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Time Value of Energy as a Low-Cost Energy Efficiency Technique

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***Abstract* – Energy efficiency is one of the most widely used tools for both energy saving and environmental protection against greenhouse gases. Some energy efficiency techniques are being used to reduce energy consumption. This research focuses on optimising the relation of time and energy, where the best scenario of energy-saving for specified applications will be considered with the time required in achieving these scenarios. To implement this, we adopt two engineering applications (car and water pumps) on each application, with specific constraints and parameters to test the time energy relation. It was being found that for both applications, there is an optimum engineering scenario where the least amount of energy (using the extra time to minimise energy consumption) can be achieved while the remaining cases will consume higher energy. For instance, for a specific type of car used in this study, the optimum car speed was found to be between 65–70 km h^{-1}; at this speed, the car consumes the least amount of energy (around 137 MJ when travelling a distance of 100 km). All the speeds less than the optimum speed will consume more energy; the same is true when the speed is increased over the optimum. For the second application using water pumps, it was found that a 1.1 kW pump is the most efficient at pumping a specific amount of water, and using higher or lower rated pumps will consume higher energy levels but correspondingly will reduce the time required to perform the same application. This research emphasised the concept that time can save energy, which is not yet covered in the literature as time value of energy when time is not an essential aspect and can be delayed without affecting the main tasks.**

***Keywords* – Energy efficiency; energy consumption; time value of energy**

Nomenclature		
Q	Flow rate	m^3 hr^{-1}
h	Elevation/Head	m
ρ	Density	kg m^{-3}
g	Gravitational force	kg m s^{-2}

1. INTRODUCTION

Greenhouse gases like carbon dioxide and other heat-trapping gases negatively affect the climate and are considered as one of the biggest challenges ever faced by humans. Due to the

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industrial revolution at the end of the 19th century, the concentration of greenhouse gases dramatically increased. The concept of energy efficiency deals directly with climate change, whereas using engineering applications more efficiently works to reduce greenhouse gases. Energy efficiency can be defined as the provision of the same service or product but with a reduced amount of energy. Energy efficiency is being applied in engineering applications to reduce the total power consumed to perform a service or product. More efficient energy applications are those with the same engineering output that uses less power; this will be determined following the rated power of each unit.

For the main selected engineering applications, studies on different centrifugal pumps meeting the 2020 EU legislation on new energy and emissions targets were undertaken using a simulated thermal model. The model considered four different centrifugal pumps with different characteristics for each type (different discharge opening). In this research, a set of 60 000 pump operations for each type to see the generated results. It was being found that pumps with variable speed drive and higher energy efficiency classification get better results in terms of both total consumption and exhaust emissions [1]–[9].

Research for pumps in industrial facilities studies the potential cost of energy savings and is a reflection on the payback period. The study was built on actual readings of the pumps' flow rate, pressure, and temperature. The efficiency of the pumps' driving motor is also measured to evaluate overall system efficiency. Many researchers have found that the foremost opportunity for savings can be found in the replacement of low-efficiency pumps, where most motors run with efficiencies of (46–56 %) [10]–[13].

In cars' energy efficiency, studies focused on the direct relation of speed variation on fuel consumption compared to the results experimentally and numerically. The study considered a specific vehicle with the same driver on the same track at different speeds. Different driving strategies were considered and compared to generated results. It was concluded that the speed variation technique applied by athletes is efficient in terms of power-saving; the similar technique applied in cars (Pulse and Glide) was found to obtain better results on fuel consumption than other techniques [14]–[16].

Many works reflect the behaviour and performance of cars and the best way to improve energy efficiency in this type of engineering application. Friction generally has a negative impact on energy consumption; studies on the effect of friction in the transportation industry found that approximately one-third of the total energy consumed in transportation is to overcome friction. The study focuses on reducing the effect of friction on mechanical parts and components in electric cars powered by advanced batteries, as well as the introduction of new lubricants and materials to reduce friction loss by 18–40 %. As a result, it was expected that a saving of 8.7 % of the total global energy could be achieved and 1.4 % of the gross national product (GNP). Additionally, it was found energy consumption and friction losses in battery-powered electric cars show a benefit of 3.4 % if compared to conventional internal combustion engines and a lowering in CO_2 emissions of 4.5 % if the source of energy in electric cars is coming from a renewable resource [17]–[22].

