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Article

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Research paper

Energy efficiency and economic impact investigations for air-conditioners using wireless sensing and actuator networks



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ABSTRACT

Air conditioning systems accountable a huge amount of energy consumption, the purpose of this work is to inspect the energy efficiency and the economic impact for air-conditioners using Wireless Sensing and Actuator Networks. Different methods are explored. Referring to ASHRAE Standard 62.1-2007 specified by manufacturers, the real case study tested for all rooms in the MUAB and using Wireless Sensor and Actuator Networks (WSAN) for detecting and assessing diverse technique of the conditioners in order to compare them with the existing on the market, the main results mention that the old conditioners should be replaced. Power parameters analysis proves that substituting actions applied in the main building enhance a preserving of 10% in the regular consumption of energy. Furthermore an investigation implemented to enclosure Stirling engine in air conditioning cycle demonstrate that can be a promoted solution and lessen meaningfully energy consumption, the novel numerical thermal model based on second order integrating irreversibility and energy losses tested on an alpha Stirling engine for the identical temperature and pressure governed in the refrigeration cycle show that it can be worked with energy efficiency around 42%.

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1. Introduction

The wireless communications is one of the technologies that changed rapidly in the last decades. The improving of our standards of living mostly led to the increase of communications technology and innovation (Rawi and Ramli, 0000). Five decades before, the most critical factor in building standards was to guarantee a healthy and safe environment for the residents of the buildings. The 1973 oil crises was a milestone in changing the building energy codes to reduce the buildings energy consumption especially in the developed or so-called third world countries. In 1975, the USA was among the first countries that enacted the Energy Policy Conservation Act through its Congress. That act aimed to support and follow energy-saving standards and regulations (Havinga and Smit, 2001a). In late 1970 and 1980, 17 European Countries followed those policies. The warm global problem and the danger of the greenhouse gases on earth environment forced all countries to start reducing the consumption of energy through adopting new policies and forming new regulations. The energy consumption codes related to the building energy consumption is refocused in 1990 (Havinga and Smit, 2001a).

More revisions for the building energy standards in the developed countries were carried out and implemented worldwide to reduce the emission of CO₂ from the buildings.

Since then more studies have shown that there is a constant concern towards the building energy consumption standards. Thus one-third of the world's countries have developed building energy codes. However, the energy standards failed to achieve the target in developing countries due to economic reasons (Havinga and Smit, 2001a). Energy efficiency becomes a challenging task for researchers, organizations and energy consumers. New research fields appeared, such as Ambient Intelligence. Wireless Sensor and Actuator Networks (WSAN) are a promised technology that is used for monitoring and controlling in the wireless environment. Based on the energy consumption, decisions made using central early-programmed software (De Paola et al., 2012).

One of the particular applications of WSAN is a synchronized time implementation for energy consumption measuring. WSAN have been extended from Wireless Sensor Network (WSN) due to its heterogeneous node structure. WSAN contains a collection of static sensors and mobile actors. The actors are active elements and less based on the energy resources than passive sensors. Actors have high processing and communications capabilities.

An actor performs actions in the event area based on the sensors information. The existing sensor network protocols may not perform well because of real time application of WSAN. However,

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these applications require energy and delay aware mechanisms to perform reliable actions in the event area. Unfortunately, these types of mechanisms in WSAFs are still undeveloped (Kiani and Fahim, 0000). According to recent studies, buildings consume almost 40 percent of the primary energy in most countries and are one of five primary users of energy (Angui et al., 2010), and the buildings energy consumption can be improved by increasing their efficiency. Thus, international effort has focused on two directions: decreasing the consumption of energy (demand side) and trying to find another source of renewable energy (supply side) (Reggae, 0000). Creating Building Energy Codes (BECs) was one of the targets that implemented by the developed countries to improve the buildings energy efficiency. Previous studies showed that concerns about climate change have promoted the use of energy efficiency standards and is updated periodically. BECs shaped the fundamentals both energy and environmental policies in the 1990s, since improving buildings' efficiency controls the increase of CO₂ emissions by reducing their consumption of energy (<https://en.wikipedia.org>, 0000).

On the other hand, there is a number of hinged barriers emerged in developing countries that obstruct the efficient use of energy efficiency in buildings; these are the absence of policies and appropriate financial support, low gas and electricity prices. Moreover, unsuccessful enforcement of such policies and absence of experience in the developing countries present other political and structural barriers (<https://www.airconco.com>, 0000).

Furthermore, the high cost of used technologies is counted as the primary barrier towards the implementation of energy efficient technology. Such barriers in improving the buildings energy efficiency raise the critical issue of the efficient allocation of resources. Substantial upfront investment is needed to reduce the energy consumption.

