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ANSYS Simulation Study to Generate Pressure from Various Water-Wind Flow Conditions to Calculate Electricity Generated Using Piezoelectric Cells

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ABSTRACT

The amount of energy usage per person has shown to increase with every year. With increase in population and depletion of non-renewable sources of energy, there is a growing need for the development of energy harvesters using renewable sources of energy. This paper aims to set a base study to address the problem of lack of energy harvesters using a lesser known renewable source of energy – rain. This paper presents a theoretical rooftop model that has been subjected to a mix of wind-water fluid simulate conditions of a rainy weather and the test data were recorded. ANSYS analysis has been performed with the fluid velocity being set at 20 m/s, 30 m/s, 40 m/s and 50 m/s which strikes the roof of a building kept at 0°, 45° and 60°. The objectives of this paper is to determine the amount of voltage that can be generated from pressure developed by the fluid striking the model surface. The pressure values, obtained from ANSYS simulation, were then used to show that the method is viable to be applied on piezoelectric cells to generate electricity from rain and wind hence the study can be used to develop a sustainable model using rain as a renewable source of energy. Low level voltage can be generated from rain striking on piezoelectric material.

1. Introduction

With the global population increase, the world consumption of energy has also risen. According to the BP Statistical Review of World Energy 2019 report, the growth of global energy consumption recorded the highest growth of 2.9% in 2018 for the past decade [1]. Research has shown that an average human being in the future will use 12 kW per person to live and this amount is equivalent to 2900 x 1015 BTU per year [2] and this figure keeps on increasing. The research showed that at that level of energy depletion, fossil fuels will be completely depleted by the year 2300.

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With the depletion of fossil fuels and non-renewable sources of energy, human beings have to heavily rely on reliable alternative and renewable energy that can harvest electricity [3, 4]. The European Union adjusted its targets such that in 2023 major countries will try to increase use of renewable sources of energy to 32%. The Government of India plans to raise its target to 227 GW by 2027. Hawaii, USA aims to reach 70% energy independence by 2030 out of which 40% will be from renewable sources of energy [5] and by 2050, it is expected to achieve 50% or more from renewable sources of energy [6].

Scientists have over the time developed electricity from renewable sources of energy with innovative research studies [7]. Some of the popular sources are solar energy, wind energy, tidal energy and geothermal energy. However, there are very few methods in which energy from falling rain can be utilized to generate electricity. There is even fewer research associated with utilizing piezoelectric materials to develop solutions for low power supply devices [8].

Piezoelectric effect allows materials to convert mechanical energy to electrical energy and vice versa. The stimuli for piezoelectric materials can be human walking, wind, tide, wave, rain, etc. [9]. Studies have been performed to harvest energy from vibrating shoe-mounted piezoelectric cantilevers. Energy produces from drops of rain striking a piezoelectric material in a cantilever configuration has been proven via experimental studies [10-12]. Research has shown the generation of voltage on the electrodes of a piezoelectric transducers subjected to rainfall [13].

A detailed study of harvesting of kinetic energy of raindrops has shown that during heavy thunderstorms, rain drops of size 5 mm can reach terminal velocity up to 9.09 m/s and has immense pressure [14]. During heavy stratiform rain, the number of raindrops per 1 second on 1 m2. A single large droplet can weigh up to 6.55×10^{-5} kg and the force generated per droplet is 5.95×10^{-4} N [15]. According to the research, electrical energy can be harnessed during the impact of a raindrop [15] and this has been proven by the studies done by Guigon *et al*., [15] and Nayan *et al*., [16].

Nayan *et al*., [14] was successfully able to show that the mechanical energy of raindrops can be harnessed by piezoelectric sensors to generate an average of 1 volt for each pressure. Using more piezoelectric sensors in series connection provides more supply to the load [16].

