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Research paper

Design & Development of a Gravity Powered Fan Using Gear Transmission

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Abstract

The provision of affordable and sustainable living has become one of the biggest challenges to rural and marginalized people where access to electricity is prohibitively expensive. The conventional energy generation and the sole nature of fossil fuels have promoted the use of renewable energy methods. There are various categories of renewable and non-renewable energy resources which are present in our planet, one of them being gravitational energy. This paper covers the design, experimentation, and development of a prototype of a fan which converts the gravitational energy to kinetic energy of the impellers by a falling mass with the help of gears for the generation of air. Renewable energy will play a vital role in providing thermal comfort to the vast population in developing hot climate countri es where access to electricity is limited.

Keywords: *Renewable energy; Gravity; Gears; Fan; Mass; Airflow*

1. Introduction

Almost two billion people, mostly in rural areas, have elevated temperatures throughout the year and have limited access to modern forms of cooling systems. In such areas, renewable energy is believed to be one of the top contenders to improve their lifestyle [1]. These people live in regions of the world where the population are growing very rapidly. To make a difference in their quality of lives, cheaper alternate forms of cooling systems must be provided.

It is very suitable to generate power by the use of gravitational potential energy as it consistent and available all over the world. The power which can be generated by the means of this energy is suitable for populated areas as it doesn't require any fuel or supply resources like water, coal, wind, etc. [2, 3]. Previously, similar principles have been used for the generation of electricity with the help of mass, gear, and an AC Synchronous motor [4]. Development of gravity powered light has also been a revolutionary means in creating illumination. The use of gravity is superior to using solar powered, as the device can be operated all day and night under any climate conditions with zero running costs [3].

The design of a fan depends on the airflow. Cubic feet per minute (CFM) is the usual unit to express fan airflow (volume of air moved by a fan per unit time). In general, airflow is calculated by four methods (area method, air change method, occupancy method, and heat removal method). Area, air change, and heat removal methods deal with occupying space and occupancy method deals with occupants themselves. This paper is concerned about the number of occupants and therefore, only occupancy method is considered for airflow rate calculations. According to U.S. Department of Energy Weatherization Program, the airflow rate must be greater than 15 CFM per occupant [5]. For the Gravity Fan, the calculations were done to get a CFM of at least 250 which will provide enough airflow for approximately 17 occupants

2. Fan Components and Derivation of the Equations

The gravity fan is used to rotate the fan by creating a large amount of torque by attaching a mass which then would rotate the fan. The mass would then fall some distance to the ground. The mass is attached to the pulley by a rope wound around it. As the pulley starts to rotate, it would rotate the input shaft attached to it. The gears connect the input shaft and the output shaft by means of a compound gear formation. By utilizing different sized gears, the gear ratio causes the output shaft to rotate at a greater speed than the input speed.

2.1. Fan Components

Figure 1 shows the major components of the fan which are required for the operation of the fan.

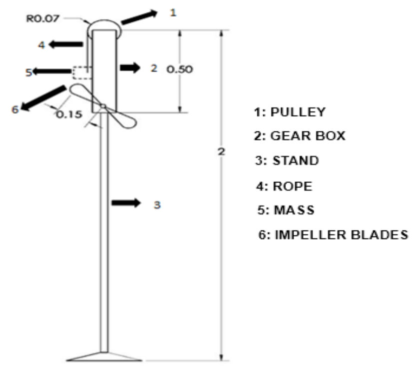


Figure 1. Components of the Fan (Units in m)

The gearbox contains an arrangement similar to the com-pound gear arrangement shown in Figure 2. The actual gearbox used in the model has an arrangement of com-pound gears having a total gear ratio of 1:216 as shown in Figure 3.

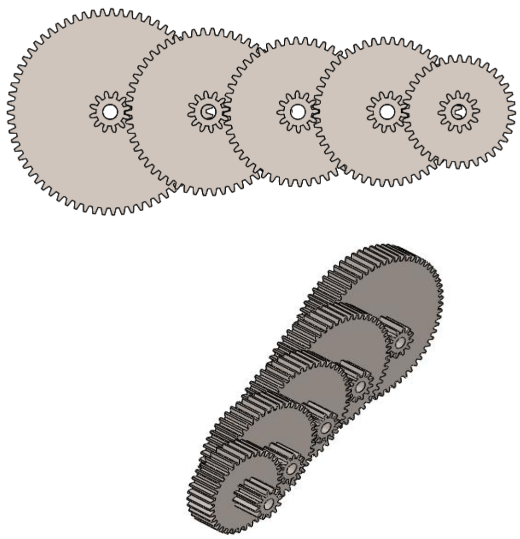


Figure 2. Front and reverse isometric views of a typical compound spur gear arrangement.