The consumption of residential electricity is affected by two factors, a socioeconomic and a direct use. In the study (Saudi Energy Efficiency program, 2013) found that gross domestic product (GDP), employment rates, residential space, and the implementation of energy labeling schemes provide significant impacts on residential electricity consumption. However, the impacts of electricity price and the energy efficiency standards do not receive significant support (Digi International Inc, 0000). Replacement of the inefficient equipment like air conditioning by other energetic efficient technologies is called Retrofit. Air conditioners are the primary energy consuming in the KSA due to the hot weather (70% of the year). The temperature changes over month during one year. The average of high recorded temperature is 42.6 C and the average of the temperature averages is 32.2 C.

Due to the complex implementation, the conditioners retrofit is a significant challenge due to the high cost and the implementation of alternative solutions such as saving plans and power consumption scheduling solutions. Conditioning technologies have improved last years. More efficiency conditioners are manufactured with a high-energy efficiency. Moreover, environmental pollution of air conditioning should be concerned and the noise level produced by the air conditioner is increasingly important. In this research, those factors will not be considered (Havinga and Smit, 2001b). Number of split conditioners is increased and this led to price reduction. In parallel, a low quality and low price air conditioners with lack of certification are brought to the market as consequence the production of low quality conditions (Bhola and Soni, 0000). Thus to perform a Retrofit of the conditioners it is necessary pay attention in the electric characteristics, conditioning technicians and quality of the product utilized. In order to revise, modify and enforce the Saudi standard SASO 2663/2012, the technical team of the Saudi Energy Efficiency Program adopted an approach based on Consensus & Unanimity. The Energy Efficiency Program developed by the KSA In the vision 2030 concentrated

on the investment in the energy efficiency measuring and power saving technologies. It is one of the primary objectives "Business Environment, Restructure Our Economic Cities, Create Special Zones and Deregulate the Energy Market to Make It More Competitive" (Chen, 2017). On the other hand, the retrofit process is not efficient due to economic issues. Enhancing the energy efficiency of the conditioner is the alternative solution to reach the desired and acceptable energy consumption.

Furthermore, to lessening the air conditioning energy consumption, we adopt another mechanical engineering design using Stirling engine in the refrigeration cycle to enhance the performance of the proposed system and reduce the energy consumption, these engine are characterized by minor noise, nethermost vibration, low maintenance and running with diversity of energy resources (Tlili et al., 2006, 2007; Timoumi et al., 2008b; Tlili, 2015; Sa'ed and Tlili, 2015; Tlili, 2012b, c, a; Tlili and Musmar, 2013; Tlili et al., 2008; Timoumi et al., 2008a, 2007).

Babaalahi and Sayyaadi (2015) established a new numerical modeling depend on polytropic examination taking in account different mechanical and thermal losses and has been applied on GPU-3 Stirling engine, the results exhibited that applying the polytropic model are very close to the reality and with more precision than the preceding model. Using Stirling engine for cogeneration and trigeneration improvement has received much awareness recently, and many theoretical and experimental studies were carried out to explore this technology, considering diverse design parameter, configuration, working fluid, difference temperature and engineering applications, and one of this application is nano scale refrigeration Stirling engine as proposed by Açikkalp et al. (2016) which represent an innovative state of modified ecological coefficient of performance for irreversible Stirling refrigerator, the performance of irreversible cycle has been generated numerically, showing that the compression ratio must have the highest value. Energy efficiency and water problematic are tortuously associated; moreover they represent the two pillars for any society necessity then require piping and electricity network to transfer them to consumers, one study performed by Sayyaadi and Ghorbani (2018) dealing with the design and optimization of couple power and desalination system depend on the Stirling engine, the humidification–dehumidification system coupled with GPU-3 Stirling engine has been investigated through multi-objective optimization, the results expected that the system might produce 23.3 m³ of the fresh water per day and 2.58 kW of electricity. Lu et al. (2015) inspect numerically a cogeneration system based on Organic Rankine cycle mixing a power generation and refrigeration to expect and evaluate the performance of the cogeneration; results show the produced power reaches 13.88 kW and refrigeration of 16.58 kW with increasing performance about 7%. Chen and Ju (2015) explore numerically and experimentally a miniature thermoacoustic Stirling heat engine for the purpose to determine the most appropriate working fluid leads to highest engine performance related to functioning frequency, difference temperature and mean pressure, the main results display that the helium leads to higher mean pressure than nitrogen and argon. Other study (Dogan et al., 2018) examined analytically the impact of working gases on the overall performance and the design parameter of the duplex Stirling refrigerator the coolant and working fluid used in this investigation are helium, hydrogen and carbon dioxide, the maximum performance is reached for the helium when used as refrigerant and working fluid. Kong et al. (2004) analyzed energy efficiency and economic viability for small scale trigeneration system based on Stirling engine, the calculations for these two pertinent parameters are established and the comparisons made between the proposed and contemporary conventional system display the feasibility of such system. Ansarinassab and Mehrpooayab (2018) examined a combined cooling, heating and power system CCHP by

