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Innovative Study on Utilizing Drainage Channels for Renewable Energy with Gravitational Vortex Turbines

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ABSTRACT

The gravitational water vortex turbine (GWVT) has emerged as a viable renewable energy solution, especially suited for settings with low head and restricted water flow. Known for its ease of installation, cost-efficiency, and low maintenance requirements, GWVT technology has been implemented in various applications. However, its potential for generating energy through commercial building drainage systems has received limited attention. This study investigates the feasibility of utilizing GWVT technology to harness energy from drainage channels in commercial buildings. Using ANSYS® CFX simulation with SST k-ω turbulence model, this study aims to evaluate the potential of utilizing GWVT technology in drainage channels with a focus on the effect of drainage slope ranging from 0.2% - 3%, four approaches of vortex turbine geometry, and concrete wall roughness on turbine performance. The findings show that increasing the inlet velocity increases the vortex formation which increases the torque, which ultimately improves the turbine efficiency. The turbine model designed in this study achieved a torque output of 632 Nm, factoring in the turbulent conditions around the runner. Furthermore, employing GWVT technology in building drainage systems has the potential to reduce CO_2 emissions by approximately 122.4 tons annually, supporting a more sustainable urban environment. Future research should focus on optimizing inlet velocity and pressure distribution to fully explore the potential of urban drainage channels as a source of renewable energy.

INTRODUCTION

The construction and building industry is said to be responsible for 36% of carbon emissions (Atabay et al., 2020). In terms of supporting green buildings and the target of net zero Emission (NZE) by 2060 which is mandatory in many countries (Priyawan & Husin, 2024), renewable energy sources are expected to

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overcome the problems of energy consumption and environmental impact (Alawad et al., 2023). Research with techno-economy analysis shows that hydropower can reduce greenhouse gas emissions (Belay et al., 2020). According to the International Hydropower Association (IHA, 2021), Indonesia ranks eighth in the use of hydropower in East Asia and the Pacific, and there is still a lot of untapped potential for maximum hydropower utilization.

In designing new buildings, there must be a good drainage system to drain rainwater before it is discharged into the city's sewers (Joyanda, 2021) and is an important facility to reduce flooding during extreme storms (Li et al., 2022). Drainage systems can also be considered as potential locations for hydroelectric power plants that are easy to install and operate (Ali et al., 2020). The potential for energy recovery from drainage systems using micro hydropower plants is an appropriate solution for improving the energy efficiency of the urban water sector (Punys & Jurevičius, 2022). In addition, using energy from wastewater samples for Pico-hydro on a blade profile prototype has been successfully demonstrated, which can generate electricity at low head and minimum flow (Titus & Ayalur, 2019). They simulated a wastewater hydroelectric system where a 741 W Pelton turbine is located 14 m below a 388 m^3 pre-treated wastewater collection tank and found that the system can generate about 6 kWh of electricity per day if the tank discharges water for 12 hours per day at a flow rate of 9 liter/s and that the total system cost is $1027 with a payback period of 6.7 years.

In planning drainage channels, it is necessary to know the planned discharge by calculating the area and estimating the rainwater that can be accommodated (Annisa et al., 2022), including the processed domestic wastewater from buildings, which is 80% of the clean water requirement (Asid et al., 2024) and is channeled to the drainage channel. The average clean water usage of commercial buildings ranges from 3.35 liter/m^2 to 4.5 liter/m^2 (Rihendy, 2019); (Borges et al., 2023), so the energy potential of domestic wastewater flowing through drainage channels is quite large. In drainage, the Manning roughness coefficient is a parameter used to measure flow resistance caused by roughness elements on the channel surface (Al Hindasi & Abushandi, 2023). Other research was conducted by changing the slope of the channel base to increase flow velocity (Wang et al., 2018).

Pico-hydro is a power plant consisting of a unique pre-fabricated circular inlet reservoir with a closed outlet designed in the 2 kW hydroelectric power plant (Maika & Wahid, 2021), and is a small-scale hydroelectric power plant, suitable for installation in low-head rivers, irrigation or small waterways, because it does not depend on water level (Huwae et al., 2020), is a 'run-of-river' scheme, can divert water resources to turbines (Troullaki et al., 2019), and is green energy with small water flows to generate electricity without relying on non-renewable energy sources (Bukar & Suleiman, 2022). The GWVT with a very low head extracts energy from artificially induced water vortex gravitation in the basin in a cylindrical or conical configuration (Ullah et al., 2020). The potential energy of the water flowing on the free surface is converted into kinetic energy through the rotation of the turbine that flows water tangentially into the basin, forming a strong water vortex (Sharif et al., 2020).

In many studies on turbines, computational fluid dynamics (CFD) is commonly used in numerical investigations to estimate the flow dynamics in turbines (Velásquez et al., 2024). Thus, the initial design analysis of gravity vortex turbines is important as a secondary tool for flow dynamics in the designed product, instead of structural analysis (Nazarudin et al., 2022). CFD analysis is used to investigate the vortex formation and optimize the design of the system basin (Esa et al., 2023), and cone angle (Septyaningrum et al., 2024). In addition, CFD modeling also helps to demonstrate the hydraulic design principles and performance criteria of the pump intake under various conditions (Yamini et al., 2022).

The novelty of this research is that it proposes to explore the resources generated by commercial buildings from drainage channels, that have never been done by previous research. How to utilize drainage channels with limited flow as a source of power generation energy with vortex turbines that can be used as environmentally friendly energy, and the fluid flow approach of the turbine study design with computational fluid dynamics is carried out.

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MATERIALS AND METHODS

Drainage channels used in the design of gravitation water vortex hydropower are a drainage channel in a modern shopping center building complex. The study of the vortex turbine was designed and applied to the final channel, where the researcher proposed a basin model with a conical cross-section, runner dimensions, and slope conditions at different inlet channels used in this study.