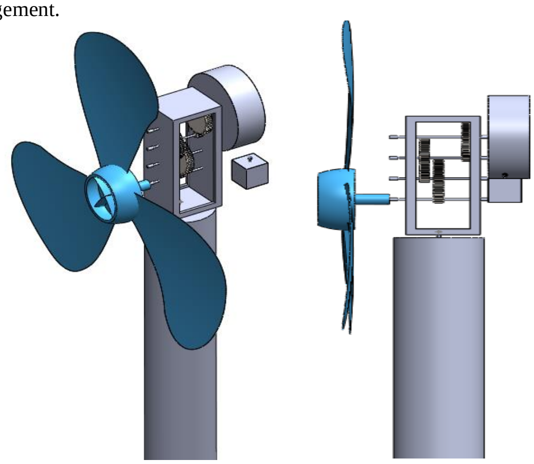


Figure 3. Solidworks Model of the Prototype

2.2. Equation Derivations

Efficiency Energy in = Energy out
This implies,

$$\eta_{gears} \times \eta_{bearings} \times \eta_{fan} \times P.E_{mass} = K.E_{mass} + R.K.E_{gears} + R.K.E_{pulley} + R.K.E_{fan} + K.E_{air} \quad (1)$$

Let,

$$\eta_{total} = \eta_{gears} \times \eta_{bearings} \times \eta_{fan} \quad (2)$$

The control volume is defined as the fan as shown in Figure 4. Air passing through the fan cannot have an increasing velocity since that would generate shockwaves. As a result, there is only an increase in pressure, which normalizes after a certain distance. To calculate the energy needed to move air across the fan, Kinetic energy equation energy can be used.

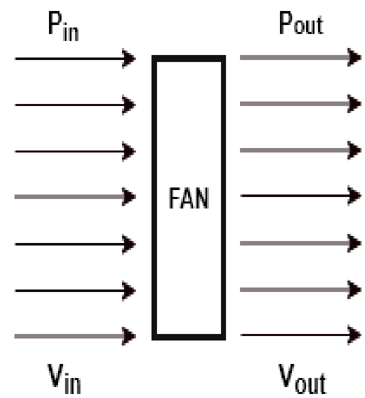


Figure 4. Control Volume

Assuming, no change in static pressure across the fan blade,

$$K.E_{air} = \frac{1}{2} m {V_{air}}^2$$

Since the mass of the air travelling through the fan is un-known, the power can instead be used.

$$Power_{fan} = \frac{1}{2} \dot{m} V_{air}^2$$

And since Power and Energy are related in terms of time, Kinetic energy of the air becomes,

$$K.E_{air} = \tfrac{1}{2} \dot{m} {V_{air}}^2 t = \tfrac{1}{2} \rho A V_{air}^3 t \quad (3)$$

Substituting in equation (1) yields,

$$\eta_{total} \times mgh = \tfrac{1}{2} m (\omega r_p)^2 + \tfrac{1}{2} I_p \omega^2 + \tfrac{1}{2} I_{g_1} \omega^2 + \Big\{ \Big[\tfrac{1}{2} I_{g_1} \omega^2 + \tfrac{1}{2} I_{g_2} \omega^2\Big] {G_1}^2 + \Big[\tfrac{1}{2} I_{g_1} \omega^2 + \tfrac{1}{2} I_{g_2} \omega^2\Big] {G_1}^2 {G_2}^2 + \Big[\tfrac{1}{2} I_{g_1} \omega^2 + \tfrac{1}{2} I_{g_2} \omega^2\Big] {G_1}^2 {G_2}^2 {G_3}^2 + \Big[\tfrac{1}{2} I_{g_2} \omega^2\Big] {G_1}^2 {G_2}^2 {G_3}^2 {G_4}^2 \Big\} + \frac{{G_1}^2 {G_2}^2 {G_3}^2 {G_4}^2}{2} I_f \omega^2 + \tfrac{1}{2} \rho A V_{air}^3 t$$