These researches showed that the use of piezoelectric transducers is a viable method to create electricity. Malaysia receives a good amount of rainfall and hydroelectric is considered to be a source of power and energy [17]. However, there is no concrete evidence of energy generation methods being applied on rooftop shingles to generate electricity from rain using piezoelectric materials. This paper further focuses on the study of pressure generated from rain and wind which can be applied on piezoelectric cells and applications of it on a rooftop model. This paper can also be used as a basis to create an actual model to further verify this papers study.

2. Methodology

2.1 CAD Design

It has been assumed in this project that the fluid only hits the surface of the roof top from one particular side. This paper does not explore the effect when the fluid hits the surface from multiple sides at the same time. The impact of raindrop is considered perfectly inelastic. So, it is important to consider effect of splashing, rebound, partial rebound and spreading of rainwater. The effect of two-raindrop impact has been neglected. Moreover, it has been assumed that there will be no dissipation of energy in the form of heat or sound.

For the analytical experiments the roof top model was first designed using SolidWorks. The roof element is measured at 210 x 210 x 500 cm. Three models were designed for the experiment with the angle of the roof positioned in 0°, 45° and 60° as shown in Figure 1.

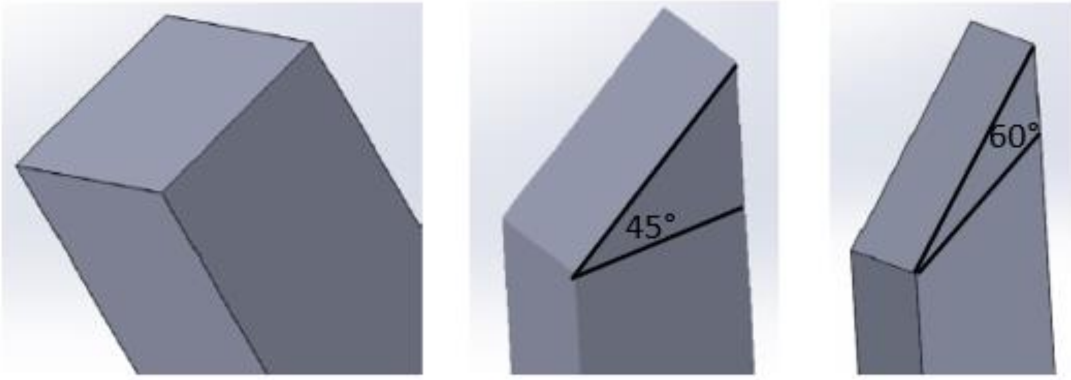


Fig. 1. Angular view of rooftop model at 0°, 45° and 60° respectively

The models were then transferred in a commercial Computational Fluid Dynamics (CFD) simulation software, ANSYS FLUENT to perform fluid flow simulations. CFD is a powerful tool commonly used for researching on how systems react to fluid flow and has been used in multiple studies for renewable energy research [3-4,17-18].

2.2 Grid Independence Study

Grid Independence Test helps in identifying the accepted level of tolerance level of the model based on the size of meshing. The output result of a coarser mesh is different from a finer mesh. When varying the mesh does not result in much difference then the minimum mesh size is selected for the final output solution. The model chosen to be the benchmark of the experiment has been shown in Figure 2. Initial default meshing was first provided on the CAD model created [19]. The size of the mesh has been then gradually increased from 1152 nodes (coarse mesh) to 15000 nodes in order to observe significant changes of the pressure contours. Based on the grid independence test, it was shown that the average pressure generated during the moment of impact was highest during very fine mesh was selected at 11532 nodes and 9900 elements.

The same methodology has been widely practiced in previous works [19-21] as finer mesh tends to provide better accuracy in terms of outputs desired.

