UNIVERSITI PUTRA MALAYSIA

HARVESTING ENERGY POTENTIAL FROM AIR CONDITIONER COMPRESSOR OF HOT GAS RECEIVER TANK USING THERMOELECTRIC GENERATOR

HANAA KADHIM KAREEM ALSABAHI

FK 2016 145

HARVESTING ENERGY POTENTIAL FROM AIR CONDITIONER COMPRESSOR OF HOT GAS RECEIVER TANK USING THERMOELECTRIC GENERATOR

By

HANAA KADHIM KAREEM ALSABAHI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

October 2016

© COPYRIGHT UPM

COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs, and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright© Universiti Putra Malaysia

DEDICATION

To my family whose support and understanding helped make this possible

© COPYRIGHT UPM

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

HARVESTING ENERGY POTENTIAL FROM AIR CONDITIONER COMPRESSOR OF HOT GAS RECEIVER TANK USING THERMOELECTRIC GENERATOR

By

HANAA KADHIM KAREEM ALSABAHI

October 2016

Chairman : Nor Mariah Adam, PhD PE
Faculty : Engineering

Fire safety signage like emergency light and exit sign that are used all year round at buildings consume electricity for operation of signage and must function during emergency situation, therefore this can be costly in terms of maintenance cost. The DC voltage that is generated by thermoelectric generator (TEGs) is enough to operate this signage as alternative for its original batteries**.** The facilities and state institutions as well as residential complexes are using large numbers of air conditioner units. The air conditioner hot receiver tank rejects large amount of waste heat to the environment. The aim of this study is concerned with experimental test for (TEG) circuit arrangement for reducing waste heat by converting waste heat into electrical power. Specific objectives are to determine the primary design of TEG parameters with high power efficiency, which is able to produce ≥ 4 volt, then to verify the primary design results with experimental validation. Also, the research study the effect of weather properties on the cooling process of TEG. The system has built-in the electrical circuit as a battery charger to save (DC) electrical energy for operate four pieces of 12V LED in a (KELUAR) sign. Figure of Merit (FOM) and heat transfer approach based on the first law of thermodynamics are considered in arrangement of TEG. A total of 18 pieces of thermoelectric generator with dimensions of $(40\,\text{mm} \times 40\,\text{mm} \times 3.4\text{mm})$ with Bismuth Telluride $(Bi_2\,Te_3)$ inside material are fixed on aluminum frame which carries thermoelectric generator and sandwiched between air conditioner hot gas receiver tank and cool heat sink. Double heat sink per one thermoelectric generator piece are used to improve heat transfer. The TEG are arranged in three lines, each line consists of 6 pieces of TEGs connected in series to increase voltage, while the three lines of TEGs are connected in parallel to increase amount of power current. Electrical circuit built for charging 3.5V battery and connected with (KELUAR) sign lights was successfully fabricated. The circuit equipped with two convertor, (0.9V to 5V DC-DC) convertor for increase voltage. The experimental test shows that the output electrical power is extremely dependent on weather properties e.g ambient temperature, air velocity and

© COPYRIGHT UPM

relative humidity (RH), and it shows that the maximum open circuit voltage obtained in this research is 5.16V at 0.17m/s of air velocity, 73% of RH and 30.4 ℃ of ambient temperature. Experimental result shows that the maximum thermoelectric generator efficiency is 46% at temperature difference of 29.2℃ and dimensionless Figure of Merit $\simeq 1$. The system is able to harvest waste heat into electricity (DC) and charge the battery which serves as reservoir.