$$\eta_{total} \times mgh = \frac{1}{2} \omega^2 \{ m{r_p}^2 + I_p + (I_{g_1}) + [I_{g_1} + I_{g_2}] {G_1}^2 + [I_{g_1} + I_{g_2}] {G_1}^2 {G_2}^2 + [I_{g_1} + I_{g_2}] {G_1}^2 {G_2}^2 {G_3}^2 + [I_{g_2}] {G_1}^2 {G_2}^2 {G_3}^2 {G_4}^2 + {G_1}^2 {G_2}^2 {G_3}^2 {G_4}^2 I_f \} + \frac{1}{2} \rho A V_{air}^3 t$$

$$\eta_{total} \times mgh = \frac{1}{2}\omega^2 \left\{ m{r_p}^2 + I_p + (I_{g_1})_1 + \sum_{i=2}^{s-1}\left[(I_{g_1}+I_{g_2})_i \prod_{j=1}^{i} {G_j}^2\right] + \prod_{j=1}^{s} {G_j}^2\ [(I_{g_2})_s + I_f] \right\} + \frac{1}{2}\rho A V_{air}^3 t \tag{4}$$

From fan affinity laws, for two fans with equal blade diam-eters,

$$\frac{AV_1}{\omega_1} = \frac{AV_2}{\omega_2}$$

This implies,

$$V_{air} = \frac{V_{ref}}{\omega_{ref}} \prod_{i=1}^{s} G_i\, \omega$$

$$V_{air} = C\omega$$

where$C = \frac{V_{ref}}{\omega_{ref}} \prod_{i=1}^{s} G_i$ (5)

Substituting equation (5) back into the last term of equation (4) yields,

$$\frac{1}{2}\rho A V_{air}^3 t = \frac{1}{2}\rho A C^3 \omega^3 t = \frac{1}{2}\rho A C^3 \omega^2 \theta$$

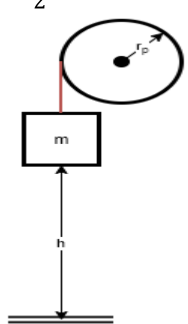


Figure 5. Mass and Pulley System notations

From Figure 5:

Angular displacement, $\theta = 2\pi\left(\frac{h}{2\pi r_p}\right) = \frac{h}{r_p}$ (6)

Therefore,

Rotational Fan kinetic energy $= \frac{1}{2}\rho A C^3 \omega^2 \frac{h}{r_p}$ (7)

Substituting equation (7) back into equation (4), and simplifying we get,

$$\omega = \sqrt{\frac{2\eta_{total} \times mgh}{\Lambda}} \tag{8}$$

Where,

$$\Lambda = m{r_p}^2 + I_p + (I_{g_1})_1 + \sum_{i=2}^{s-1}\left[(I_{g_1}+I_{g_2})_i \prod_{j=1}^{i} {G_j}^2\right] + \prod_{j=1}^{s} {G_j}^2\ [(I_{g_2})_s + I_f] + \rho A C^3 \frac{h}{r_p}$$

Assuming constant acceleration, α, we can find the time taken for the mass to fall.

Since, there is no initial angular acceleration, and substitut-ing equation (6)

$$t = \frac{2h}{\omega r_p} \tag{9}$$

The flow rate in cfm can also be calculated in this manner,

$$V_{air} = C\omega$$

$$Q = 2118.88 A_{fan} V_{air} \tag{10}$$

Notations used:
$I_p = Moment\ of\ Inertia\ of\ the\ pulley$
$I_f = Moment\ of\ Inertia\ of\ the\ fan$
$I_{g_1} = Moment\ of\ the\ Inertia\ of\ the\ first\ gear\ in\ the\ stage$

$I_{g_2} = Moment\ of\ the\ Inertia\ of\ the\ first\ gear\ in\ the\ stage\omega$
$= Angular\ velocity\ of\ the\ first\ gear\ or\ pulley$
$G_1, G_2, G_3, G_4 = Gear\ ratios\ at\ different\ stages$
$m = Mass\ Attached$
$s = Number\ of\ compound\ gear\ stages$
$g = Gravitational\ Pull\ of\ the\ Earth$
$\rho = Density\ of\ air$
$A = Area\ of\ the\ fan$
$V_{air} =$
$Velocity\ of\ air\ passing\ through\ the\ fan$
$Q = Airflow\ rate$

3. Results

3.1. Preliminary Experimentation

In order to benchmark the Gravity Fan, an experiment was carried out on a conventional fan using a digital anemome-ter and a tachometer. The digital anemometer was used to obtain the speed of the air from a working fan. The tachometer was used in order to find the rotational speed of the output shaft in a fan. These data were then used in order to calculate the mass required to provide sufficient torque to the shaft in order to meet the criteria set by current fans. The results found by experimentation are depicted in Table 1.