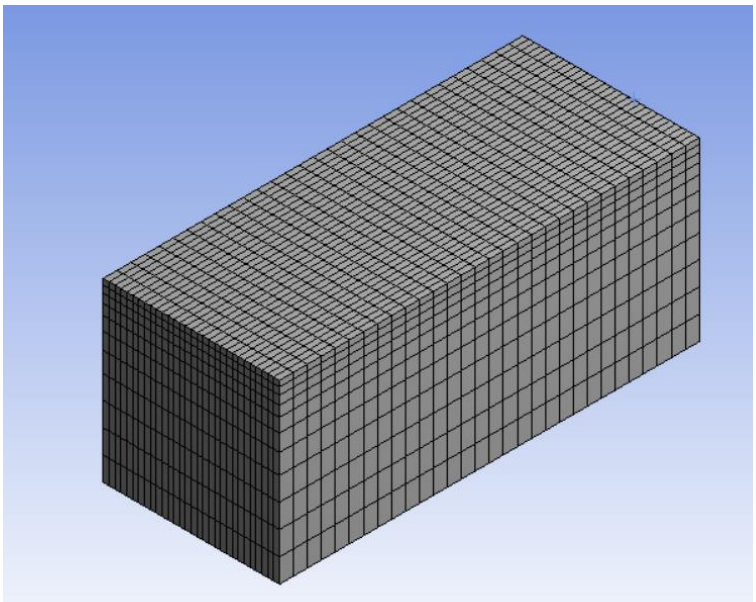


Fig. 2. Final fine mesh selected for experimentation

2.3 Solver Settings

The Solver was set as 'Pressure Based' and the turbulence model was set as k-epsilon. The k – epsilon turbulence model is widely used in research and industries application [19] hence k-epsilon turbulent model is employed for the present study. In the material section, both wind and rain (water) were created as fluids for the simulations. The fluid speed for the velocity inlet was set at 50 m/s for x axis. The fluid velocity from y and z axis was set at zero as the study aimed to understand conditions from a single direction flow. The pressure contours recordings were then taken and recorded.

2.4 Validation

To validate the selected mesh, experiments were performed to check for the ideal pressure contour readings. The mesh model was varied using number of divisions which varied the number of nodes used for the mesh. The nodes were varied from 1152 to 15000. The mesh with 1152 nodes was obtained from the default mesh generated by ANSYS. The readings obtained from the study has been showed in form of a graph in Figure 3. As it can be seen from the graph, the pressure readings begin to slightly decrease and then stay constant from the 11532 nodes and since the main imperative of the study is to record the highest and most accurate pressure reading, the mesh model shown in Figure 2 with 11532 nodes and 9900 elements was chosen as the final model. Figure 3 signifies that the model is now stable and there is not much change in pressure when the model reaches 11532 nodes. This can be further validated from other studies [20-21]. The mesh model setting in Figure 2 was performed on the 0° rooftop model. The same settings were then set for the 45° and 60° rooftop model to maintain consistency.

