity. However, the method of using the gravitational energy of water is not without limitations. Even though science and technology in the field of energy production for buildings has reached an advanced stage of development, there is still a considerable part of the population that does not have access to electricity.

Currently, renewable energy (Solar, Wind, Geothermal, Hydro, Wave Energy, Biogas) are considered sources that will meet future energy requirements, but have geographical limitations, are not available throughout the territory and are difficult to integrate into energy systems due to the unpredictable character, their operation being determined by the weather conditions. Also, the power and efficiency of renewable systems are still limited.

Given that gravity (the fundamental force of nature) is available everywhere regardless of the climatic conditions, it represents an inexhaustible source of energy. In the context of apocalyptic scenarios or cyber-attacks on energy systems, gravitational electrical systems can offer solutions for restoring electricity supply from simple to most complex solutions.

Starting from the operating principle of an elevator, whose constructive and functional principle have not exceptionally advanced since 1835, the experimental stand made for the study of electric gravity conversion analyses the conversion of potential energy as a measure of gravity into electrical energy.

Energy conservation in buildings is a major goal for energy policy at all levels. The conversion of gravitational energy into electricity, in present, is considered a major technical challenge [8-12].

2. Materials and Methods
The experimental installation was installed to highlight the possibility of recovering potential energy that is lost through the drainage system of water-water heat pumps.

The water-water heat pump "Termocasa" with a power of 8kW provides the necessary thermal energy for heating the "Energy Conversion" laboratory from Politechnica University of Timișoara. The water-water heat pump uses surface water from Bega channel as the primary energy source.

The experiments were performed at room temperature \( T_i = 25 \, ^\circ C \) and at a humidity of 70%. The functional diagram of the experimental installation and the components elements are shown in figure 1.
Figure 1. Functional diagram of the experimental installation and components: (a) Tank at Top Dead Center (TDC); (b) Tank at Bottom Dead Center (BDC)

1 - permanent magnet mounted inside the tank, 2 - actuating rod for closing the drain valve, 3 - actuating rod for opening the drain valve, 4 - damper spring, 5 - adjustable ferromagnetic plate, 6 - metal structure for gravitational system, 7 - permanent magnet for retaining the counterweight, 8 - inductive sensor, 9 - Gall chain.
After passing through the heat exchanger, the water is currently discharged back into the emissary. Figure 2 shows the heat pump, the gravitational installation, and the hydraulic connection between the two systems. The potential energy provided by the supply pump of the heat pump is practically lost once the water is discharged into the emissary. Water is pumped at a continuously regulated flow rate of 1.06 l/s.

![Figure 2. Water-water heat pump "Termocasa", 8kW](image)

The experimental installation consists of two gravity systems of tank-counterweight type. The two tanks are made of stainless steel with the shape of a rectangular prism with the dimensions 50 cm x 40 cm x 45 cm and a mass of 22 kg which kept are pendent at the top by a Gall chain (Figure 3).

![Figure 3. The experimental installation with gravity system of tank-counterweight type:](image)

(a) Waste water tanks; (b) Counterweight mechanism
Inside the tanks we inserted a permanent magnet with a breaking force of 100kg with the role of delaying the ascent of the tank until complete emptying. On the supporting metal structure (in the area of the tanks we mounted a ferromagnetic part with the help of which the magnetic force can be adjusted and implicitly the emptying time of the tank. The counterweights in the shape of a rectangular prism are made of carbon steel sheet, the fixed mass of the counterweights being set constructively at 60 kg (Figure 3 b). Under each counterweight we mounted a permanent magnet with a breaking force of 100kg in order to delay the lift up of the counterweight until the tank is completely filled. At the bottom of the tanks are mounted two ball valves that have the role of emptying the tanks when they reach the bottom dead center (BDC). Drain valves (DV) are mechanically operated (open) at the bottom dead center and close at the top dead center (TDC).

Both tanks are loaded with wastewater from the water-water heat pump. The drive of the tank-counterweight mechanism is due to the filling of the tanks, during which time it stores potential energy until the total filling.

At this point, the weight of the tank filled with wastewater is able to overcome the magnetic force and the weight force of the counterweight, so the stored potential energy sets the mechanism in motion, the tank descends raising the counterweight.

Once in the lower dead center, the tank empties, its potential energy becomes less than the potential counterweight energy, the tank rises to the upper dead center and the filling / emptying cycle resumes.

The translational movement, on a height of 2.5 m, is performed with the help of the Gall chain which operate, by means of a speed multiplier, a three-phase generator with permanent magnets.

The conversion of potential energy into electricity is performed with a three-phase generator with permanent magnets coupled to the gravitational system by means of the speed multiplier with chain wheels. Ignoring the frictional forces in the mechanical systems, the electric resistance force introduced by the electric generator regulates the movement speeds of the counterbalancing mechanism of the tank. The average descent speed is 0.25 m / s, and the ascent speed is 0.26 m / s.