innovative exergy cost study process, the studied system involves Stirling engine for augmenting refrigeration and electrical performance from the viewpoints of energy and exergy analysis authors recommend three plans to improve the overall performance and to reduce cost. Ercan Ataer (2002) provided a Numerical analysis based on thermodynamic simulation for regenerator of free-piston Stirling engines by means of Lagrangian formulation. In this approach the basic equations are formulated for working gases and regenerative channel under most of the displacement. The temperatures of the cylinder and displacer wall have been obtained. The performance of developed Stirling engine are very weak compared to theoretical one, this can be explained by the fact the produced prototype display a very large thermal and mechanical losses and irreversibilities, numerical simulation have been developed for the description of real reasons that restricted the performance (Araoz et al., 2015). A second order Stirling engine simulation have been established to assess the consequence of design and working parameters, this study recognize scales for some pertinent parameter as mean pressure, difference temperature, dimension and geometrical parameters crank phase angle where the engine performance was enhanced. Hachem et al. (2017) developed an experimental and numerical analysis for a Beta type Stirling refrigerator. The effect of all pertinent parameter on net cooling capacity and input power are explored, results show that enlarging swept volume for the cooler leads to reach cold temperatures. Li and Grosu (2017) developed an isothermal modeling based on energy and exergy balance analysis for cryocooler Stirling including thermal and mechanical losses, results displays that mechanical friction the highest losses compared to other irreversibilities. Nie et al. (2009) studied micro and nano scale Stirling refrigeration, considering the quantum boundary effect of gas particles. It is found that for this scale of Stirling refrigeration, the refrigeration heat and COP of cycle are significantly affected by area of the system.

The first part explains the WSAN measuring system and collecting data about the energy consumption of air conditioners followed by energy consumption calculations for a specific period.

The second part of this work aims is to perform a qualitative and comparative analysis of high performance efficiency conditioners to evaluate its economic, cooling–heating and electric parameters. This part aims also to save generated to low-income beneficiaries and impacts on the electrical network after low cost retrofit, check quality regulatory requirements of quality and demonstrate if the conditioners are able to replace old ones with quality and economy.

The third part shows an effective novel method to decrease the energy consumption. This method is the implementation of running Stirling engines using difference of temperature in refrigeration cycle

2. Energy efficiency systems using WSAN

The designed WSAN monitoring system architecture contains three stages:

2.1. Sensing and actuating phase (Pervasive layer)

In this phase sensors provides the Graphical User Interface (GUI) data about the energy consumption in different rooms in different floors within the building. The sensing process is a continuous process that is provided every half an hour. The sensed device was mainly a conditioner, printer, light of the offices and classrooms.

All sensors are linked to each other using wireless transmission, and it has a WSN specification that has a range up to 10 m among devices. The is a coordinator that controlled the other devices for connection and data exchange. It is similar to Bluetooth Protocol using Master and slaves network architecture (<https://en.wikipedia.org>, 0000).

2.2. WSAN interface phase (Controlling)

In this phase, the WSAN interface is acting as a gateway for supporting the controlling mechanism provided by actors and gathering data by sensors. In this phase, integration to wireless networking protocol is performed.

2.3. Implementation layer (Applications)

The software used is suitable for a web browsing and smart-phones. It is connected to the system to support secure access.

The adaptability of any wireless system is the critical issue to achieve a high dynamic environment. Some factors can be applied to attain a high energy efficiency, e.g. <https://www.airconco.com> (0000)

The WSAN technique that presented in this paper connects WSANs with Ethernet/Internet to perform an energy saving algorithm that can be performed online to implement some steps that measured the energy consumption. This technique is managed and controlled by the distribution of WSANs in the lecture halls, laboratories, faculty members' offices in the assigned building using the communication protocols such as ZigBee and 6LoWPAN. Such protocols are integrated into a large number of home automation devices are usually integrated with computation, sensing, WSAN devices are available commercially with low cost, and radio communication capabilities (Digi International Inc, 0000).systems. Most small size and low power features.

In the proposed energy saving technique, these devices include nodes with integrated sensors measuring energy and combined power switch and sensors to measure voltage, current, frequency, load and power consumption. Data from the sensors are stored in distributed repositories, such as a gateway and internal/external servers (Digi International Inc, 0000).

3. Research methodology

The methodology used is based on analyzing the measured energy consumption values of the old working air-conditioners with the new high quality air-conditioners that satisfy the KSA Saudi standard SASO 2663/2015. The energy consumption of the air-conditioner in room 802 shows different values based on the time of day and the month.