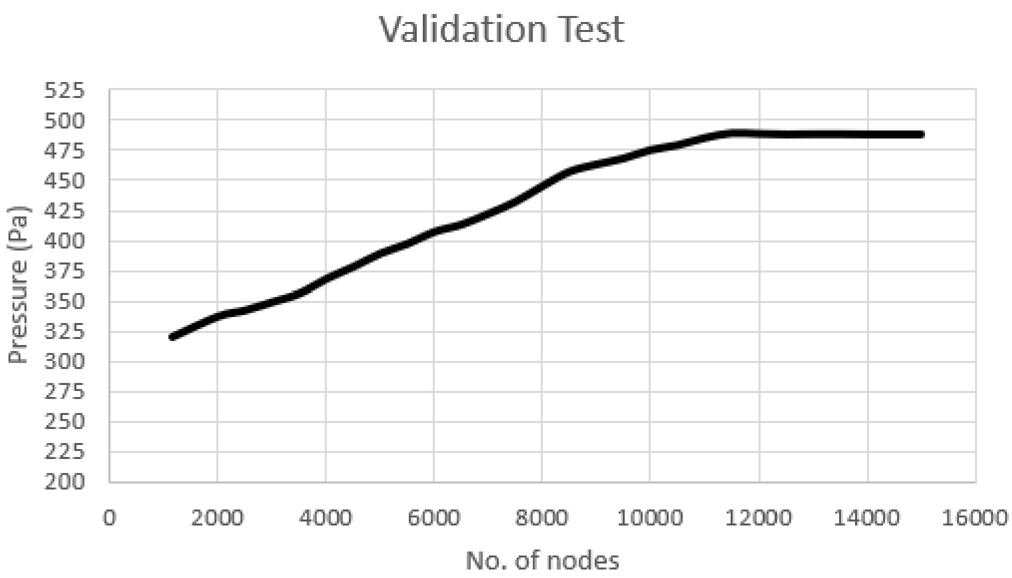


Fig. 3. Validation test study

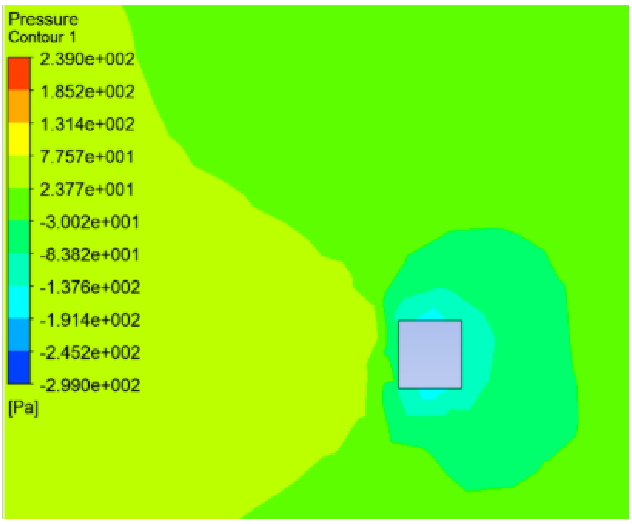
3. Results
3.1 Pressure Distribution

Having set up the ANSYS FLUENT model, the pressure contour resulting from the fluid motion hitting the rooftop at various angles at fluid speeds of 20 m/s, 30 m/s, 40 m/s and 50m/s has been recorded in Figures 4, 5 and 6.

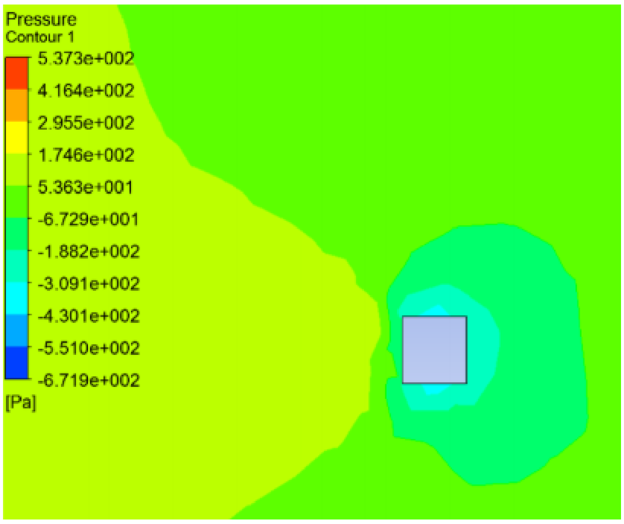
As observed from the pressure contour diagrams in Figures 4(a), (b), (c) and (d) for the rooftop at 0° angle, the pressure developed increases with an increase in fluid velocity.

As observed from the pressure contour diagrams in Figures 5(a), (b), (c) and (d) for the rooftop at 45° angle, the pressure developed increases with an increase in fluid velocity. However, when compared to the 0° rooftop angle, the pressure developed at the time of impact is less. With an increase in the rooftop inclination, the pressure during impact shows to be reducing.