The well-known concept "time equals money" highlights the value of time in terms of money. For instance, USD 100 today will be USD 110 after one year (with a 10 % interest rate), which means one year is equal to USD 10. In a similar approach, we tried to assign a time value of energy as a low energy efficiency technology to highlight the effect of time to save energy.

Introducing time as an energy efficiency technique application is a new strategy, where we gain the benefit of time by obtaining a relation between time and energy. This can be witnessed when pumping water for a particular activity, and there is a need for a certain amount of water with a limited amount of energy; engineers are required to not only use the most efficient pumps but pumps that use the least amount of energy.

Household energy consumption remains ripe for behavioural intervention, being responsible for an estimated 31 % of U.S. CO_2 emissions. Many attempts to understand the factors that influence household energy efficiency behaviours [23]. Occupant behaviour is a complex element that has a substantial influence on building energy performance. Implied models are likely to remain the leader in simulating the differences in occupant behaviour shortly. Simulated occupant behaviour may not be predicted precisely and interfaces with other buildings' elements [24]–[27].

Energy behaviour research is vast and has been primarily focused on the residential sector, striving to establish behaviour determinants and the best strategies and instruments to promote more efficient energy behaviours. Potential savings of energy behaviours are referred to reach 20 %. Different modelling techniques have been used to model energy behaviours, such as qualitative approaches from the social sciences trying to interpret behaviour [28].

Users behaviour one of the main factors affecting energy consumption for many machines and home appliances in the residential, industrial; commercial, and transport sectors. For instance, in the residential sector, the occupants behaviour influence the overall building energy consumption as the occupants in energy-efficient buildings should consider natural methods of ventilation by adapting to changes in the weather instead of being reliant on mechanical systems of heating and cooling. So for building the designers have some responsibilities in training the occupants of how to use their future home using, for example, a simple brochure/ manual illustrating when and how to apply the main energy-efficient techniques inside the building [29]–[32].

Seven air-conditioned buildings in South Korea were used to assess the effects of the occupants' control on their environment and their effects on cooling energy consumption. The findings suggest that the level of control of the occupants over their thermal environment could reduce thermal energy consumption by almost 10 % without impacting occupant thermal comfort [33].

The implementation of driving styles in adaptive cruise control systems promises to reduce fuel consumption of vehicles considerably. As drivers have to accept the optimized driving styles of such systems, which implement longitudinally automated driving, to meet the expectations of drivers by directly accounting for driver's preferences on weighting up travel time against fuel consumption relative to the average driving profile [34].

A study on the impact of driving characteristics on electric vehicle energy consumption and range showed that over several driving trials that energy consumption is significantly affected by driving style, and that through fundamental statistical analysis of acceleration profiles, for instance, a metric for assessing 'good driving practice' can be obtained. It is ultimately shown that the difference between driving moderately and more aggressively can make a ~30 % difference in energy consumption – amounting to 30 g km^{-1} of CO_2 (equivalent) over the driving duty considered in this case [35].

Introducing time as the main factor of energy efficiency is a new technique and is considered the first of its kind to adopt such a relation; as such, it was difficult to find literature that directly considered this relation.

This research will select two engineering application pumps and cars to apply this concept and find a relation between time and energy for each application. The research will go through each selected engineering application individually in order to analyse the way each application works, what factors have a direct impact on energy consumption, and the main differences are between different types of each application.

The main objective of this research is to study ways to save energy by considering time as a significant factor and low-cost energy efficiency techniques. Another expected objective is to obtain a correlation between time and energy that can be used for different engineering applications. The benefit of this correlation is the direct conversion of time into energy. In other words, they are converting the additional time available, into more useful "energy" so that engineers can base their decisions on them accordingly.

2. METHODOLOGY

To apply energy time relations, two machines were selected a car and a pump. To perform the analysis, constraints were created for each application – the following section will identify these constraints and the setting for each application. Due to the changing behaviour of each engineering application, it is expected that the analysis methodology will vary for each application based on the application of nature. MATLAB software will be used as an analysing technique for selected applications.

2.1. Cars

In our trial, we will select a car and a track. We will endeavour to fix most of the variables that affect fuel consumption (such as driving technique, rolling resistance, engine modification, car aerodynamics, acceleration, etc.). The only variations will be to alter the car speed or fuel consumption; this will allow us to study the effect of time in energy for the cars. In order to implement this, we will execute the study experimentally, selecting a particular car, and studying all the constraints that the car may expose while on a particular track. The track, driver, and the car are also fixed factors to obtain similar results for each trial.