Table 1. Preliminary Experiment Data

S No.	Anemometer Readings (m/s)	Tachometer Reading (rpm)
1	4.21	1455
2	4.01	1449
3	4.29	1450
4	4.02	1452

Upon averaging and converting these values, we get,

$V_{ref} = 4.13\ m/s \omega_{ref} = 152\ rad/s$

These values will be useful in the next section where the theoretical results are found.

3.2. Theoretical Values

From [6] assuming Anderson and Lowenthal model,

$$\eta_{gears} = 0.9$$

From [7] for a fan efficiency grade of 71, $\eta_{fan} = 0.68$
Assuming negligible bearing resistance, therefore $\eta_{bearings} = 1$

$$\eta_{total} = 0.9 \times 0.68 \times 1 = 0.612$$

Only two types of gears are used for fabrication of the real product, 10 teeth and 60 teeth, Module 1.5 gears. Therefore, the product had three compound gear stages with a total gear ratio of 1:216. Other values are as shown below.

$$I_f = 0.0017\ kg.m^2 I_p = 0.0012\ kg.m^2 I_1 = 0.000599\ kg.m^2 I_2 = 0.000299\ kg.m^2 r_p = 0.007\ m r_f = 0.015\ m$$

For the first case, the height of the mass from the ground was fixed at 2m.
Upon substituting these values for a range of masses, results obtained are as shown in Figure 6.

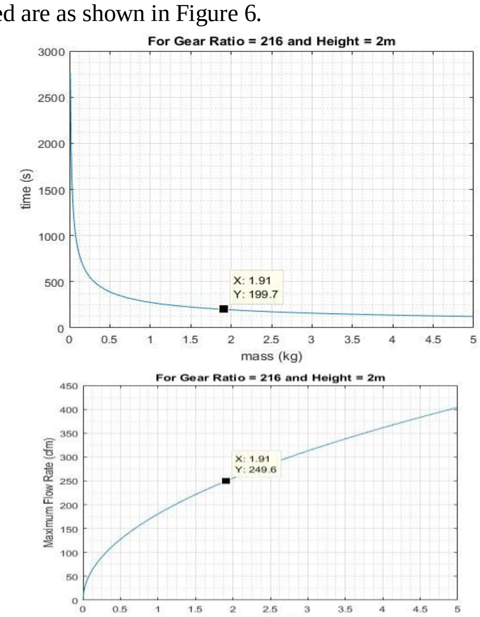


Figure 6. Effects of Mass Attached on Time and Flow Rate

As observed, the minimum required flow rate that was decided upon in previous sections in cfm was 250 cfm. For 250 cfm, a mass of 1.91 kg is required and the prototype operates for a total time of about 199.7 s. These plots suggests that as mass increases, the flow rate increases but is compensated by decrease in time. Therefore, choosing an optimum mass is very important to have sufficient air flow and time.

For the next case, the effect of gear ratio is evaluated with respect to flow rate and time. In this case a mass of 10 kg, and a height of 2m was fixed. The results obtained are shown in Figure 7.

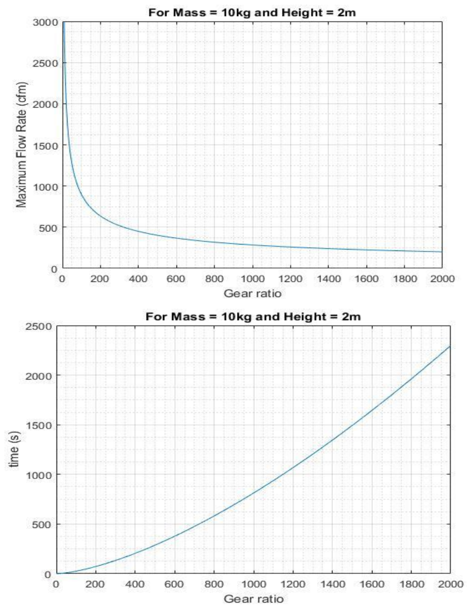
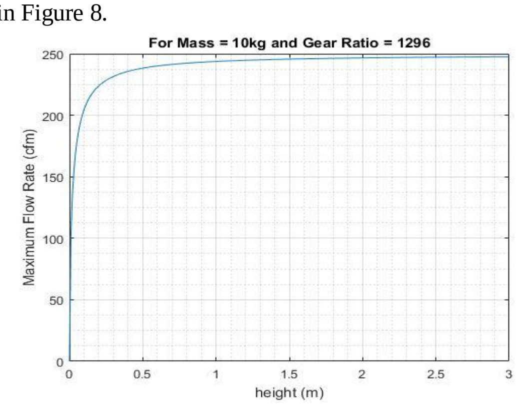


Figure 7. Effects of Gear Ratio on Time and Flow Rate

As observed from the plots, increasing gear ratio decreases the flow rate and increases time. But this ideal condition will not work out. Since, every system will have a friction force to overcome. Therefore, the minimum mass required will keep increasing as the gear ratio increases. Choosing a very high gear ratio will also be useless as the mass requirements will increase by a lot and the person lifting the mass will have to work harder.