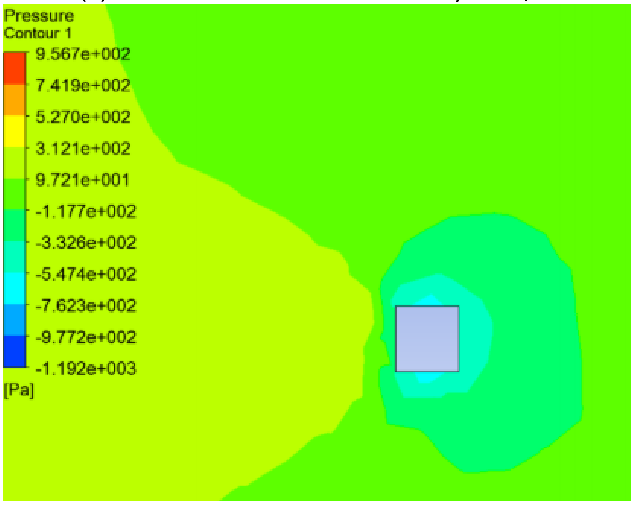
The simulation in the figures above shows that with an increase in the rooftop inclination angle, the effect of impact by the rain is less. This is shown by the pressure developed at the moment of impact is decreasing with increase in inclination angle. This suggests that the effect of pressure on the roof by the rainwater and wind fluid mix will be the highest for a flat surface as compared to a roof which is at an inclination. The pressure at the time of impact has been used to develop the corresponding voltage that can be developed from it as shown in Table 1 using Eq. (1).



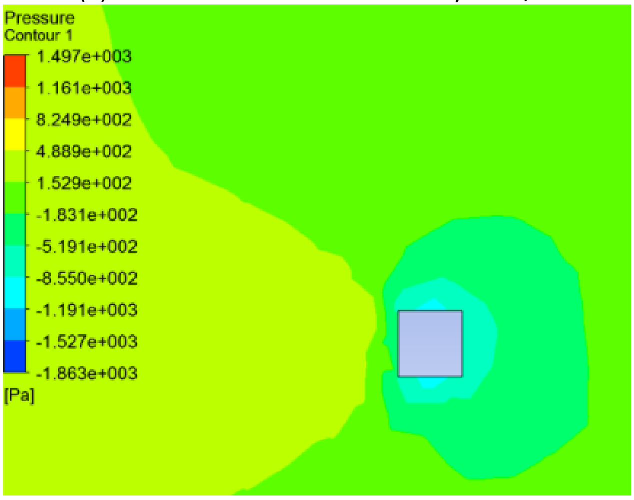
(a) Pressure Values at Fluid Velocity 20 m/s