Fig. 1. The selected track route (Using Google Maps).

As a result of our study, we are expecting to find a relationship between fuel consumption and extra time saved. Some constraints must be identified in order to obtain this relationship.

To gain consistent results, some variables need to be fixed to avoid affecting fuel consumption (such as the driving technique, rolling resistance, engine modification, car aerodynamics, acceleration, etc.), the only exception being changed to speed (fuel consumption). To perform this, we conducted the trial experimentally using a car with the same driver and track (Toyota Prius 2015). The only factor we changed is the car speed for every executed trial that results in a change in both fuel consumption and time. The selected track is 20 km, and due to expected jams and traffic lights, all the trials were executed in the early morning around 6:00 AM to avoid unnecessary delays resulting from rush hour.

To determine the real fuel consumption, we will use the car consumption sensors available on the monitoring screen of the car (Toyota Prius 2015). This reading is individually calculated for each trip at a rate of (l/100 km). From the collected data, we will obtain the car's average speed and fuel consumption; based on the average targeted speed, the time required to travel a 100 km distance will be obtained; and from the fuel consumption we can obtain the total energy required to cover the required distance by considering the higher heating value of gasoline to be equivalent to 45.7 MJ kg^{-1} and the density of gasoline is 0.75 kg L^{-1}.

2.2. Pumps

When comparing the performance of pumps, we use the pump characteristics curve to provide a precise prediction for all the variables that control the performance. The power of the pump is calculated by either knowing the characteristic curve of the pump or by the relation that controls the power. Both the volume flow rate (Q) and the total pump head (h) are the factors affecting the power as per the primary controlling relation if we consider the density (ρ) and the gravitational force (g) to be constant for the same location and same water properties.

$$P = Q \cdot \rho \cdot g \cdot h \tag{1}$$

The above factors will be fixed, and only the flow (Q) will be changing. This will give us a curve relation expressing the velocity (flow rate) – power relation. The second step will be changing both power and velocity into energy-time relation.

We will be using different pumps, and thus a different characteristic curve for each trial; in order to make a reasonable comparison, we will assume a fixed volume of (150 m^3) and fixing the head is at a point of (10 m).

3. Results and Discussions

During this section of the research, we will illustrate the data collected for each application and collate the results in order to get the time energy relation of each application. In each trial reading, there are primary data to be collected; time is taken to reach the endpoint of the track, the speed of the car, and the fuel consumption. This data is reflected in 100 km distance in order to obtain more accurate data. Based on these data, the below graph is generated for the time and energy.

Figure 2 shows real data collected for a car travelling a distance of 20 km then recalculated to find the energy consumption for a 100 km distance. From the figure, it is found that reducing the time (t) to cover the same distance requires more energy (E).

From the graph, the lowest energy consumption point is called the optimum car speed in which the car consumes the least amount of energy; the relation that controls the Figure 2 is illustrated in Eq. (2).

$$E = 43.51t^2 - 62.24t + 147.3 \tag{2}$$

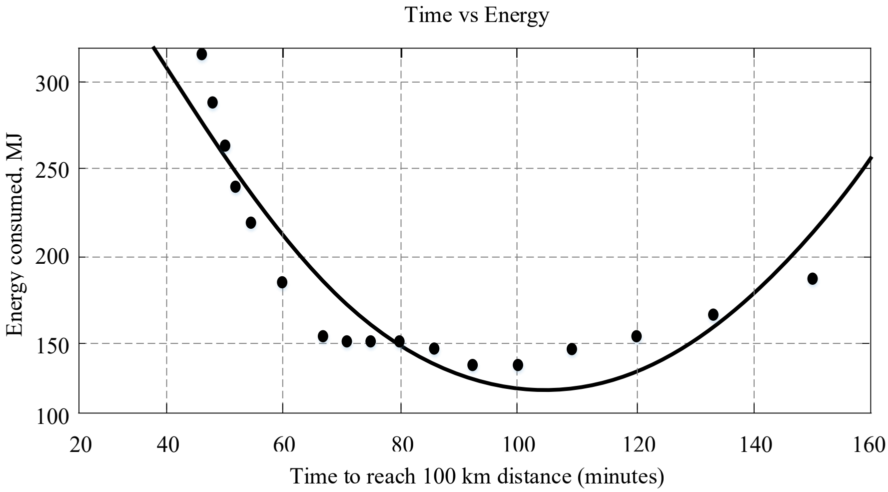

Fig. 2. Time and energy relation for Toyota Prius car.