Drainage Channel Characteristics

Variations in research sources regarding the application of drainage channels in several places that have different sizes, slopes, and discharge conditions in Indonesia and several countries in the world, using diverse analysis methods, are used to validate the application of the channel model that will be used in this research. For high-rise buildings, drainage was used in areas of 3002 m^2 and 15686 m^2, with channel dimensions of 600 x 600 mm and 400 x 600 mm, slopes ranging from 0.09% to 0.3%, and a maximum flow of 0.075 m^3/s (Asid et al., 2024); (Putra, 2023). In transportation buildings, an 800 x 800 mm channel was used with a flow of 0.121 m^3/s (Wibisono et al., 2022). For tunnel construction, channels with a depth of 410 mm were implemented, with a maximum flow of 0.497 m^3/s (Yang et al., 2024). In building complexes, channels with diameters of Ø 460 mm and Ø 500 mm were used, slopes ranged from 0.08% to 0.3%, and flows reached up to 2.57 m^3/s (Yulianur et al., 2018); (Nsabimana & Estallo, 2019). For residential areas, drainage channels measured 600 x 300 mm and 1200 x 900 mm (Stec & Słyś, 2023); (De Silva et al., 2023). In irrigation rivers, channels with dimensions of 270 x 1580 mm and 220 x 1320 mm were used (Salisu et al., 2014) and (Seetpal et al., 2020). Finally, for parking lots with an area of 1500 m^2, a channel with a diameter of Ø 200 mm and a flow rate of 0.0015 m^3/s was applied (Stec & Słyś, 2023).

In drainage channels, the Chazy formula is one of the most used equations to estimate flow velocity in channels (Fatxulloyev et al., 2023), as shown by Equation 1.

$$V = \frac{S}{n} {R_h}^{2/3} \tag{1}$$

where *V* is the flow velocity, *n* is the Manning roughness coefficient, *Rh* is the hydraulic radius, and *S* is the slope of the channel surface. With this equation, the velocity of the drainage channel to be used in the turbine can be known.

Hydraulic Parameters of Vortex Turbine in Hydropower Systems

The vortex turbine system is a combination of a reaction turbine and an impulse turbine (Timilsina et al., 2018). When water flows into the basin, a vortex is formed and moves the turbine blades in the axial direction (Williamson et al., 2020). In this case, Equations 2 and 3 are used to obtain the maximum turbine power (*P*) and torque (*T*) (Maika et al., 2023), (Velásquezet al., 2021);

$$P = \ \eta v \rho g Q \tag{2}$$

$$T = \frac{60.P}{2\pi N} \tag{3}$$

where ηv is the system efficiency in converting water power into electrical power, maximum 85% (Velásquez et al., 2021); (Velásquez et al., 2022), ρ is the density of water with 998.81 (kg/m^3), g is the gravitational acceleration of 9.81 (m/s^2), Q is the water flow rate (m^3/s), and *N* is the shaft rotation (rpm).

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The slope of drainage channels affects the flow and inlet velocity, impacting vortex turbine performance. Studies show that optimizing the inlet velocity profile enhances turbine efficiency, particularly in low-head installations (Galván et al., 2015). The modified Bernoulli equation is used to analyze energy, accounting for head loss and surface roughness (Atesmen, 2018). The Rankine vortex model estimates flow behavior at the inlet by describing velocity distribution through the superposition of elementary vortices, although it does not consider the boundary layer near the wall (Galván et al., 2015), is applied to symmetric rotating flows, and is used in Equations 4 to 8 with varying degrees of complexity.

$$V_t(r) = \Omega_o r \tag{4}$$

$$V_t(r) = \Omega_0 r + \Omega_1 \frac{{R_1}^2}{r}\left[1 - exp\left(-\frac{r^2}{{R_2}^2}\right)\right] \tag{5}$$

$$V_a(r) = U_0 + U_1 exp\left(-\frac{r^2}{{R_2}^2}\right) \tag{6}$$

$$V_t(r) = \Omega_0 r + \Omega_1 \frac{{R_1}^2}{r}\left[1 - exp\left(-\frac{r^2}{{R_2}^2}\right)\right] + \Omega_2 \frac{{R_2}^2}{r}\left[1 - exp\left(-\frac{r^2}{{R_2}^2}\right)\right] \tag{7}$$

$$V_a(r) = U_0 + U_1 exp\left(-\frac{r^2}{{R_1}^2}\right) + U_2 exp\left(-\frac{r^2}{{R_2}^2}\right) \tag{8}$$

where Vt is dimensionless tangential component of velocity, V_a is the dimensionless axial component of velocity, R_1 and R_2 are dimensionless vortex core radius, U_0, U_1, and U_2 is dimensionless axial velocities, Ω_0, Ω_1, Ω_2 is dimensionless angular velocities references, and r is dimensionless radius.

In CFD modeling, where calculations of fluid variables are performed, mathematical models are used to estimate the results. In this case, the following Navier-Stokes Equations describe the continuity equation (Equations 9 to 12) in cylindrical coordinates (Burbano et al., 2022).

$$\frac{\partial V_r}{\partial r} + \frac{\partial V_z}{\partial z} + \frac{\partial V_r}{r} = 0, \tag{9}$$

$$V_r\left[\frac{\partial V_r}{\partial r}\right] + V_Z\left[\frac{\partial V_\theta}{\partial z}\right] - \left[\frac{V_r V_\theta}{r}\right] = V\left[\frac{\partial^2 V_\theta}{\partial r^2} + \frac{\partial V_\theta}{r\partial r} - \frac{V_\theta}{r^2} + \frac{\partial^2 V_\theta}{\partial z^2}\right], \tag{10}$$

$$V_r\left[\frac{\partial V_r}{\partial r}\right] + V_Z\left[\frac{\partial V_r}{\partial z}\right] - \left[\frac{V_{\theta^2}}{r}\right] + \left[\frac{\partial \rho}{\rho \partial z}\right] = V\left[\frac{\partial^2 V_r}{\partial r^2} + \frac{\partial V_r}{r\partial r} - \frac{V_{r\theta}}{r^2} + \frac{\partial^2 V_r}{\partial z^2}\right], \tag{11}$$

$$V_r\left[\frac{\partial V_r}{\partial r}\right] + V_Z\left[\frac{\partial V_z}{\partial z}\right] - \left[\frac{\partial \rho}{\rho \partial z}\right] = V\left[\frac{\partial^2 V_z}{\partial r^2} + \frac{\partial V_z}{r\partial r} + \frac{\partial^2 V_r}{\partial z^2}\right], \tag{12}$$

The angular, radial, and axial velocity components are denoted by V_θ, V_r, and V_z respectively, while the kinematic viscosity is denoted by V, according to Burbano et al. (2022). Due to the complexity of the equations, analytical solutions cannot be obtained directly, so CFD techniques are used to estimate the solutions in this study.