© COPYRIGHT UPM

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

POTENSI PENUAIAN TENAGA DARIPADA TANGKI UDARA PANAS PENGHAWA DINGIN MENGGUNAKAN GENERATOR TERMAL ELEKTRIK

Oleh

HANAA KADHIM KAREEM ALSABAHI

Oktober 2016

Pengerusi : Nor Mariah Adam, PhD PE
Fakulti : Kejuruteraan

Papan tanda keselamatan kebakaran seperti lampu kecemasan dan tanda keluar yang digunakan sepanjang tahun di bangunan menggunakan tenaga elektrik untuk operasi papan tanda tersebut dan mesti berfungsi waktu kecemasan. Oleh itu boleh melibatkan kos penyelenggaraan yang mahal. DC voltan yang dijana oleh penjana termoelektrik (TEGs) adalah mencukupi untuk operasi papan tanda tersebut sebagai alternatif untuk bateri asal. Kemudahan di institusi negara serta kompleks kediaman menggunakan sejumlah besar unit penghawa dingin. Tangki udara panas penghawa dingin menolak sejumlah besar haba buangan kepada alam sekitar. Tujuan kajian ini adalah berkenaan dengan ujian eksperimen untuk (TEG) supaya mengurangkan haba buangan dengan menukar haba buangan kepada kuasa elektrik. Objektif khusus adalah untuk menentu kan reka bentuk utama parameter TEG dengan kecekapan kuasa tinggi, yang mampu menghasilkan voltan ≥4V, kemudian mengesahkan keputusan reka bentuk utama dengan pengesahan eksperimen. Selain itu, kajian penyelidikan menyentuh kesan ciri-ciri cuaca pada proses penyejukan TEG. Sistem ini telah terbina dalam litar elektrik sebagai pengecas bateri untuk mengurangkan tenaga elektrik (DC) untuk mengendalikan empat keping 12V LED dalam papan tanda (KELUAR). *Figure of Merit* (FOM) dan pendekatan pemindahan haba berdasarkan hukum pertama termodinamik dipertimbangkan dalam susunan TEG. Sebanyak 18 buah penjana termoelektrik dengan dimensi (40 mm × 40 mm × 3.4mm) dengan bahan Bismut Telluride ($Bi_2 Te_3$) sebagai bahan TEG satu bingkai aluminium yang dilekatkan TEG dan diapit diantara tangki panas penghawa dingin dan sink haba sejuk. Sinki haba kembar bagi satu bahagian TEG digunakan untuk meningkatkan jumlah pemindahan haba. TEG disusun dalam tiga baris, setiap baris terdiri daripada 6 keping TEGs disambung secara siri untuk meningkatkan voltan, manakala tiga barisan TEG disambungkan secara selari untuk meningkatkan jumlah arus kuasa. Litar elektrik dibina untuk mengecas bateri 3.5V bagi papan tanda (KELUAR) telah berjaya di bina. Litar ini dilengkapi dengan dua penukar, (0.9V untuk 5V DC-DC) yakni penukar untuk peningkatan voltan. Ujian eksperimen

© COPYRIGHT UPM

menunjukkan bahawa output kuasa elektrik adalah amat bergantung kepada ciri-ciri cuaca contohnya suhu ambien, halaju udara dan kelembapan relative (RH), dan ia menunjukkan bahawa voltan litar terbuka maksimum yang diperoleh dalam kajian ini adalah 5.16V pada 0.17m / s halaju udara, 73 % RH dan 30.4 ℃ suhu ambien. Hasil eksperimen menunjukkan bahawa kecekapan penjana termoelektrik maksimum adalah 46% pada perbezaan suhu 29.2 ℃ dan *Figure of Merit* $\simeq$1. Sistem ini dapat menuai sisa haba kepada tenaga elektrik (DC) dan mengecas bateri yang berfungsi sebagai takungan.

© COPYRIGHT UPM

ACKNOWLEDGEMENTS

Firstly thanks to Almighty God for giving me the strength and blessed with the knowledge to complete this study successfully. I wish my express my special thanks and most appreciation to my Supervisor, Associate Prof. Dr. Nor Mariah Adam for her guidance, helpful advice, suggestion, support and valuable opinion, in the preparation of this research. Thanks are also expressed to Dr. Azizan As'arry as the Co-supervisors for his kindness, information and suggestion during the project research.