The Arduino open-source software (IDE) made it easy to write and load the program into the ARDUINO data acquisition system (Figure 4).

![Figure 4. ARDUINO data acquisition system: (a) view, (b) wiring diagram](image)

The proximity sensors (marked with 9 in Figure 1), coupled to the data acquisition system, provide information on the status / position of the tank for one operating cycle.
3. Results and discussions

We determined experimentally the power generated according to the mass of the counterweight (mc), the type of load (resistor / accumulator) and the load resistance R for a time interval t corresponding to the ascent and descent times of the tank. During filling and emptying the tank, the experimental installation is at rest and does not produce energy.

For the evaluation of the maximum power, the variation of the power according to the load resistance was plotted graphically, as follows:

- keeping the mass of the counterweight constant at 65.7 kg (Figure 5);
- changing the mass of the counterweight from 65.7 kg to 74.9 kg (Figure 6);
- changing the type of load and the mass of the counterweight (Figure 7).

![Figure 5. P=P(R) with constant mc](image1)

![Figure 6. P=P(R) with variable mc](image2)
For certain values of the mass of the counterweight (mc) and of the load resistance (R), the descent and ascent times were registered and were calculated the average electric powers (P_{av,d} and P_{av,a}) and respectively the electric energy (E_d and E_a) corresponding to the descent and ascent cycles. The results are presented in Table 1.

Table 1. Recorded and calculated values

| mc [kg] | R [Ω] | t_d [s] | t_a [s] | P_{av,d} [W] | P_{av,a} [W] | E_d [J] | E_a [J] |
|--------|-------|---------|---------|--------------|--------------|---------|---------|
| 70.4   | 3.5   | 12      | 14      | 15.67        | 10.95        | 188.04  | 153.30  |
| 70.4   | 5.9   | 12      | 12      | 28.82        | 19.56        | 288.20  | 234.72  |
| 70.4   | 7.5   | 10      | 10      | 35.05        | 25.62        | 315.45  | 256.20  |
| 70.4   | 9.0   | 9       | 10      | 33.79        | 26.27        | 304.11  | 262.70  |
| 70.4   | 10.0  | 8       | 10      | 33.15        | 24.76        | 295.20  | 259.00  |
| 70.4   | 15.0  | 7       | 9       | 31.79        | 24.76        | 222.53  | 222.84  |
| 74.8   | 15.0  | 7       | 9       | 29.37        | 24.76        | 205.59  | 222.84  |
| 79.6   | 15.0  | 7       | 9       | 30.68        | 26.19        | 214.76  | 235.71  |
| 74.8   | 20.0  | 8       | 10      | 29.67        | 24.75        | 207.69  | 198.00  |
| 74.8   | Battery | 10     | 10      | 31.24        | 26.67        | 312.40  | 266.70  |
| 79.6   | Battery | 9      | 10      | 29.54        | 32.52        | 265.86  | 325.20  |

1 mc [kg] - counterweight mass, 2 R [Ω] – electrical resistance, 3 t_d [s] - descent time, 4 t_a [s] - ascent time, 5 P_{av,d} [W] – average power at deascent, 6 P_{av,a} [W] – average power at ascent, 7 E_d [J] – energy at descent, 8 E_a [J] – energy at ascent.

The variation of the electric power depending on the load resistance for the situation of maintaining a counterweight constant mass at 65.7 kg, shown in Figure 5, indicates that the power is maximum both when the tank descent and ascent for R = 7.5Ω. In the same representation it is observed that the descent and ascent speeds have an unequal variation, and the ascent time is longer than the descent time, which can be observed also in Table 1.

The difference between the maximum power generated at the tank descent and respectively ascent, is only 2.5W. It is observed that the power at the tank ascent has an increase towards the end of the stroke due to the accelerated motion of the system.
From Figure 6 it is observed that keeping the load resistance constant (R = 15Ω) and varying the mass of the counterweight, the power does not change significantly, instead when charging on the battery (Figure 7), the power increases when the tank up once with increasing the mass of the counterweight.

The overall efficiency during the descent \( \eta_d \) and ascent of the tank \( \eta_a \) was calculated as the ratio between the electricity generated by the experimental installation and the potential energy recovered from the heat pump exhaust circuit, according to relations (1) and (2).

\[
\eta_d = \frac{E_d}{(m_r + m_w) \cdot g \cdot H_r - m_c \cdot g \cdot H_c} \tag{1}
\]

\[
\eta_a = \frac{E_a}{m_c \cdot g \cdot H_c - m_r \cdot g \cdot H_r} \tag{2}
\]

where:
- \( m_r \) - mass of the tank [kg];
- \( m_c \) - mass of the counterweight [kg];
- \( m_w \) - water mass [kg];
- \( E_d \) - the electricity on the descent [J];
- \( E_a \) - the electricity on the ascent [J];
- \( g \) - gravitational acceleration [m/s²];
- \( H_r \) - tank stroke [m];
- \( H_c \) - counterweight stroke [m].