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In vortex turbine systems, power output and overall efficiency are important quantitative performance variables. The ambiguity may occur and is the main reason why there are so many studies on efficiency among vortex turbine systems in confined flow, installed and studied.

From Table 1, variations in runner design, basin configuration, cone angle, and other parameters have a significant impact on vortex turbine performance. All these data indicate that optimizing each turbine component, from inlet velocity to runner angle and outlet size, can significantly improve efficiency, especially in micro-hydro turbine systems designed to maximize output power with limited resources.

Table 1. The influence of hydraulic parameters on hydro-turbine reference

Properties	Source	Flow [m^3/s]	Head [m]	Power [kW]	Method		Results
					Analysis	Numeric	
Flow and head	www.kourispower.com, www.zotloeterer.com	0.05 - 20	0.7 - 3.0	0.2 - 500	-	-	Available discharge 0.05 m^3/s and above, with the lowest head at 0.7 m
	(Maika & Wahid, 2021)	0.09	1.7	2	√	-	Turbine efficiency 49.36%, at flow 0.09 m/s & Basin diameter 1.5 m
Inlet velocity	(Harmiansyah et al., 2023), (Nazarudin et al., 2022)	0.085	-	0.013	-	√	Inlet velocity 0.3 m/s and 0.18 m/s
Runner configuration	(M. Ali et al., 2021), (Kim et al., 2021), (Burbano et al., 2022), (Jiang et al., 2022)	0.004 - 0.53	1.5 - 2	0.002 - 1.7	√	√	Runner with baffle has higher efficiency, with 155° - 170° (β) and 10° - 130°(α) for angle
Basin model	(Kumar Jha et al., 2018), (Ullah et al., 2020)	0.004 - 0.01	0.85	0.10 - 5	√	√	Cone basin model, increased turbine efficiency
Height of basin	(Teber, 2024)	0.18	1.2	1	√	√	Basin heights 0.31 and 0.57 m, found the best vortex.
Cone angle	(Bajracharya et al., 2018), (Sharif et al., 2020)	0.002	0.6	0.0117	√	√	60^0 of angle provides higher strength
Runner position	(Salem et al., 2020), (Salem et al., 2020)	0.004 - 0.009	0.5	0.02 - 0.095	√	√	Runner position 65% - 75% from Top basin with maximum rotation
Runner angle	(Bajracharya et al., 2020)	0.009	0.5 - 1.9	0.0953	√	√	50° − 60° for best efficiency
Runner height	(Sitindaon & Arizona, 2023)	0.009	0.5	0.39 - 0.09	√	√	Runner height to basin height ratio 0.31% – 0.32%
Thickness of runner	(Betancour et al., 2023)	0.003 - 0.41	0.04 - 0.38	-	√	√	Maximum turbine efficiency 0.58%, blade thickness 0.0025 m - 0.003 m
Runner diameter	(Irwansyah et al., 2020)	0.004		0.53 - 5	√		Ideal runner reviewed from the Basin ratio the best is 0.6
Outlet size	(Kamil et al., 2024)	Steady flow	0.7 - 3		-	√	Outlet Diameter 30% – 40% Basin diameter provides maximum power output.

Pre-Experimental Site Study

The design study of the hydropower plant from the utilization of drainage channels is in the construction project of a modern shopping center building, located in Badung City, Bali, with a built area of ±95,000 m^2. The study was conducted to answer the circular of the Bali Government (Governor of Bali, 2022), to apply clean energy and new renewable energy technology to commercial, industrial, social, and domestic buildings.

Fig 1 illustrates a schematic of the GWVT system integrated with the building's drainage channel, employing a zero-runoff drainage approach. In this configuration, the building's drainage channel directs flow into a retention pond with a capacity of 307 m^3, where the system harnesses and generates energy. Water from the building's processed domestic waste and rainwater from the surrounding area is directed to

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the retention pond via the drainage channel. This water then flows to the vortex turbine through an automatic water gate that controls the flow. After passing through the turbine, the water returns to the river. Elevations A-A and B-B depict the height profile of the main components, ensuring that the water flows smoothly from the retention pond to the turbine and overflows back to the river.

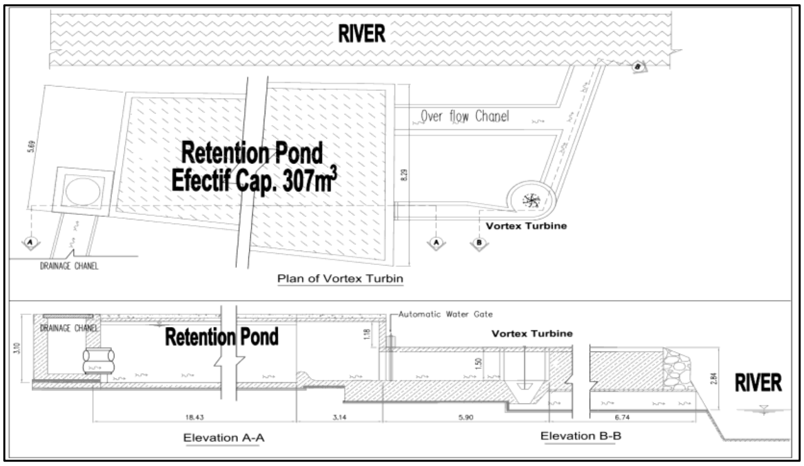

Fig. 1. Schematic application of vortex turbine.