A significant number of units for sale in the Kingdom do not meet SASO acceptance standards for true capacity and efficiency compared to labeled specifications. Air conditioner power consumption trumps that of most appliances. The power consumption of air conditioners averages 228 kWh per month (for a 24,000 BTU unit) in most KSA buildings. That would cost:

The gap in energy consumption is converted into money factor based on the average cost of the air-conditioner that satisfies the Saudi standard SASO 2663/2015 (24,000 BTU) unit is around 2500 SAR (667\$) and the Consumption Tariff shown in Table 1. Here, a new tariff that apply New Consumption for all Categories of Service According to Council of Ministers' Decree Dated 12/12/2017, this consumption tariff will be applied from 1/1/2018. For private educational facilities and private medical facilities, there is one category.

The Average energy consumption for survey dwellings based on the type of air-conditioning systems: kWh/m²/year for Central 221.5, Mini-split 144.3, Window-type and 183.3 Window-type and Mini-split 156.8 (Havinga and Smit, 2001b).

After calculations of the retrofit process economic impact results, the decision will be made regarding this process. If the method is not efficient, the novel method to decrease the energy consumption will be the best choice.

Table 1
Consumption tariff.

Consumption categories (kWh)	Governmental (Halalah / kWh)	Industrial (Halalah / kWh)	Private educational facilities, private medical facilities (Halalah / kWh)
1–6000	32 (0.088\$)	18 (0.048\$)	18 (0.048\$)

4. Dynamic model of the Stirling engine

Our established dynamic model for the proposed Stirling engine is founded on some assumptions:

- The working fluid temperature in the diverse sections is variable.
- The temperatures of the cooler and heater walls are constant.
- The law of perfect gases is used.

The energy losses taken in account are:

- Energy Lost by internal conduction, along the regenerator is given by:

$$\delta \dot{Q}_{p\text{cdr}} = k_{\text{cdr}} \frac{A_r}{L_r} (T_{r-h} - T_{f-r}) \quad (1)$$

- Losses of energy by external conduction through the regenerator is given by:

$$\delta \dot{Q}_{p\text{ext}} = (1 - \varepsilon) (\delta \dot{Q}_{r1} + \delta \dot{Q}_{r2}) \quad (2)$$

- The pressure losses by friction:

$$\delta \dot{Q}_{p\text{ch}} = - \frac{\Delta p \dot{m}}{\rho} \quad (3)$$

- The losses of energy by Shuttle effect through exchanger piston:

$$\delta \dot{Q}_{p\text{shtl}} = \frac{0.4 Z^2 k_{\text{pis}} D_d}{J L_d} (T_d - T_c) \quad (4)$$

- Losses by irreversibility effect:

$$\delta \dot{W}_{p\text{irrc}} \cong \sqrt{\frac{1}{32} \omega \gamma^3 (\gamma - 1) T_{\text{pac}} P_{\text{cmoy}} k_{\text{pac}}} \left(\frac{\Delta V_c}{V_{\text{cmoy}}} \right)^2 A_{\text{pac}} \quad (5)$$

Energy and mass conservation balance are applied in the dynamic model (Tili, 2012c):

- The balance of energy conservation is written:

$$\delta \dot{Q} + C_p T_E \dot{m}_E - C_p T_S \dot{m}_S = P \frac{dV}{dt} + C_v \frac{d(mT)}{dt} + \sum Diss \quad (6)$$

$\sum Diss$: is the sum of energy losses.

- The mass conservation in the engine gives:

$$M = m_d + m_c + m_f + m_r + m_h \quad (7)$$

- Taking into account the losses by internal and external conduction in the regenerator

$$\delta \dot{Q}_r = \varepsilon h_r A_{\text{par}} (T_{\text{par}} - T_r) - \frac{\delta \dot{Q}_{p\text{cdr}}}{2} \quad (8)$$

- The work assumed by the cycle is:

$$\frac{\delta W}{dt} = P_c \frac{dV_c}{dt} + P_d \frac{dV_d}{dt} - \frac{\delta W_{\text{irrc}}}{dt} - \frac{\delta W_{\text{irrd}}}{dt} \quad (9)$$

- The thermal effectiveness is:

$$\eta = \frac{W}{Q_h} \quad (10)$$

Our established dynamic model for the proposed Stirling engine is resolved numerically using fourth order Runge–Kutta method by iteration till stationary intermittent conditions are extended. We found stabilities condition in iteration cycle 6. The calculations of error are performed and analyzed as shown in Table 2, it can