For the next case, the effect of height on flow rate and time is evaluated. In this case, a mass of 10 kg, and a gear ratio of 1:1296 was fixed. The performance when this arrangement is used is shown in Figure 8.



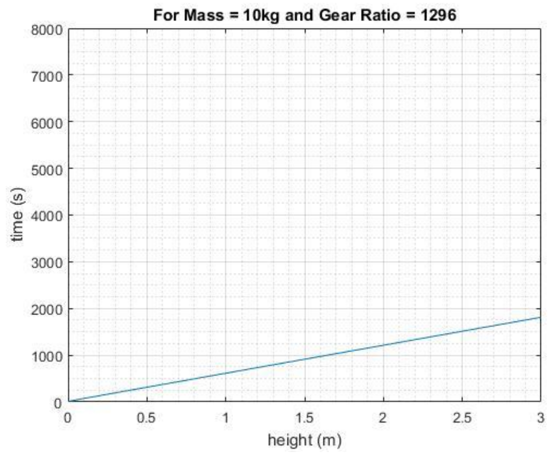


Figure 8. Effects of Height from Ground on Time and Flow Rate

As observed, increasing height increases time but it has neglibible effect on the flow rate. Since in the equation the last term has the highest value and when substituted into equation (8), h variable almost cancels. But this will not be true if the gears are made of heavier material or larger dimensions.

3.3. Verification by the Prototype

After manufacturing all the parts and assembling the prototype, experiments were conducted to observe the actual effects of different masses on the system performance. The results were recorded using a digital anemometer and a stopwatch to measure the velocity of air and the time taken for the mass to fall, respectively. The averaged results are as shown in Table 2.

Table. 2 Prototype Experiment Data

Mass (kg)	Time (s)	Velocity (m/s)	Flow rate (cfm)
1.5	198	1.11	164.79
2	170	1.41	209.73
2.5	151	1.59	239.69
3	130	1.82	269.65

The results when plotted in comparison to the theoretical values as shown in Figure 9 show similar behaviour. The fan starts rotating at a minimum of 1.5 kg. The curve before that is realistically impossible to achieve, as there is inertia and friction forces that the mass has to initially overcome. But as observed to get a flow rate of 250 cfm, a mass of almost 2.8 kg is required. Which is 0.9 kg more from the theoretical value. Also the experimental efficiency is 0.513, which is lower than the theoretical efficiency taken to be at 0.612.

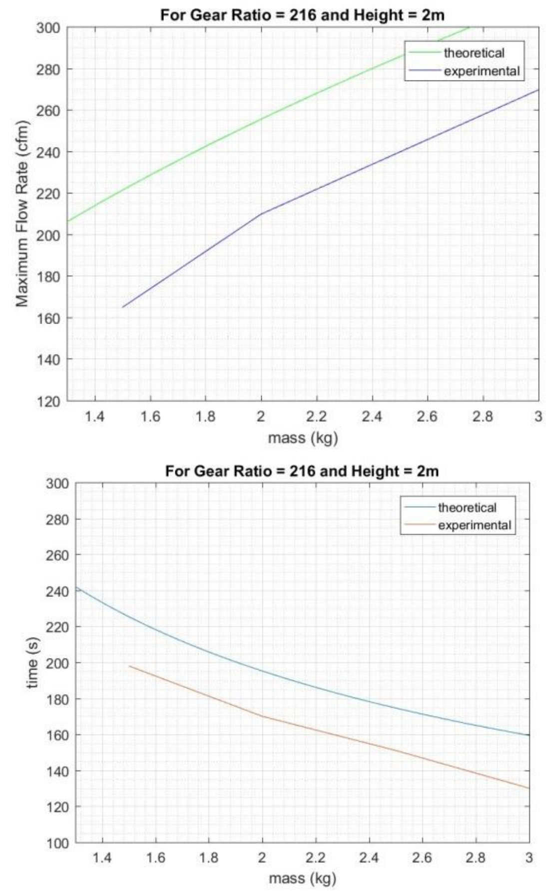
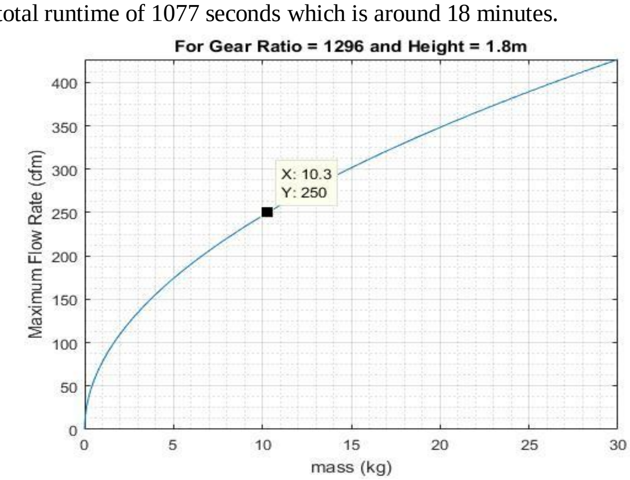