Last but not least, I would like to express my heartfelt gratitude to my family members especially my beloved husband and my mother for their utmost support and motivation throughout this research work.

© COPYRIGHT UPM

I certify that a Thesis Examination Committee has met on 31 October 2016 to conduct the final examination of Hanaa Kadhim Kareem Alsabahi on his thesis entitled "Harvesting Energy Potential from Air Conditioner Compressor of Hot Gas Receiver Tank Using Thermoelectric Generator" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Suraya Mohd Tahir, PhD
Senior lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Nuraini Abdul Aziz, PhD
Associated Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohd Zarhamdy Md Zain, PhD
Associated Professor
Faculty of Mechanical Engineering
Universiti Technology Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:26 January 2017

© COPYRIGHT UPM

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the supervisory committee were as follow:

Nor Mariah Adam, PhD PE
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Azizan As'arry, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

© COPYRIGHT UPM

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice- Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature:______________________ Date:______________________

Name and Matric No: Hanaa Kadhim Kareem Alsabahi, GS41634

© COPYRIGHT UPM

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ________________________________

Name of Chairman of Supervisory Committee: ________________________________

Signature: ________________________________

Name of Member of Supervisory Committee: ________________________________

© COPYRIGHT UPM

TABLE OF CONTENTS

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF TABLES

© COPYRIGHT UPM

LIST OF FIGURES

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF ABBREVATIONS

AC	Alternative Current
Bi_2	Bismuth
CO_2	Carbon Dioxide
COP	Coefficient of Performance
DC	Direct Current
DOE	Department of Energy
FC	Foot Candle
FOM	Figure of Merit
HP	Horse Power
HS	Heat Sink
LED	Light-Emitting Diode
N_u	Nusselt number
PTC	Parabolic Trough Collector
Te_3	Telluride
TE	Thermoelectric Effect
TEG	Thermoelectric Generator
THE	Thermoelectric Harvesting Energy
UPM	Universiti Putra Malaysia
US	United State of America

© COPYRIGHT UPM

LIST OF NOMENCLATURES

A :	Total surface area (m²)
A_{fin} :	Fin heat transfer section area (m^2)
A_s :	Heat transfer surface area (m^2)
A_{unfin}:	Area of un-finned surface of heat sink (m^2)
A_{fin}:	Area of fin surface of heat sink (m^2)
COP_{max}:	Maximum coefficient of performance
H :	Total high of heat sink (mm)
H :	Convection heat transfer coefficient $(W/m^2 . ℃)$
I :	Electric current (A)
k :	Thermal conductivity (W/m .K)
L :	Fin length (m)
N :	Number of fin per heat sink
P :	Thermoelectric cooler input power (W)
P_{TEG} :	Output power of thermoelectric generator (W)
Q :	Heat transfer (W)
$\dot{Q}_{total,fin}$:	Total heat transfer rate from heat sink (un-fin and fins) (W)
$\dot{Q}_{unfin}$:	Heat transfer rate from un-finned surface of heat sink (W)
$\dot{Q}_{fin}$:	Heat transfer rate from fin of heat sink (W)
$q_{emit,max}$:	Maximum radiation heat transfer rate (W)
R :	Electric resistance (Ω)
R_{ex} :	External load resistance (Ω)
R_{th} :	Thermal resistances of the various materials
S :	Seebeck coefficient (V/K)
T :	Temperature (K)
T_b :	Temperature at fin base (℃)
T_s :	Surface temperature (℃)
T_∞ :	Fluid temperature (℃)
T_w :	The surface plate temperature (℃)

© COPYRIGHT UPM

t :	Fin thickness (m)
V :	Thermoelectric voltage (V)
w :	Fin width (m)
Z :	Figure of Merit (1/K)
ZT :	Dimensionless Figure of Merit
ΔT :	Local temperature difference between two fluids (K)
ΔV :	Voltage difference (V)
$\Delta T_{overall}$:	Temperature difference between two sides wall (K)
Δx :	The wall thickness (m)