The design of the inlet channel and construction of the vortex turbine are planned to use concrete so that they can be implemented together and become part of the building drainage system plan. The material properties of the drainage channel built with concrete have several important properties; concrete compressive strength of 19.3 MPa, with a density of 2400 kg/m³. This concrete also has a thermal expansion coefficient of around 1.4 x 10-5 [m/m]/°C, a thermal conductivity of 0.72 W/m°C, and a specific heat capacity of 1 J/kg°C, which are important in dealing with temperature changes. The elastic modulus is 20647.92 MPa, and the ultimate tensile strength is 5 x 106 Pa. Poisson's ratio is 0.2, with a shear strength of 8603.30 MPa. Additionally, the Manning roughness coefficient is 0.014 (Fatxulloyev et al., 2023). These properties, taken from Ansys Engineering Data and scientific studies (Khalaf et al., 2019); (Aprisandi et al., 2019), ensure that the drainage channel balances strength, durability, and thermal stability.

The concrete data above aims to ensure that simulation results closely resemble actual implementation conditions. Concrete channels are selected for their high mechanical resistance and thermal stability (Khalaf et al., 2019); (Aprisandi et al., 2019). Additionally, the surface roughness of concrete influences the pressure distribution and flow patterns around the turbine, which are crucial factors in optimizing turbine performance (Ma et al., 2020). By incorporating concrete material data into the simulation, this study's findings become more relevant for commercial applications, where concrete is the primary drainage material due to its low cost and widespread availability.

Research Method

Approaching model

The three-dimensional (3D) turbine construction was made in Ansys Space Claim 2024 for its components (blades, channels, and basins) shown in Fig 2, and adjusted to the flow rate and head available in the research building drainage channel. Further model development was made to obtain analysis options, regarding the right hydraulic flow and the best torque value produced by the turbine. Then concrete material

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properties are entered into the solid material parameter settings used to determine whether there is a significant impact on the vortex flow rate in the turbine.

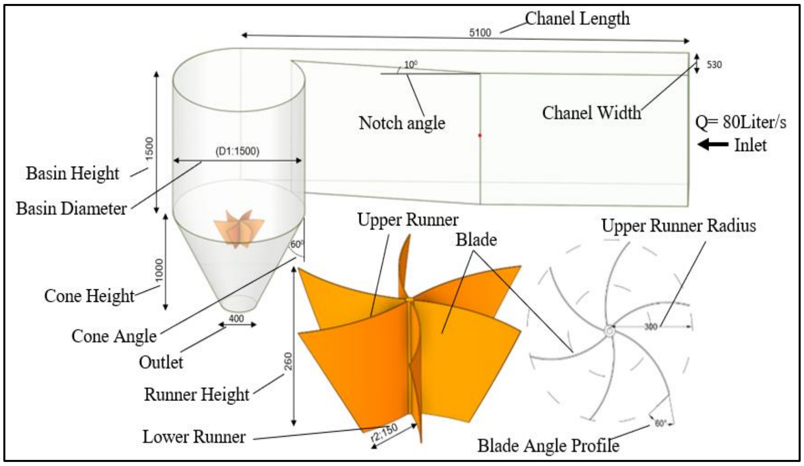

Fig. 2. Research turbine construction.

The original turbine model was taken with reference from previous research; the basin diameter (D1) of 1500 mm (Maika et al., 2023), upper runner diameter (Rd1) of 600 mm (Ullah & Cheema, 2022), lower runner diameter (Rd2) of 300 mm (Maika & Wahid, 2021), and runner height (Hr1) of 260 mm (Bajracharya et al., 2020). Model development was carried out by modifying the basin diameter (D1) to 1000 mm, upper runner diameter (Rd1) to 720 mm, and runner height (Hr2) to 320 mm. The water flow rate from the retention pond in the final drainage channel was set at 80 liters/second so that the turbine operating time could work for more than 1 hour. The number of blades used was 5, with a 60° blade angle profile (Harmiansyah et al., 2023), and the runner rotation speed for all tests referred to Burbano et al. (2022), and was taken as 10.48 rad/s. The type of channel used is a rectangular open channel model with a length of 5100 mm, a channel width of 530 mm, and a height of 1500 mm (Maika & Wahid, 2021), with a notch angle of 10° (Dhakal et al., 2016), and a conical basin angle of 60° (Sharif et al., 2020).

The approach model and development of turbine testing are shown in Table 2. The experimental configuration was carried out by changing the slope value (s), which is commonly applied to drainage channels. In this study, a slope ranging from 0.2% to 3% was used to obtain a choice of fluid inlet velocity (*V*) into the turbine.

Table 2. Approaching for method simulation

Simulation Number	Basin *A* (Ø1.5 mtr)	Basin *B* (Ø1 mtr)	Runner type 1	Runner type 2	Slope (s = %)	Velocity (v = m/s)
Approach 1	•		•			
Approach 2	•			•	•	•
Approach 3		•	•			
Approach 4		•		•		

Then, for numerical analysis, Ansys 2024 thermal fluid analysis CFX software (Ansys, Inc.) was used, setting up the flow analysis model with SST k-ω turbulence with 3D free-stream modeling. The SST k-ω turbulence model is very useful in modeling the torque performance of vortex turbines because it can capture the effects of turbulent flow around the turbine blades. The SST k-ω model is used to model the turbulent flow more accurately, especially in the zone close to the turbine blades (Iov et al., 2019).

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Research on the analysis of the fluid flow inlet angle into the vortex basin with a critical angle has been conducted by Wang & Liu (2019) on a laboratory scale, which in this study is identical to the inlet slope, but will not be more than 10°. Furthermore, the researcher proposed that the wall roughness should be considered to minimize losses, including fluctuations in power output. The roughness of the channel wall can cause increased friction and turbulence in the fluid flow. In this case, the fluid flow analysis of channel roughness uses the SST k-Ɛ turbulence model and the complex flow visualization method with the line integral convolution (LIC) method (Wang & Liu, 2019). The simulation uses a time step count of 500, while the time step size used is 0.001.