With the results obtained analytically, the variation of the yield was plotted according to:
- load resistance (Figure 8);
- counterweight mass (Figure 9);
- type of load (Figure 10).

**Figure 8.** Cycle efficiency as a function of load resistance (mc constant)
The overall efficiency for the descent phase of the tank is higher than for the ascent phase (Figure 8, Figure 9 and Figure 10).

When charging on the load resistance in the maximum power area, the efficiency is maximum (Figure 9). By changing the mass of the counterweight, the yield on the descent increases and decreases on the ascent (Figure 9).

In the case of battery charging, there is an increase in efficiency above the values recorded in the case of charging on loads resistance (Figure 10). In this case there is also an increase in power in ascent area of the tank (Figure 7).

4. Conclusions
Starting from the fact that any technical system discharges a certain fraction of the useful energy into the external environment, as lost energy, the experimental installation highlights ways of converting and storing energy. Experimental tests confirm that the system registers a maximum power for certain operating conditions (load resistance and counterweight), and the data obtained show that in the case of charging on a resistive load (Figure 5 and Figure 8), the maximum power is recorded for \( R = 7.5 \Omega \). The increase of the efficiency can be achieved by reducing the emptying times, respectively filling the
tanks, time in which the installation does not produce energy. The emptying time can be constructively reduced by increasing the flow sections. The filling time is dependent on the supply source (water discharged from the water-water heat pump) and therefore the efficiency increases depending on the size of the heat pump. For this reason, all urban settlements that have surface water sources (rivers, lakes) can adopt heating systems with water-water heat pumps with COP over 3.5. The energy lost by draining water from the primary circuit of heat pumps can be recovered by gravitational-electric conversion, either individually or coupled to several evacuation systems from heat pumps at a single conversion system of this type. These conversion systems are suitable for low heights, heights at which other gravitational systems (micro-hydro power) do not operate. The efficiency can be improved by changing the transmission ratio of the speed multiplier to which the electric generator is coupled. The experimental data obtained show that gravitational systems can become an alternative source of energy that uses as primary source wastewater from technical systems or rainwater, both free.

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References
[1] A. Kahraman, A. Çelebi, “Investigation of the Performance of a Heat Pump Using Waste Water as a Heat Source”, Energies, vol. 2, pp. 697-713, 2009.
[2] D. Tokar, A. Tokar, M. Adam, “Experimental stand for the study of energy conversion and storage”, Romanian Journal of Civil Engineering, vol. 3, pp. 245-253, 2020.
[3] Newport Partners LLC, “Innovative Building Technology Guide Selecting the Best Solutions for Your Project”, Prepared for: U.S. Department of Housing and Urban Development, 2012.
[4] Z.L. Wang, “Triboelectric nanogenerators as new energy technology for self-powered systems and as active mechanical and chemical sensors”, ACS Nano, vol. 7(11), pp. 9533-9557, 2013.
[5] S.H. Wang, L. Lin, Z.L.Wang, “Nanoscale triboelectric-effect-enabled energy conversion for sustainably powering portable electronics”, ACS Publications - Nano letters, vol. 12(12), pp. 6339–6346, 2012.
[6] F. Aquino, “The Gravelectric Generator: Conversion of Gravitational Energy Directly Into Electrical Energy”, Bulletin of Pure & Applied Sciences- Physics Physics, vol. 35d (1 and 2), pp. 55–64, 2016.
[7] B. Sushmitha, G. Sowmya, K. Sravani, P. Lakshmi Kalavathi, “Power generation by gravity”, International Journal Of Core Engineering & Management, Special Issue (NCIAEE-2017), pp. 187-192, 2017.
[8] Y. M. Alkubaisi, W. Z. Wan Hasan, S. Noor, A.H. Sabry, “Review of Gravitational Electric Energy and Application Perspectives on Modern Buildings”, Journal of Computational and Theoretical Nanoscience, vol. 15, 2018.
[9] Y. Sun, X. Huang, S. Soh, “Using the gravitational energy of water to generate power by separation of charge at interfaces”, Chem Sci., vol. 6(6), pp. 3347–3353, 2015.
[10] I. David, I. Vald, C.C. Stefanescu, “Replacement possibilities of the heavy over load piston of gravity hydro-power-tower energy storage plants using compressed air”, In Proceedings SGEM Series, 18th International Multidisciplinary Scientific GeoConference SGEM 2018, Sofia, Bulgaria, 02-08 July 2018.
[11] D. S. Jadhav, S. N. Hullule, N. N. Jejurkar, “Gravity power generation”, IJARSE, vol. 5 (03), pp. 249-252, 2016.
[12] C. Licai, W. Zhihao, X. Xinhong, “Power generation lighting device based on gravity potential energy of rainwater pipeline”, Proceedings of the IOP Conf. Series: Earth and Environmental Science 242 (2019), Xi’an, China, 28–30 December 2018.