(b) Pressure Values at Fluid Velocity 30 m/s

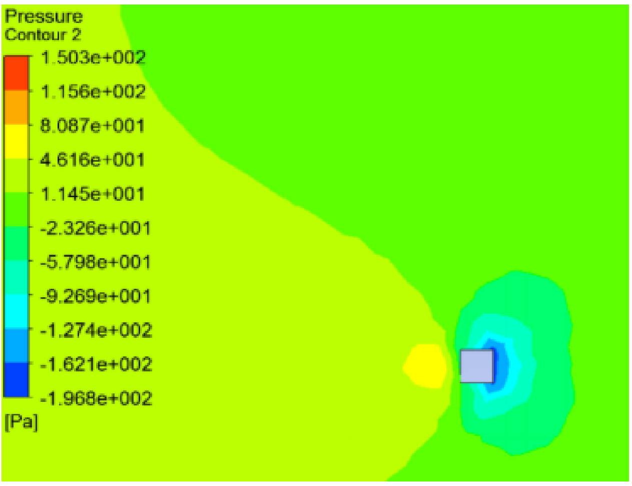


(c) Pressure Values at Fluid Velocity 40 m/s

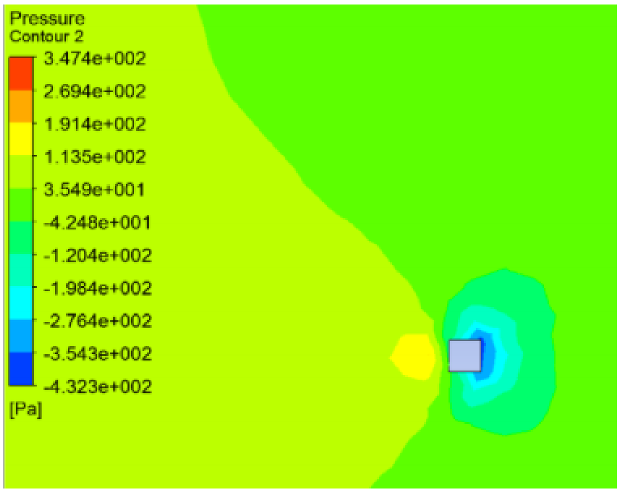


(d) Pressure Values at Fluid Velocity 50 m/s

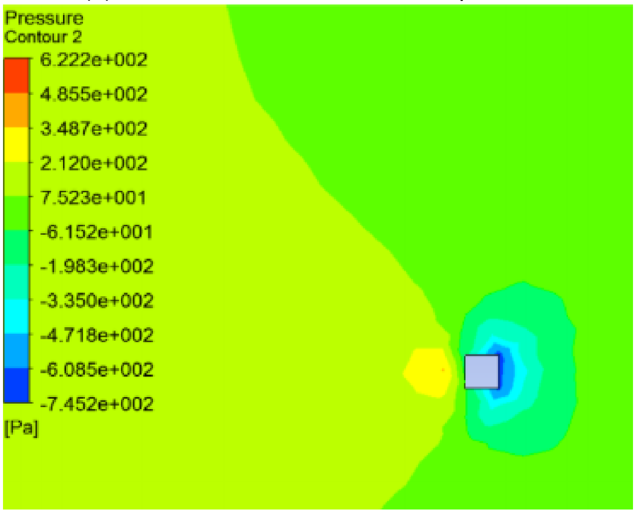
Fig. 4. Pressure contours of fluid striking rooftop at 0°



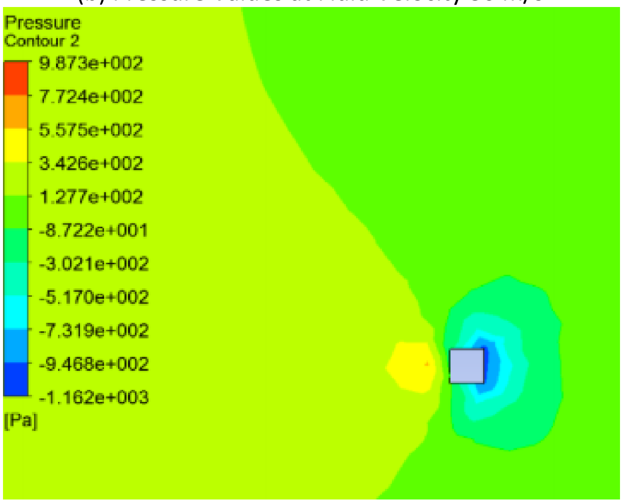
(a) Pressure Values at Fluid Velocity 20 m/s