Model validation

The simulation method used in this study, specifically for modelling the effects of wall roughness and inlet velocity on the performance of gravitational water vortex turbines (GWVT), is validated by findings from several previous studies. Increasing wall roughness significantly increases turbulence and energy losses, especially around the blade surface. Roughness causes a decrease in static pressure and changes in velocity distribution, thus decreasing hydraulic efficiency (Kan et al., 2022). Research by Sharif et al. (2021) evaluated the impact of varying inlet velocity and head on vortex formation and turbine mechanical efficiency, revealing that higher inlet velocities significantly improve turbine performance, particularly torque and shaft power generation.

Furthermore, the study of grid independence is essential to understand the meshing elements and computational requirements for the analysis (Karthik & Parammasivam, 2016). In Fig 3, which is the result of grid dependency testing from approach 4, there are 9 mesh elements (x-axis) with values between 2.5 x 10^5 to 3.1 x 10^5 used, and the analysis is carried out to extract the output at the maximum velocity output (y-axis) from the modelling used.

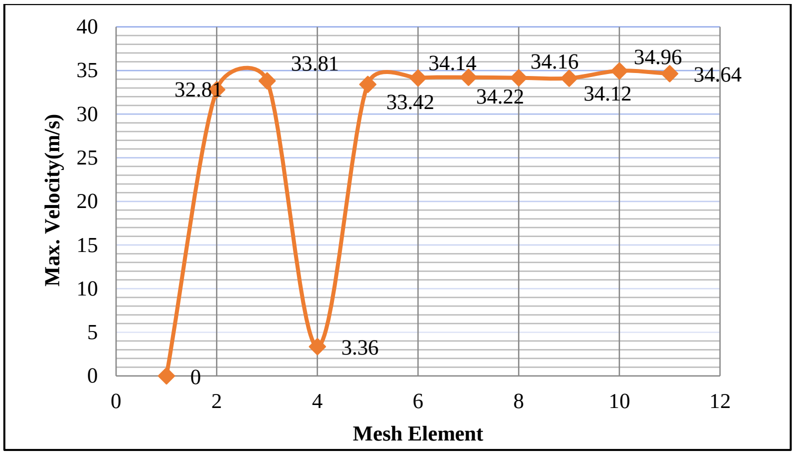

Fig. 3. Graphic dependency for Approaching 4.

The results of the grid dependency test for numerical simulations on the built model can be analysed as follows: At the maximum velocity variation, the graph displays the maximum velocity (m/s) for each grid element. Initially, the maximum velocity increases until it reaches a stable value around the second to third element, approximately 33.81 m/s. However, there is a drastic decrease at the fourth element, where the velocity drops to around 3.36 m/s. This drop may indicate numerical interference or inconsistency at that particular grid level. Starting from the fifth element, the velocity increases significantly again and stabilizes between 34.12 m/s and 34.96 m/s in subsequent elements. After the fourth element, the test results demonstrate that the maximum velocity remains stable with only minor variations. This suggests that the

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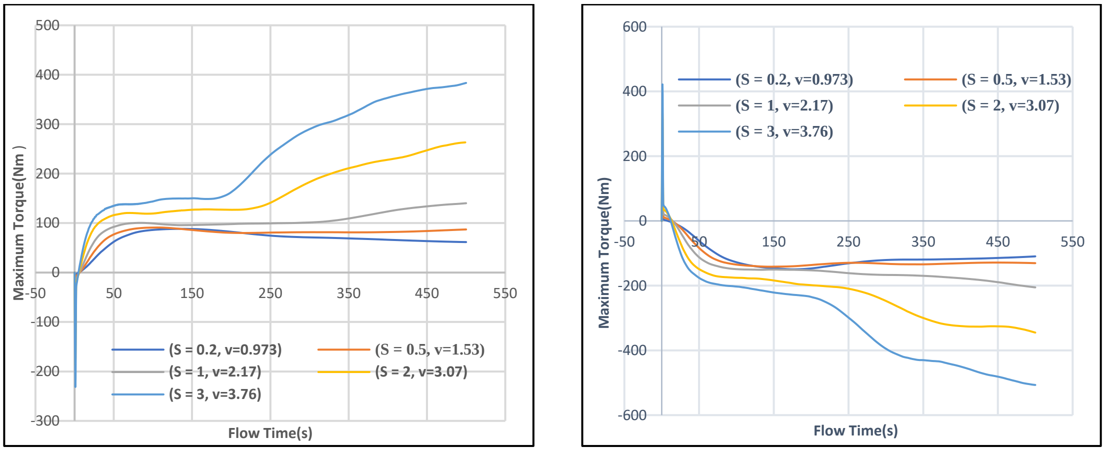
grid is beginning to converge towards a stable solution. Grid convergence is indicated when the test parameter values (in this case, maximum velocity) show no significant changes, even as the number of grid elements increases. Based on the graph of the test results, stabilization begins from the fifth element onward.

RESULTS AND DISCUSSION

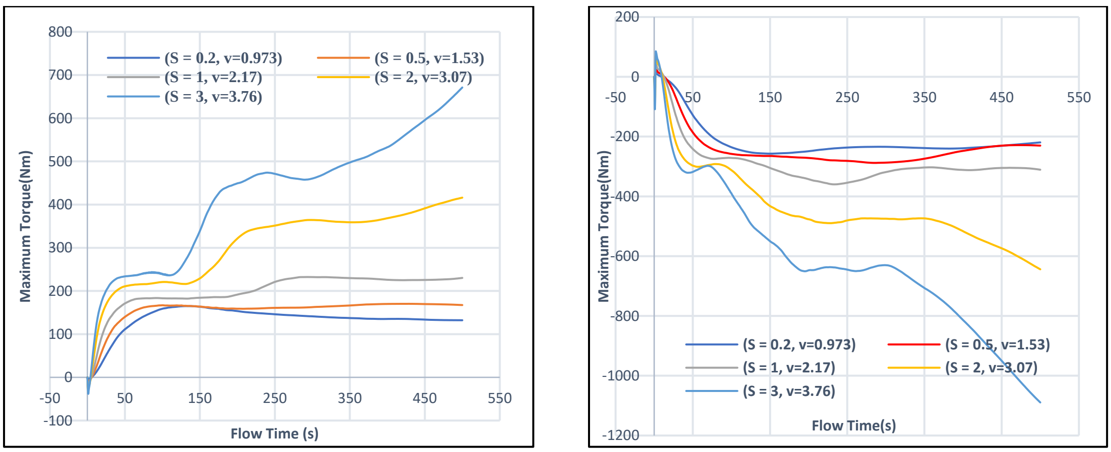
Analysis of Turbine Performance

In the torque performance analysis using SST k-ω, the study has defined the geometry and boundary conditions of the research turbine model, which are not discussed in this section, but the simulation has included the inlet velocity parameters entering the turbine obtained from different channel slopes. According to Burbano et al. (2022), fluid velocity at the inlet affects the momentum of the fluid entering the vortex turbine. Higher velocities produce greater forces on the blades, which will increase torque.