Table 1. CARS ENERGY CONSUMPTION TO TRAVEL 100 KM

Speed, km h^{-1}	**Time, minutes**	**Energy, MJ**	**Δ*T*, %**	**Δ*E*, %**	**Δ*T*/Δ*E*, %**
40.00	150.00	188.51	–63 %	38 %	166.67 %
45.00	133.33	167.95	–44 %	23 %	198 %
50.00	120.00	154.24	–30 %	13 %	240 %
60.00	100.00	137.10	–8 %	0 %	Optimum
65.00	92.31	137.10	0 %	0 %	Optimum
70.00	85.71	147.38	7 %	7 %	95 %
75.00	80.00	150.81	13 %	10 %	133 %
80.00	75.00	150.81	19 %	10 %	188 %
85.00	70.59	150.81	24 %	10 %	235 %
90.00	66.67	154.24	28 %	13 %	222 %
100.00	60.00	185.43	35 %	35 %	99 %
110.00	54.55	219.56	41 %	60 %	68 %
115.00	52.17	240.23	43 %	75 %	58 %
120.00	50.00	263.29	46 %	92 %	50 %
125.00	48.00	288.75	48 %	111 %	43 %
130.00	46.15	316.60	50 %	131 %	38 %

There are two developed expressions in order to analyse the above relation quickly, the first expression is called (ΔT, %) and can be identified as the time-saving percentage comparing to the optimum value; where the negative value means it takes extra time and the second is the energy consumed percentage (ΔE, %) compared to the optimum value. This provides a more unobstructed view of time energy relation; all the percentage readings are calculated beyond the optimum car speed as a reference data point for the lowest fuel consumption.

(T_1, E_1) are time and energy calculated concerning the car's optimum speed, and (T_2, E_2) represents the time and energy for the point of speed to travel the 100 km distance. The above indicators can give a percentage of time-saving concerning the percentage of the energy consumed based on the datum (starting) point. From Table 1, the optimum engineering scenario is when driving at a speed of 65–60 km h^{-1}, and the energy consumption level is increased for both speeds lower and higher than this speed.

It is found that at the optimal average speed, the car consumes 137.1 MJ as the least point of energy consumption through the levels of average speed change, while in one case, we consumed 316 MJ to achieve the same application but with less time. So, the value of time would be around 180 MJ to travel the same distance but with a shorter period (almost half the time required compared with the optimum scenario).

TABLE 2. DATA COLLECTED FOR DIFFERENT PUMPS FOR 10 M HEAD

Pump Name	Volume flow rate, m^3 hr^{-1}	Power, kW
NM4-25/200	5.9	0.29
NM4-32/20	11	0.65
NM4-40/20	21	1
NM4-50/20	32	1.1
NM4-65/20	55	1.95
NM4-80/20	92	3.3
NM4-100/20	157	5.7
NM4-100/250	180	7.7
NM4-125/250	320	14.5
NMS4-150/315	395	18

For the second selected application "pumps", the selected pumps have different rated power; and by exposing each pump to the same application (filling the same tank with an exact head), each pump will give different results and can express the relation between time and energy correctly. By referring to the manufacturer catalogue, the power of these pumps ranges from 0.39 HP (for pump number NM4-25/200) to 24.1 HP (for NMS4-150/315). The required power has a direct impact on the time required to fill the desired tank. Below is the Table 3 showing these pumps. The relation between time (in terms of minutes) and energy (in terms of MJ) shown in Figure 3.

By looking at the Figure 3, it is found that reducing the time to fill the required tank is translated into increasing energy consumption. From the Figure 3, we can conclude that some low capacity pumps require both high power and a longer time to fill the tank, due to the low flow rate and inefficient pumps for to perform this task compared with more efficient pumps.