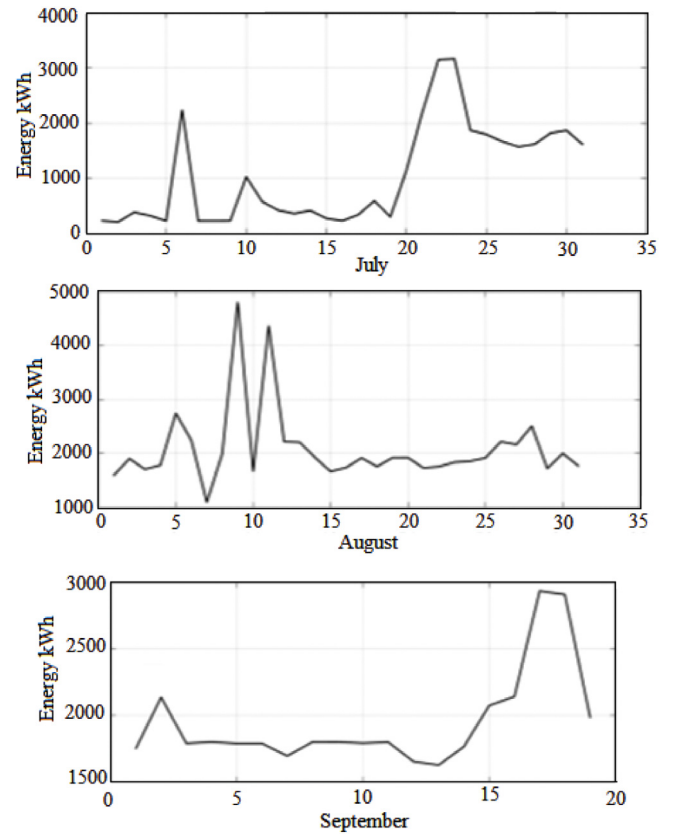


Fig. 1. Energy consumption of room 802 for the month of July, August, and September.

be seen that the established code running cycle by cycle based on iteration and compare power and efficiency of the cycle $n+1$ with cycle n if this difference higher than permitted value the code run the cycle $n+2$ otherwise it will stop and keep the last performance values, Table 2 prove that the steady condition reaches from iteration cycle 6.

5. Results and discussion

Some preliminary results are shown by monitoring the energy consumption of air-conditioner in 802 in the University during one academic year tracing the change in the consumption during the different seasons. Fig. 1 shows the energy consumption for 3 months (July, August and September). Other months not considered due to the low average energy consumption during the winter and spring days.

The total price of the energy consumed by the air-conditioner (Type 24,000 BTU mini-split unit) with SASO Compliance Standards is $144.3 \text{ (kWh/m}^2\text{/year)} \times 8 \times 2 \times (0.048\text{\$/kWh)} = 55.8\text{\$}$. The total price of the energy consumed by the air-conditioner (Type 24,000 BTU mini-split unit) monitored by WSA is $1602 \text{ (kWh/16 m}^2\text{/year)} (0.048\text{\$/kWh)} = 76\text{\$}$.

The saving difference between the two air conditioners is 20\$ and for 113 rooms, the total saving is 2326. Assuming 5 years plan cost compensation, the total saving is 11632.67\$.

Table 2
Error analysis.

Cycle restatement	1	2	3	4	5	6	7	8
Power by cycle restatement	23.8807	22.5903	22.2088	22.1731	22.1701	22.1698	22.1698	22.1698
Efficiency by cycle restatement	0.3760	0.3030	0.2949	0.2942	0.2942	0.2942	0.2942	0.2942
Error for power ε_p	1.2904	0.3815	0.0387	0.003	0.003	0.0000	0.0000	0.0000
Error for efficiency ε_e	0.0730	0.3428	0.0081	0.0000	0.0000	0.0000	0.0000	0.0000

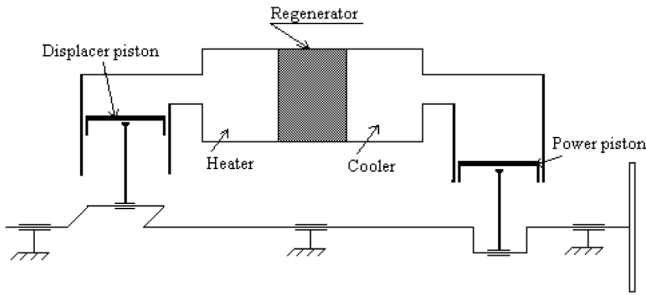


Fig. 2. Alpha Stirling machine pattern.

The Retrofiring process is very expensive and the saving difference based on the electricity costs will be compensated only after $75145/2326 = 32.3$ Years.