(b) Pressure Values at Fluid Velocity 30 m/s

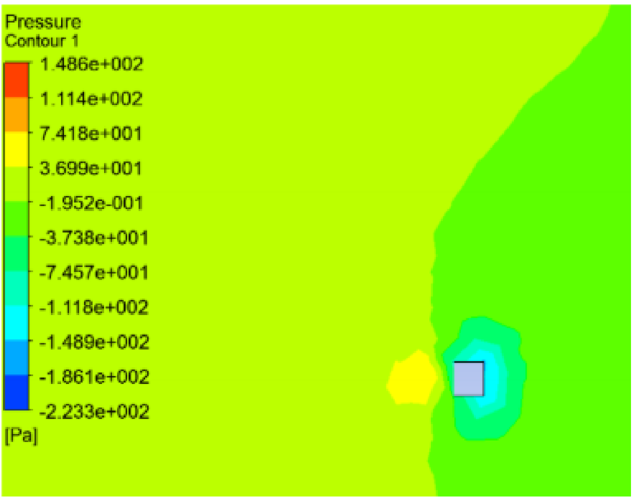


(c) Pressure Values at Fluid Velocity 40 m/s

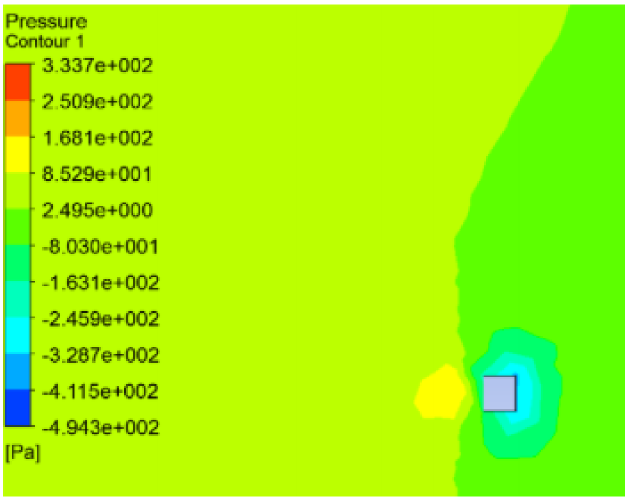


(d) Pressure Values at Fluid Velocity 50 m/s

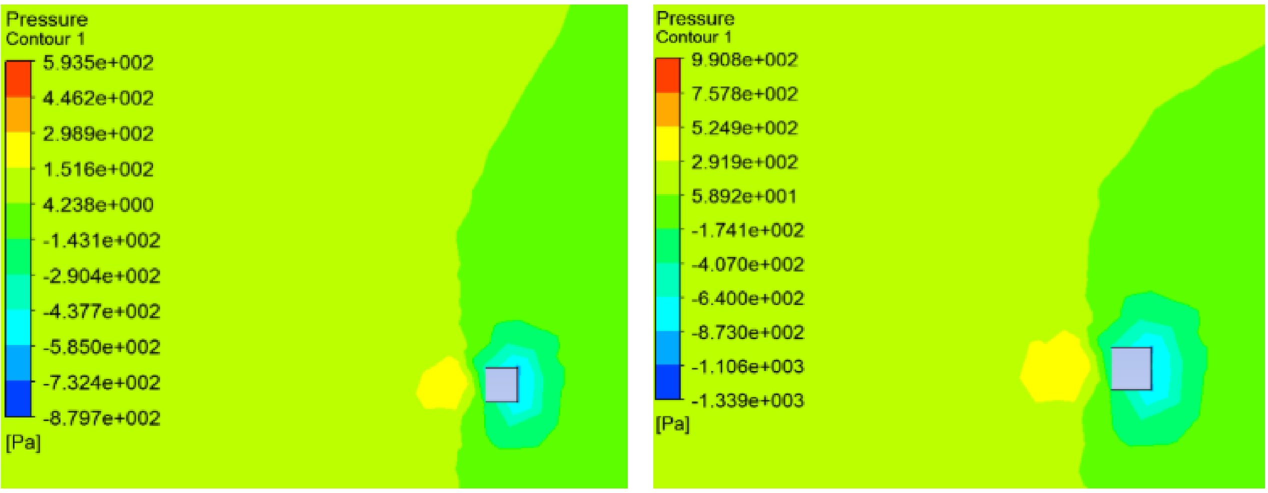
Fig. 5. Pressure contours of fluid striking rooftop at 45°