Figure 9. Theoretical vs. Experimental values

3.4 Recommended Specifications for Industrial Application

Upon testing different combinations theoretically, the best combination chosen is as following. Minimum gear ratio of 1:1296 for 4 compound gear stages, with a gear ratio of 1:6 at each stage. Height from mass to ground: 1.8m.

The performance of this configuration is shown in Figure 10. To get a flow rate of 250 cfm, 10.3 kg mass is required and this provides a total runtime of 1077 seconds which is around 18 minutes.



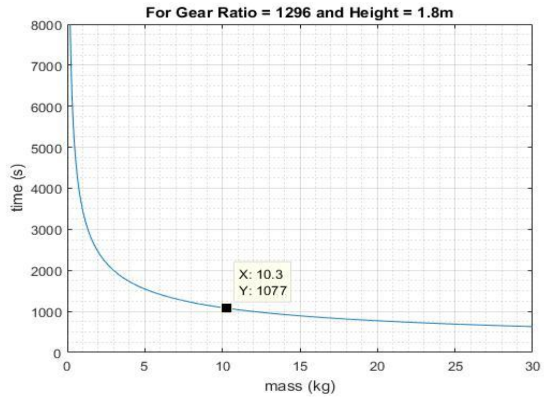


Figure 10. Performance of Recommended Configuration

4. Conclusion

The prototype designed was able to achieve sufficient air flow rate and time for an acceptable mass. To improve the performance, another configuration was suggested in the previous section. The fan has scope for improvement. The pulley-mass system can be improved by making the pulley using a freewheel ratchet mechanism. This mechanism will allow the users to pull the mass back to the starting point without rotating the gears or the fan. Also, to reduce the noise due to the gear contact, helical gears may be used instead of spur gears.

References

[1] J. P. Painuly, “Barriers to renewable energy penetra-tion: A framework for analysis,” Renew. Energy, vol. 24, no. 1, pp. 73–89, 2001.

[2] R. S. Ambade, R. Prabhakar, and R. S. Tayade, “A Review on Gravity Power Generation,” vol. 3, no. 4, pp. 11084–11086, 2014.

[3] S. Hossen, T. Islam, and S. Hossain, “Design &Fabri-cationOf A Gravity Powered Light,” Proc. Int. Conf. Mech. Eng. Renew. Energy 2015 26 – 29 November, 2015, Chittagong, Bangladesh ICMERE2015-PI-254 Des., no. November 2015, 2016.

[4] R. F. Rangel, A. J. V. Dos Santos, C. Da Rocha Souto, and R. L. Pimentel, “Generation of Electricity Using Gravity,” Conf. Rec. - IEEE Instrum. Meas. Technol. Conf., vol. 2015–July, no. 7, pp. 527–532, 2015.

[5] R. Aldrich and L. Arena, “Evaluating Ventilation Sys-tems for Existing Homes,” U.S. Dep. Energy, no.February, pp. 1–26, 2013.

[6] N. Anderson and S. Loewenthal, “Comparison of spur gear efficiency prediction methods,” 1983.

[7] T. Mathson and M. Ivanovich, “AMCA’s Fan Effi-ciency Grades : answers to frequently asked Ques-tions,” AMCA Int. inmotion, vol. 9, pp. 8–13, 2011.