The formula that controls the relationship between time and energy is a polynomial relation from the fourth degree, as shown in the Eq. (3).

$$E = 9.187t^4 - 29.79t^3 + 10.71t^2 + 19.63t + 21.93 \quad (3)$$

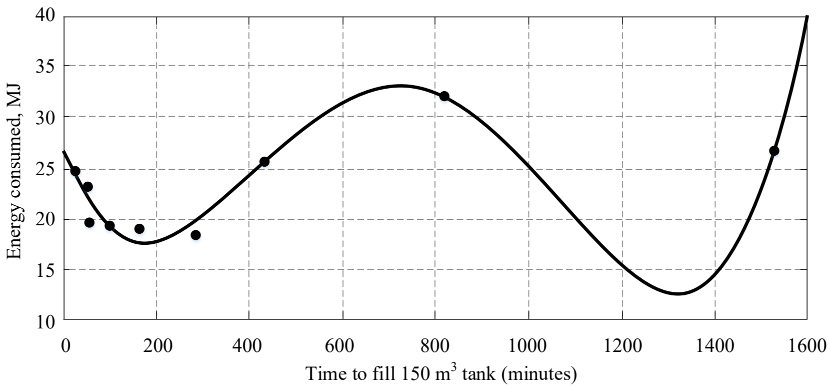

Fig. 3. Time and energy consumption to fill the 150 m^3 water tank.

It was assumed that the time energy relation is a fourth-degree parabolic relation to allow more realistic results to be collected. The below table expresses the collected data from each pump characteristic curve, where it is found that the pump named "NM450/20" is the optimum used pump for such an application.

TABLE 3. TIME AND ENERGY RESULTS GAINED FOR PUMPS

Pump	**Time required, min**	**Δ*T*, %**	**kWh**	**MJ**	**Δ*E*, %**	**Δ*T*/Δ*E*, %**
NM4-25/200	1525.42	442 %	7.37288	26.54	43 %	1029 %
NM4-32/20	818.18	191 %	8.86364	31.91	72 %	266 %
NM4-40/20	428.57	52 %	7.14286	25.71	39 %	136 %
NM4-50/20	281.25	0 %	5.15625	18.56	0 %	Optimum
NM4-65/20	163.64	–42 %	5.31818	19.15	3 %	1332 %
NM4-80/20	97.83	–65 %	5.38043	19.37	4 %	1500 %
NM4-100/20	57.32	–80 %	5.44586	19.61	6 %	1418 %
NM4-100/250	50.00	–82 %	6.41667	23.10	24 %	336 %
NM4-125/250	28.13	–90 %	6.79688	24.47	32 %	283 %
NMS4-150/315	22.78	–92 %	6.83544	24.61	33 %	282 %

From Table 3, the fit design pump consumes 5.15 kWh for a particular application, and by using different pumps, the power consumption is increased. Lower rated pumps consume higher energy and require a longer time to perform the required job because it is an unsuitable application for such pumps.

Each pump is required to fill a tank of 150 m^3 on the same head of 10 m. Due to the change in the rated power of each pump, a variance on the generated energy and the time taken to fill the tank is varied. It was found that using a pump with 1.1 kw power results in a minimum amount of energy compared to different sized pumps but with a longer time.

This study covered two engineering applications and could be extended to cover more application such as heat pumps and home appliances were using time could be one of the most effective tools to save energy and enhance the overall energy efficiency for residential and industrial sectors.

4. CONCLUSION

The research concentrates on the relation between time and energy, and it is considered cutting-edge research focusing on a topic such as an energy efficiency tool. The idea of connecting time and energy in the same correlation could benefit energy saving. Two applications were considered to study the behaviour of these applications and the effect of energy change on time.

On the first application (the car), an analysis was made based on the car speed, in which for each speed travelled both energy and time are collected and analysed. It was found that when driving 60–65 km h^{-1} is considered as the optimum driving speed, the consumed energy at this speed is the lowest among different driving speeds. When driving a speed of 130 km h^{-1}, the level of energy consumption is 130 % of the optimum driving speed.

On the other hand, on the second selected application (pumps), we fixed the primary need of the application and changed the size of the pump for each trial. From the collected data, it was found that there is an optimum rated pump that consumes the least amount of energy, and based on this pump, all other pumps that exert the same application have different behaviour regarding both time and energy. Each pump is required to fill a tank of 150 m^3 on the same head of 10 m. Due to the changes in the pumps rated power, which cause a variation in the generated energy and time were required to fill a specified volume. It was being found that using a pump with 1.1 kW power results in the minimum amount of energy expended compared to other different sizes of pumps but with a longer time.

We recommend the extension and implementation of this relation on different engineering applications. We have illustrated enhancements to the end-user relating to the understanding of the time value of energy as a low-cost energy efficiency technique, especially when time is not a critical factor in the process.

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