(a) Pressure Values at Fluid Velocity 20 m/s



(b) Pressure Values at Fluid Velocity 30 m/s



(c) Pressure Values at Fluid Velocity 40 m/s (d) Pressure Values at Fluid Velocity 50 m/s

Fig. 6. Pressure contours of fluid striking rooftop at 60°

3.1.1 The effect of pressure developed before striking the surface

The piezoelectric material used with taken into consideration for this experiment is a 7BB-20-3 model. It is made of brass with a plate diameter size of 20 mm, electrode diameter size of 12 mm, element diameter size of 14 mm and thickness of 0.22 mm. This is within the recommended settings [22]. As per the data sheet of the material, the piezo electric constant is 2.65×10^{-3} Vm/N.

Having found the pressure values, the following equation was then used to identify the voltage that can be generated from the piezoelectric cells in disc form and force being distributed over the thickness.

$$V = \frac{g_{33}Fh}{\pi r^2} \tag{1}$$

where the static voltage is V, Force acting per unit area is F, the Piezoelectric constant is g_{33}, the thickness of the disc is h and radius of the electrode size disc is r.

Table 1
Voltage calculations from the ANSYS FLUENT simulation

Roof angle	Fluid flow speed (m/s)	Max pressure developed before hitting (Pa)	Voltage generated per cell (V)
0°	20	77.0	3.96
	30	175.0	9.02
	40	312.0	16.08
	50	489.0	25.21
45°	20	46.2	2.38
	30	113.5	5.85
	40	212.0	10.93
	50	343.0	17.68
60°	20	36.9	1.90
	30	85.3	4.40
	40	151.6	7.81
	50	291.9	15.05

In all rooftop inclination angles, it is observed that with an increase in fluid velocity, more voltage is generated. This indicates a direct collaboration with voltage developed with respect to pressure generated and fluid velocity during impact with the rooftop element. The comparison is further summarised in Figure 7.

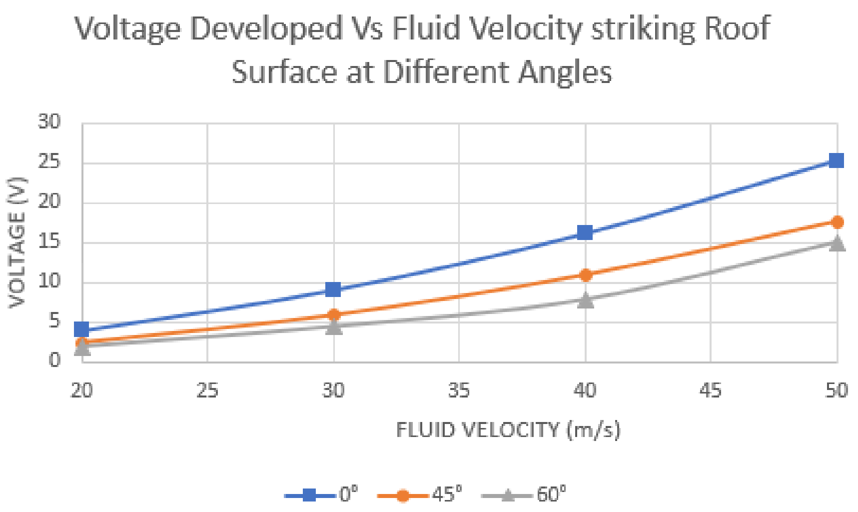


Fig. 7. Voltage vs fluid velocity comparison

4. Conclusions

In conclusion, ANSYS FLUENT simulation has successfully shown that rainwater and wind can definitely act as potential sources to generate electricity by utilising the pressure developed from rain and wind striking roofs of buildings at various speeds. The simulation results shown the piezoelectric models can be substantially used to generate electricity from pressure generated.

The study can be used to design appropriate piezoelectric cells or piezoelectric harvesters to improve efficiency of generating electricity from falling rainfall and can be implemented in areas that receive moderate to heavy rainfall.

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