(a) (b)

Fig. 1Torque with velocity inlet o;n Approaching 1 and 2 for Basin A; (a) runner type 1 and (b) runner type 2



(a) (b)

Fig. 5. Torque with velocity inlet on Approaching 3 and 4 for Basin B; (a) runner type 1 and (b) runner type 2

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Based on the simulation results on the research turbine as shown in Fig 4 and Fig 5, several conditions were found that produced negative torque, especially those using runner type 2, whether applied to basin A or B. In Fig 4(a), all tests obtained positive torque at all flow velocities (0.973 m/s, 1.53 m/s, 2.17 m/s, 3.07 m/s, and 3.76 m/s), in contrast to Fig 4(b), where all test results obtained negative values. Then, in Fig 5(a), was conducted the simulation on basin B, which has a smaller diameter than basin A, but has a higher blade, the simulation results obtained are identical to those produced in Fig 4. However, it has a larger maximum negative torque value, especially on runner type 2.

Several reasons can cause negative torque values during simulation; turbine rotation direction, asymmetric (turbulent) pressure (Del Rio et al., 2022), boundary conditions (Naik et al., 2021), or blade shape (Kamal & Saini, 2022). Under these conditions, the study did not find any opposite rotation direction, poor boundary conditions, or asymmetrical blade shape, but turbulent flow was found around the turbine, which may have influenced the negative torque (Strom et al., 2022); (Chamorro et al., 2013).

According to Rahman et al., (2024) in a study on Savonius turbines, negative torque is influenced by the presence of turbulence flow on the convex side of the blade and the concave side is the recipient of positive torque. With a contour application, Table 3 shows the turbulence flow conditions around the blade, where the faster the inlet flows and the greater the tangential force produced, the larger the turbulence area will be.

From each panel in Table 3, different velocity and turbulence distributions are seen. If the analysis is based on inlet velocity and turbulence; low inlet velocity (as in some panels in the first and second rows) results in low turbulence and a calmer flow, but it also reduces turbine efficiency because less energy is transferred to the blades. High inlet velocity (as seen in panels j to l) results in increased kinetic energy, but also causes excessive turbulence, which can reduce efficiency due to energy losses in uneven flow and potential mechanical damage. The optimal inlet velocity is seen in some panels in the third row, where the flow has moderate turbulence and a more even flow distribution. This condition provides the highest efficiency because the flow is stable and there is enough kinetic energy available to be converted into mechanical energy.

From the discussion of the relationship graph between torque and channel slope, as well as the turbulent flow in the turbine, it is obtained that the fluid velocity obtained from the channel slope affects the force on the turbine blades, which ultimately impacts the efficiency and torque produced. The channel slope factor that affects efficiency and torque is in accordance with the research results (Velásquez et al., 2022); (Burbano et al., 2022); (Rahman et al., 2024); which states that the geometry of the inlet affects the torque produced by the gravitational vortex turbine.

Roughness Effect of Channel Material

Although the SST k-ω model is more suitable than the standard k-ε model for simulating vortex turbine flows, the SST k-ε turbulence model can capture the pressure phenomena on the turbine channel walls (Iovănel et al., 2019), so this model allows for more accurate predictions of the pressure, friction, and fluid velocity distributions around the turbine blades.

Fig 6 and Fig 7 show the visualization of the flow field and vector of line integral convolution (LIC), obtained by the SST k-ε turbulence model. From the figure, the typical flow that occurs in the area around the turbine is known. In Fig 6(a), Fig 6(b), Fig 7(a), and Fig 7(b), where field 1 is part of the notch channel wall, and points around 2 and 3 are the fields of the basin wall. In Fig 6(c) and Fig 6(d), the inlet velocity is made at 3.76 m/s with a wall roughness level = 0, and it appears that the pressure and flow vector are low and directional.

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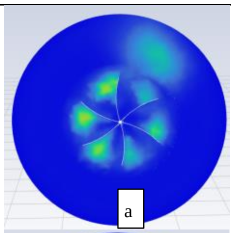
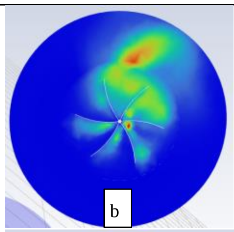
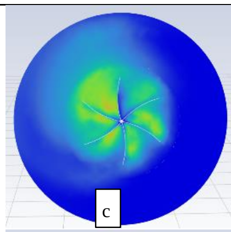
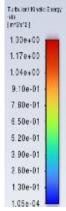
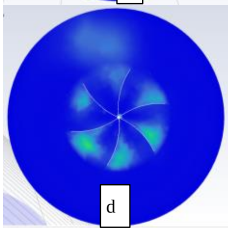
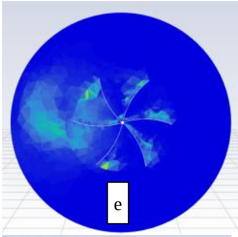
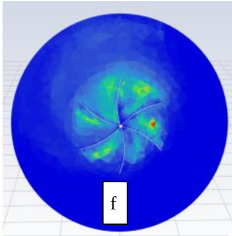
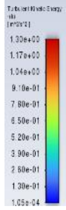
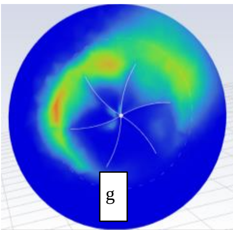
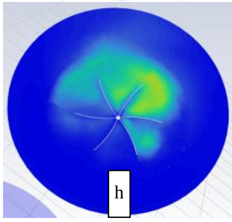
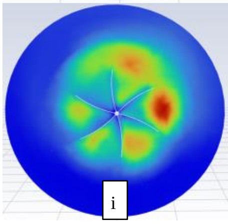
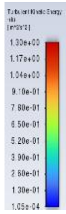
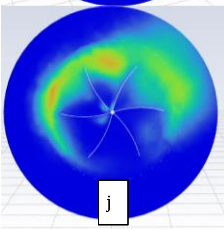
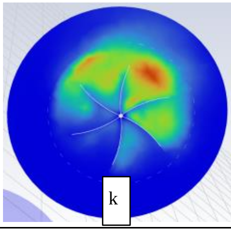
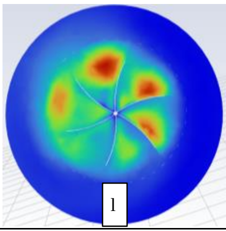
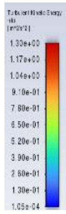
Table 3. Turbulence on variative turbine conditions