The alternative solution is the merged power saving plan using optimization energy saving plans that can save up to 10% and the total saving will be $113 \times 16\$ = 1808\$$ per year. Using the difference in energy consumption cots, a three air-conditioners can be replaced and this will give additional 60\$ per year

Running Stirling engines with renewable energy sources were attract consideration by several researchers and engineers. In this part, we establish an innovative design for air-conditioning integrating Stirling engine and a numerical modeling has been performed, which allows to simulate and to get closer to reality by considering several phenomena that are not taken into account in previous researches by taking in account thermal and mechanical irreversibilities such as effectiveness of heat exchangers, friction forces and the losses of charges. In the best authors knowledge no study concerning such proposed system and the proposed Stirling engine is alpha type moreover we perform an optimization for higher performance. Different investigations demonstrate that alpha Stirling engine **Fig. 2** has more benefits than other types. The results of numerical simulation founded are more accurate and are very appropriate with the working environment. The engine performance inside air-conditioning has been predicted.

Fig. 3 displays the pressure variation during the cycle, it is found that the average pressure is 4.7 bar, the maximum pressure is 6.62 bar for $\theta = 130^\circ$ which means at the end of compression.

Fig. 4 depicts the closed loop (PV) diagram for compression and expansion space, the surface area for each diagram represent the work in compression and expansion space. It can be interpreted on this fact that the difference in area of these two surfaces is equal to the total network produced by the motor.

The variation temperatures through the cycle in each cell and in the wall are in **Fig. 5**.

It is perceived that the temperature variation in the regenerator divided in two cells is around 15°C . Furthermore, the difference of temperature between the working fluid and the material filled in the regenerator is about 50°C . It can be interpreted on this fact that the heat transferred in the regenerator is small which means that the regenerator has a low efficiency. However in the cooler and heater the difference of temperature is very higher respectively 100°C and 150°C . This can be attributed to the effectiveness of

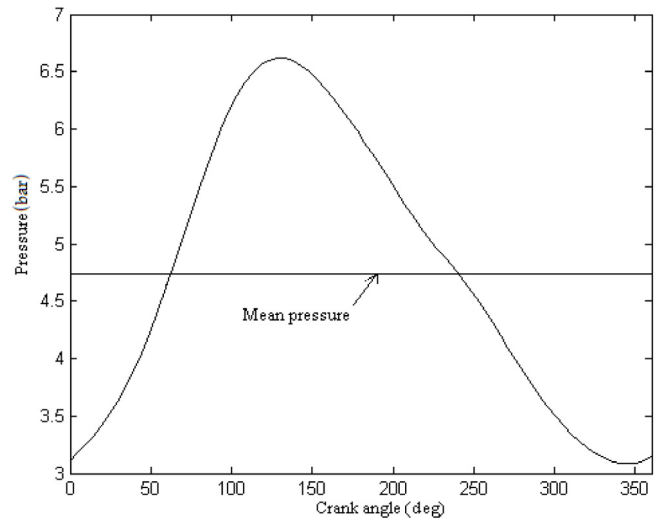


Fig. 3. Pressure variation through the cycle.

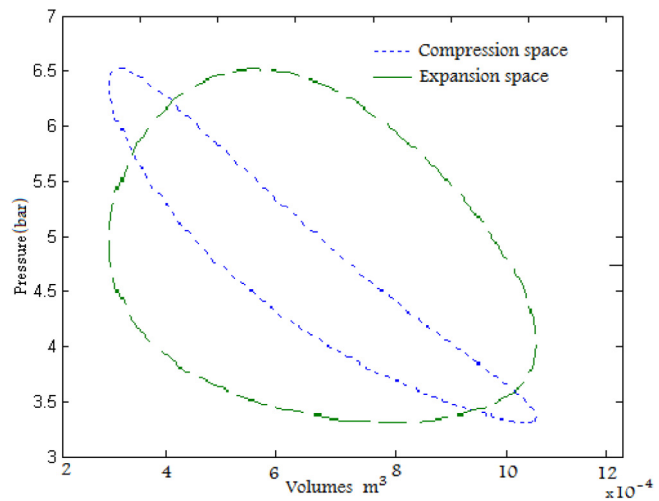


Fig. 4. The closed loop diagram of pressure changes for compression and expansion space.

these heat exchangers. This signifies that the regenerator represent the most important in the proposed system and is the main preventive issue in Stirling engine performance.

Fig. 6 exposes the different irreversibilities in the engine for both thermal and mechanical energy losses. It is found that the regenerator has the highest energy dissipation, as observed, it reaches 390 W and the calculated average is around 95 W, however the cooler has the lowest energy lost by dissipation. It should be pointed out that the energy lost by internal conduction is almost observed in the regenerator which represents 30% of total energy lost in the engine, whereas, in the heater and the cooler it remain insignificant compared to the regenerator. We realize that heat flow lost by Shuttle effect of the two pistons represent 15% of total lost energy.