Greek symbols

σ :	Electric conductivity (S/m)
η_{max} :	Maximum thermoelectric generation efficiency
Π :	Peltier coefficient

Subscripts

c :	Cold side
conv. :	Convection
cond. :	Conduction
h :	Hot side
ex :	External load
in :	Inside
out :	Outside
load :	Circuit Load
max :	Maximum
min :	Minimum
TEG :	Thermoelectric generator
1 :	Inlet, Side 1
2 :	Outlet, Side 2

© COPYRIGHT UPM

CHAPTER 1

INTRODUCTION

1.1 Background

Future challenges of our society, include limited reserve of fossil fuel and localized energy shortages. The world energy requirement is expected to rise more than 60% in 2030. Nowadays, heat engines that operate by fossil fuel generate more than 80% of world's energy requirements that explains the large emissions of carbon dioxide (CO_2) (Yazawa & Shakouri 2011). As a result of using heat engines, the environment receives 10 TW of heat lost in 2015 (Zhang & Yong-wei 2015).

On the other hand, the world's demand of electric energy is ongoing increase, therefore, many countries start to use alternative source of energy such as wind, solar, and geothermal energy to produce electrical energy. However it is costly and cover small range of electric demand, for example, the wind, solar and geothermal supply 2.7 % of electric demand in the United States (Lawrence 2010). Therefore, waste heat energy can be included as important source of energy to generate electric energy by using thermoelectric effect (TE).

Thermoelectric is a device used to transfer the heat energy into electric energy, and that will lead ultimately to decrease in using fossil fuel and carbon dioxide emissions (Zhang & Yong-wei 2015). Actually, it is difficult to replace the Rankine cycle steam engine with thermoelectric, however it can play a huge role in our society by transferring waste heat from thermal system to electricity (Yazawa & Shakouri 2011).

In tropical climate of Malaysia, the facilities and state institutions as well as residential complexes use large numbers of air conditions unit all day (Muhieldeen 2010), this is because of hot and wet weather in this country with ambient temperature range from (24 to 32)℃, and the temperature increase by (5 to 7)℃ as a result of heat emissions from car engine, air conditioner units and furnaces (Mahlia et al. 2004; Wong et al. 2009; Kong et al. 2014). Actually, the air conditioner (hot gas receiver tank) produces large amount of waste heat to environmental.

In Malaysia too many buildings have a large number of exit sign (see Figure 1.1), that are used as part of the fire safety requirements and have to be operated all the time. It has batteries to operate it when the alternative current (AC) electrical power goes on. Energy harvesting by thermal electric generator TEGs can be used as an alternative to a battery (Matiko et al. 2014).

© COPYRIGHT UPM

Figure 1.1: KELUAR sign

1.2 Problem Statement

Fire safety signage, emergency light and exit signs that use all year round at buildings consume electricity for operation. Direct current (DC) voltage that generated from TEGs is enough to operate this signs as alternative of batteries which can be costly (Matiko et al. 2014). However, it should be added DC LED is also suitable for the signage. By utilizing waste heat system to operate (KELUAR) sign can help to improve safety level through reliable power supply. In addition heat source, thermoelectric generator needs to increase temperature difference between two (hot and cold reservoir) sides of TEG to produce voltage as a result of temperature gradient between hot and cold sides (Faraji & Akbarzadeh 2013). Dust, relative humidity and air velocity has a big effect on cooling process, thus, temperature difference variable to be considered as environment proprieties (Mekhilef et al. 2012).

This study used experimental test to harvest the waste heat from air conditioner compressor (hot gas receiver tank) (see Figure 1.2) and converts it by using thermoelectric generator into electrical energy saved by a battery to operate (KELUAR) sign as shown in Figure 1.3.