Model	Velocity (m/s)			Value
	0.973	2.17	3.76	
Approaching 1				
Approaching 2				
Approaching 3				
Approaching 4				

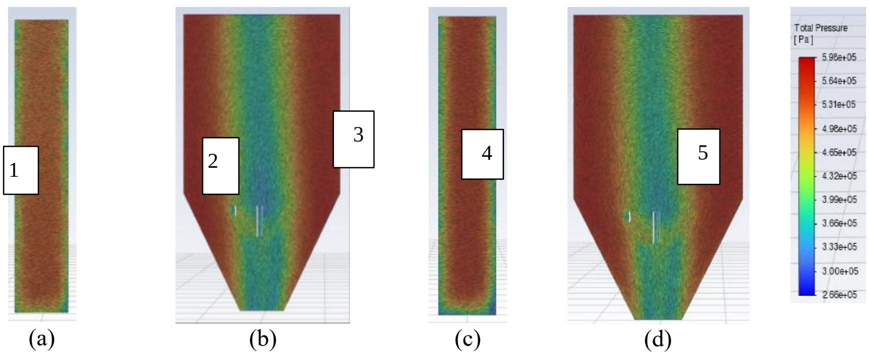


Fig. 6. Pressure on the channel wall of Approaching 1 and 2, wall roughness = 0.

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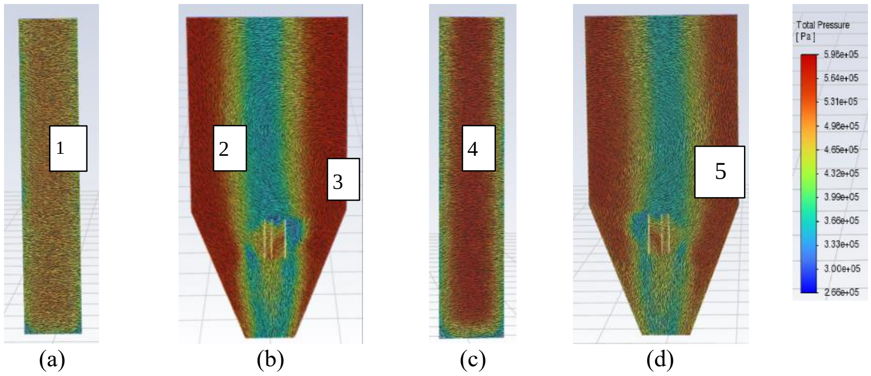

Fig. 7. Pressure on the channel wall of Approaching 3 and 4, wall roughness = 0.014.

Different things are shown in Fig 7(c) and Fig 7(d), where it appears around point 5, namely by entering the wall roughness value, the effect caused is that the pressure on the wall increases and spreads towards the turbine axis. This is different in Fig 7(c) at point 4, where the pressure increase on the wall does not occur.

The same thing is shown in Fig 7, namely by using a smaller basin diameter, where the effect caused by friction against the wall, allows for turbulence (Fig 7d), pressure in the turbine rotation area, and irregularities in the flow field in area 5. Thus, these results are by research that states that roughness can cause an increase in local pressure and changes in flow patterns (Ma et al., 2020). From Fig 6 and Fig 7 several differences can be explained as follows.

(i) Fig 6(a), Fig 6(c), Fig 7(a), and Fig 7(c); the notch channel wall sections in Fig (a) and Fig (c) in both images, with dominant red zones indicating higher pressures along the walls. However, the second image in Fig 7(a) and Fig 7(c) shows slightly more distinct variations in the center region in both figures. This could be due to higher surface roughness or changes in the flow speed.

(ii) Fig (b) in both images; in the first image, Fig 6(b) shows a smoother pressure distribution in the tapered section with green and blue in the central region, representing lower pressure. However, in the second image, Fig 7(b) shows a more complex and turbulent pattern, especially near the bottom, where large blue regions (low pressure) are more prominent. The pressure gradient appears to be more abrupt in the second image, which could indicate different surface roughness or operational conditions that lead to more significant pressure drops.

(iii) Fig (d) comparison; in Fig (d) of both images, the second image in Fig 6(d) shows a more detailed low-pressure zone near the bottom of the tapered region. The second image in Fig 7(d) also highlights some flow disturbances or potential vortices in this low-pressure zone, represented by more intricate blue and green color variations.

(iv) The first image's Fig 6(d) shows less variation in this area, with a smoother transition of colors from red to green. This could indicate more uniform pressure behavior.

The difference between turbulence and flow complexity in Fig 6 and Fig 7;

(i) Fig 7 shows more complex turbulence and larger pressure variations, especially in the tapered sections. This suggests that the conditions in the second case (such as surface roughness or inlet conditions) might create more disturbances in the flow, leading to more uneven pressure distribution.

(ii) Pressure drops; both images show pressure drops toward the center of the vortex turbine, but the second image (Fig 7) has more pronounced blue regions, indicating more significant

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pressure loss. This could reflect a higher degree of interaction between the fluid and surface roughness.