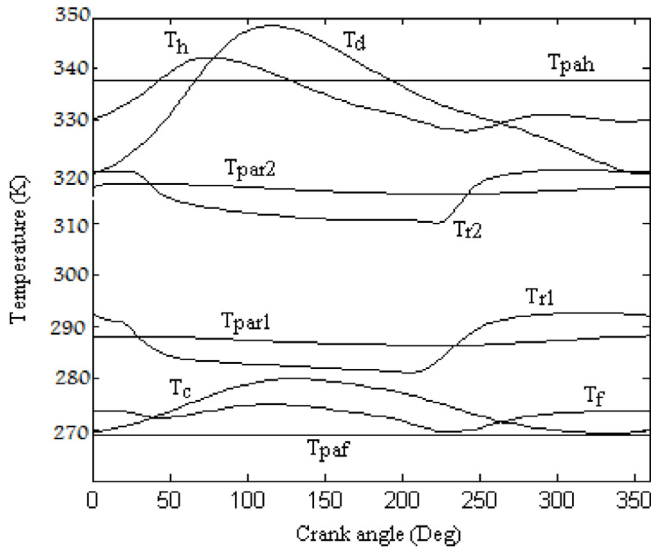


Fig. 5. Variation of temperature in the different sections.

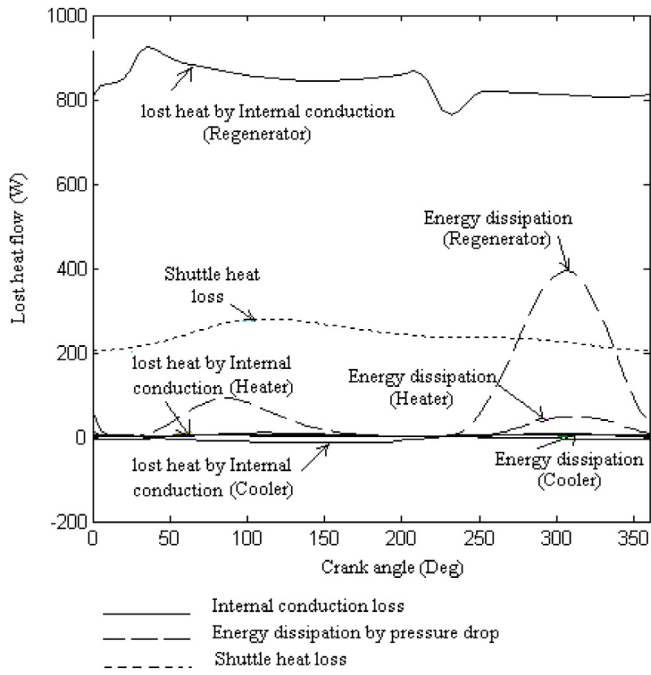


Fig. 6. Heat flow losses.

Fig. 7 exposes the effect of the fluid mass in the performance of the engine. The enhancing of fluid mass is expected to alter the energy lost by dissipation, nevertheless we realize that the engine power increase significantly and the efficiency of the engine at fluid mass equal to 0.8 g reaches an optimum value around 40%, this can be explain by the fact the energy lost by dissipation increase and the restraint of the heat exchanger.

The effect of the regenerator porosity has been presented in Fig. 8. It can be seen that the engine performances lessen with the porosity, the physical reason behind this is that amplification of external conduction losses and to the lessening of the heat exchanged between the working fluid and the regenerator, the optimum value of porosity in our system is 65.5%.

The expansion volume affects considerably the power of the engine as presented by Fig. 9; however, it is found that there is

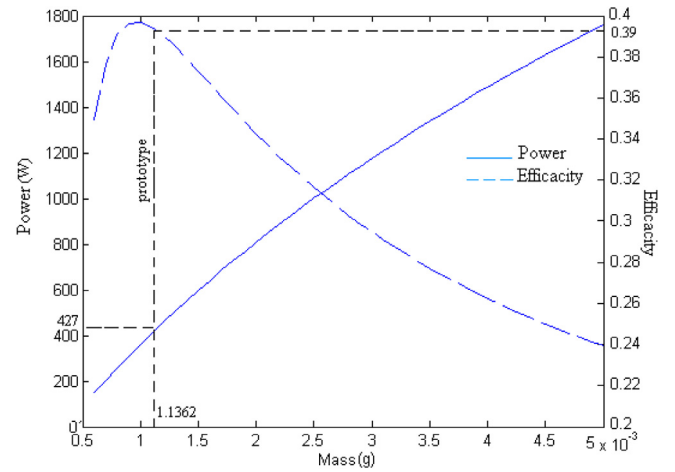


Fig. 7. Engine performance variation with the fluid mass.