Figure 1.2: Air conditioner hot gas receiver tank

© COPYRIGHT UPM

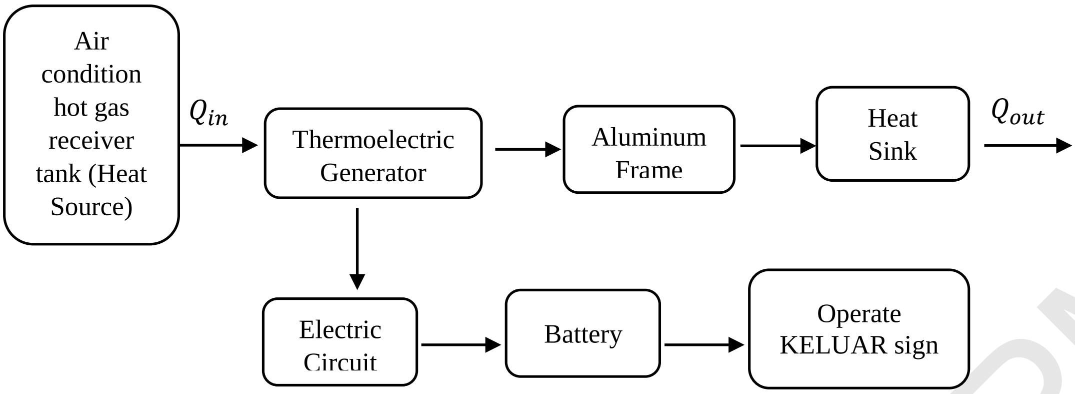

Figure 1.3: Schematic of waste heat harvesting system

The research hypothesis is thermoelectric generator produce DC voltage as a result of temperature difference between both sides of TEG. Therefore, when temperature difference ($\Delta T = 0$) it not possible to harvest energy whereas at ($\Delta T \neq 0$) it is possible to harvest energy from heat source.

1.3 Research Objective

Generally, the overall objective of this study is to develop a system to harvest energy from waste heat for electricity generation with voltage ≥ 4 volt as minimum value to charge 3.5 volt battery.

The specific objectives are as follows:

1) To determine the primary design of thermoelectric generator parameters.
2) To determine the weather properties effect on the cooling process of the thermoelectric generator.
3) To verify the primary design results with experimental validation.

1.4 Scope and Limitations

Designing the optimum heat harvesting convertor system with high efficiency is divided into two sub projects as thermoelectric device (heat convertor) and electrical circuit (electric energy storage). This study will focus on fabrication of aluminum frame to fix TEG with heat source as well as selecting suitable thermoelectric model. The limitations of this study are:

1) Consider $40\,mm \times 40mm \times 3.4\,mm$ thermoelectric size due to limited gap between conditioner and wall surrounding compressor.
2) Consider air conditioner hot gas receiver tank as a heat source.
3) Select aluminum frame for fixed thermoelectric generator with air conditioner receiver tank body (light weight).

© COPYRIGHT UPM

4) Arrange the system to produce more than 4 voltage.

Aluminum frame will be used for placement of thermoelectric elements attached to air conditioner hot gas receiver tank. This material (aluminum) is selected based on following considerations

- Mechanical properties like corrosion resistance and strong.
- Thermal specification such as melt point and thermal conductivity (k).

The scope of this study is to present simple design of TEG for reducing waste heat by converted it into electrical power and presented reliability design of heat harvesting system (thermoelectric model) with high power efficiency, able to produce voltage ≥ 4 as well as, built-in electrical alternative source. Moreover, a study on the effect of the environmental temperature, humidity conditions and air velocity on thermoelectric generator performance was carried out.

1.5 Thesis Layout

This thesis starting with introduction in the first chapter. The second chapter included literature review with essential equation of heat transfer types. Third chapter is presented methodology with heat transfer and efficiency of thermoelectric generator calculation. Further, this chapter is presented the validation method of the system design. A comprehensive explanation of the experimental test with its results are presented in Chapter Four. Finally, Chapter Five introduce the conclusion of the research with future work recommendations.