The outline from the two images above in Fig 7 seems to illustrate a more turbulent and uneven flow pattern compared to the first image, especially in the tapered section. This could be due to differences in surface roughness, inlet velocity, or other simulation parameters. The first image has smoother transitions in pressure distribution, while the second image highlights more complex flow behavior with more defined low-pressure regions.

Renewable Energy Contribution

The drainage channel in this study primarily collects processed water from the building's waste treatment unit and rainwater runoff. Calculations show that electricity generation from domestic wastewater amounts to 6.26 kWh, derived from the turbine's electrical output multiplied by a minimum operating time of one hour, which is obtained of dividing the retention pond capacity by the inlet flow to the turbine channel. For rainwater, previous research by Nyoman et al., (2023) showed that the maximum turbine operation can work for six hours, which is determined from the Mononobe method in calculating rainfall intensity for return periods of 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years, with rainfall duration ranging from 15 minutes to 360 minutes. This results in an estimated electricity generation of 37.56 kWh from rainwater.

In this study, the energy produced by the turbine from the drainage channel is proposed as an alternative source for powering the building's external lighting system. Fig 8 presents a comparison of energy supply options for the external lighting system, categorized by different energy sources.

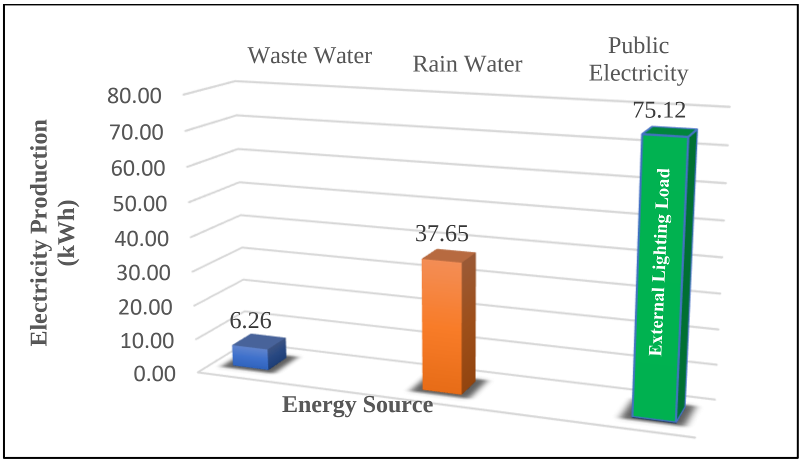

Fig. 8. Potential of electricity production.

The horizontal axis (x-axis) represents the sources of energy, while the vertical axis (y-axis) shows electricity consumption measured in kilowatt-hours (kWh). The data indicates that energy derived from wastewater processing has the lowest consumption, while the rainwater system contributes 37.56 kWh. This amount is part of the total electricity required for utility needs outside the building, which is sourced from public electricity at 75.12 kWh. However, this energy source can reduce energy needs.

The potential torque generated is calculated to produce electrical energy from the turbine, which can be utilized as an efficient backup power source during blackouts (Belik & Nohacova, 2019). This application has already been implemented in water treatment facilities (Kotulla et al., 2022). Additionally,

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the configuration for utilizing the electrical energy produced by the turbine can be based on research findings from various studies (Muneer et al., 2022); (Naik et al., 2021), which suggest using an automatic transfer switch system to meet the electrical energy needs of buildings. The turbine can also serve as an alternative energy source, as demonstrated in other research, thereby reducing reliance on grid electricity. In this study, the focus is on harnessing the energy generated by the turbine to power external lighting for the building. Overall, this energy source has the potential to fulfill 50% of the building's energy requirements. Or as an alternative energy source, thus minimizing the use of state electricity.

CONCLUSION

This study shows that commercial building drainage channels can be utilized as a renewable energy source through the installation of vortex turbines. Controlling the inflow velocity and the effect of wall roughness are key to improving system efficiency. Overall, the contribution in showing the potential of utilizing drainage channels as an alternative energy source, especially in commercial building environments with limited water flow needs to be very strong and must be carried out continuously.

Increasing the water flow velocity at the inlet contributes to the formation of a vortex and increases the turbine torque, but some configurations produce negative torque which may be caused by the unstable turbulent flow around the runner. Then the basin design and runner configuration significantly affect the performance of the vortex turbine. Conical basins produce higher efficiency compared to other shapes. Furthermore, the roughness of the drainage channel wall affects the pressure distribution and fluid flow velocity around the turbine. High roughness causes increased turbulence and decreases system efficiency.

From these results, maintaining the inlet velocity at an optimal level with controlled turbulence is the key to achieving the highest efficiency in overall turbine operation. From several simulation models to determine the torque and flow values in the turbine, this researcher proposes using the best torque by considering low turbulence flow, and potentially not damaging the turbine mechanically. In the presentation, basin B, with a type 1 runner and a torque of 632 Nm, is worthy of being recommended as the target result of this study.

On the other hand, with the contribution and the application of renewable energy sources from the utilization of building drainage channels in buildings is expected to contribute to reducing carbon dioxide (CO_2) emissions and preserving a better environment. The calculation of CO_2 Emission reduction issued by (Ministry of Energy and Mineral Resources (ESDM), 2020) concerning the Methodology for Calculating Greenhouse Gas Emission Reduction and Increasing Carbon Absorption within the Mitigation Action Verification Framework intended for off-grid run-of-river hydroelectric power plants, the potential reduction in carbon emissions will be obtained by 122.4 Tons of CO_2/per year. Finally, to thoroughly evaluate that the building drainage channel has great potential as a source of renewable energy, the inlet flow velocity factor from the discharge generated by the building and the average pressure on the channel wall can be considered in the multi-objective optimization process. This additional work will be needed to improve the methodology and generalize it to more complex inlet flow velocities.

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CONFLICT OF INTEREST

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

CONTRIBUTION OF AUTHORS

The authors confirm their contribution to the paper as follows: study conception and design: JVT, PYN; data collection: PYN, JVT, MKR; software and simulation; DKI, PYN; analysis and interpretation of results: PYN, RKP, DKI; draft manuscript preparation: PYN, MKR. All authors reviewed the results and approved the final version of the manuscript.

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