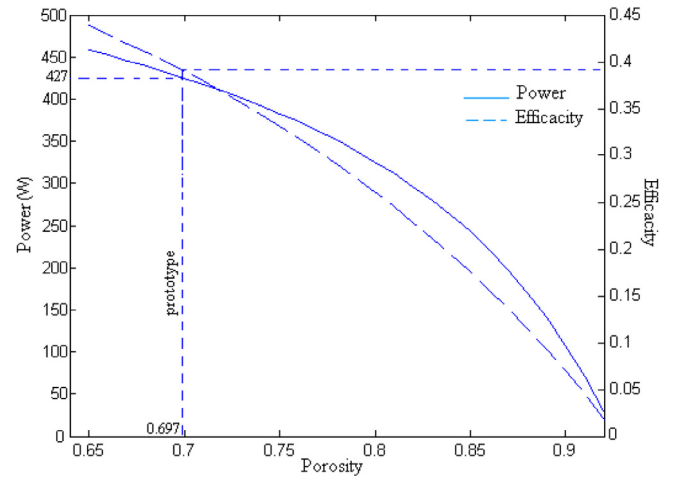


Fig. 8. Engine performance variation with the porosity of the regenerator.

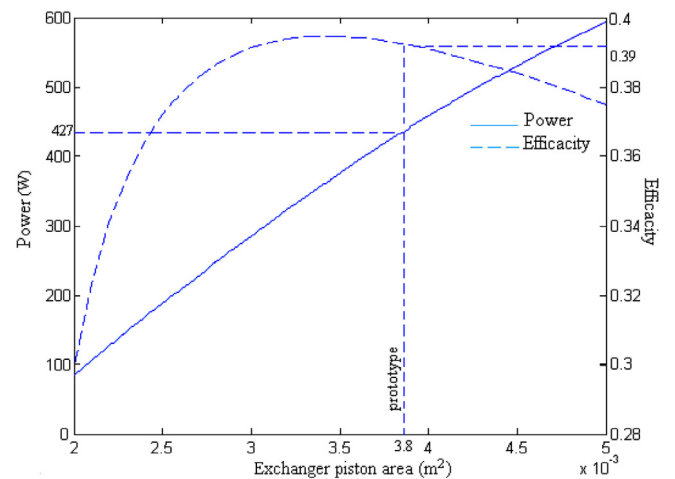


Fig. 9. Engine performance variation with expansion volume.

an optimum value for the expansion volume related to engine efficiency

6. Conclusion

The need to enhance the efforts for additional progress and advancement of energy performance in last decade a lot of attention has been paid to energy efficiency. This work inspects the energy efficiency and the economic impact provided by air conditioning in a real case study related to governmental building (Majmaah University Administrative Building MUAB). Alternative solutions are provided. Using Wireless Sensor and Actuator Networks (WSAN) for detecting and assessing diverse technique of the conditioners in order to compare them with the existing on the market, the main results mention that:

- The old conditioners should be replaced.
- Power parameters analysis proves that substituting actions applied in the main building enhance a preserving of 10% in the regular consumption of energy.

Furthermore an investigation implemented to enclosure Stirling engine in air conditioning cycle demonstrate that can be a promoted solution and lessen meaningfully energy consumption, the novel numerical thermal model based on second order integrating irreversibility and energy losses tested on an alpha Stirling engine for the identical temperature and pressure governed in the refrigeration cycle show that:

- The regenerator represents the most important component in the proposed system and it can recover more than 60% of energy loss.
- The engine performances reduce with the porosity and the optimum value is around 65%.
- The new proposed system enhances performance and energy efficiency augment to around 42%.

Nomenclature

A	Area	m^2
C_p	Specific heat at constant pressure	$J\ kg^{-1}\ K^{-1}$
C_{pr}	Heat capacity of each cell matrix	$W\ K^{-1}$
C_v	Specific heat at constant volume	$J\ kg^{-1}\ K^{-1}$
D	Diameter	m
ε	Regenerator efficiency	
f_r	Friction factor	
G	Working gas mass flux	$kg\ m^{-2}\ s^{-1}$
k	Thermal conductivity	$W\ m^{-1}\ K^{-1}$
M	Mass of working gas in the engine	kg
\dot{m}	Mass flow rate	$kg\ s^{-1}$
P	Pressure	Pa
Q	Heat	J
\dot{Q}	Power	W
R	Gas constant	$J\ kg^{-1}\ K^{-1}$
T	Temperature	K
V	Volume	m^3
W	Work	J

Subscripts

c	Compression space
ch	Load
cd	Conduction
d	Expansion space
E	Entered
ext	Outside
f	Cooler
h	Heater
irr	Irreversible
p	Loss
Pa	Wall
$shtl$	Shuttle

Greek letters

θ	Crank angle	rad
μ	Working gas dynamic viscosity	$kg\ m^{-1}\ s^{-1}$
ρ	Density	$kg\ m^{-3}$
ω	Angular frequency	$rad\ s^{-1}$
γ	$C_p\ C_v^{-1}$	

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