© COPYRIGHT UPM

REFERENCES

Air condition, 2006. http://www.elektronika-sa.com.pl/tcmodel.php?line=HCSSC-ZP-2006&model=ZP83KCE-TFD&RID=5&Tab=1[Accessed July 4, 2015].

Alex, M. K., 2008. Science review of internal combustion engines $. , 36(2008), pp.4657–4667.

Aghaali, H. & Ångström, H., 2015. A review of turbocompounding as a waste heat recovery system for internal combustion engines. *Renewable and Sustainable Energy Reviews*, 49, pp.813–824.

Ahiska, R. & Ahiska, K., 2010. New method for investigation of parameters of real thermoelectric modules. *Energy Conversion and Management*, 51(2), pp.338–345.

Ahıska, R. & Mamur, H., 2014. A review : Thermoelectric generators in renewable energy. , 4(1).

Aly, A.H. & El-gawaad, N.S.A., 2015. Thermal Conductance and Seebeck Effect in Mesoscopic Systems. *International Journal of Thermophysics*, 36(10), pp.2845–2853.

Anemometers, A. & A.T.A._ A.V.M._, 2015. https://www.instrumart.com/products/34573/tsi-alnor-avm430-and-avm440-thermal-anemometers [Accessed March 14, 2016]

Banta, J.C. & Jardiel, K., 2012. Design of Thermoelectric Generator using Bismuth Telluride Thermocouples with Automated Data Logger System by. , (September).

Benenti, G., Casati, G. & Mejía-Monasterio, C., 2014. Thermoelectric efficiency in momentum-conserving systems. *New Journal of Physics*, 16.

Boost, D., 2015. https://www.amazon.com/XL6009-Converter-Voltage-Adjustable-Module/dp/[Accessed March 20, 2016]

Brito, F.P., Alves, A. & Martins, L.B., 2016. Analysis of a Temperature-Controlled Exhaust Thermoelectric Generator During a Driving Cycle. *Journal of Electronic Materials*, 45(3), pp.1846–1870.

Brito, F.P., Martins, J. & Antunes, N., 2015. Thermoelectric Exhaust Heat Recovery with Heat Pipe-Based Thermal Control. *Journal of Electronic Materials*, 44(6), pp.1984–1997.

Cengel, 2008. Introduction to Thermodynamics and Heat Transfer. , p.865.

Cengel, Y. a., Klein, S. & Beckman, W., 2002. Heat Transfer: A Practical Approach. In p. 896.

© COPYRIGHT UPM

Chen, G., 2009. Introduction to Thermoelectricity.

Chen, W.H., Liao, C.Y. & Hung, C.I., 2012. Experimental study on thermoelectric modules for power generation at various operating conditions. *Energy*, 45(1), pp.874–881. Available at: http://www.sciencedirect.com/science/article/pii/S0360544212005282 [Accessed April 2, 2015].

Convertor, 2015. https://www.amazon.com/TOOGOO-Control-0-9V-5V-Step-up-Supply/dp/B00K67X8PQ?ie=UTF8&*Version*=1&*entries*=0.

Data logger, C.P. 91000 00 D.S.T.T.K.T. w P._, 2015. http://www.ebay.com/itm/COLE-PARMER-91000-00-DIGI-SENSE-THERMOMETER-TYPE-K-THERMOCOUPLE-W-PROBE-/151049550790. [Accessed May 8, 2015]

Deng, Y.D., Zheng, S.J. & Su, C.Q., 2015. Effect of Thermoelectric Modules ' Topological Connection on Automotive Exhaust Heat Recovery System. *Journal of Electronic Materials*, 45(3), pp.1–11.

Du, H., Yuan, X.H. & Wang, Y. P., 2016. Experimental Investigation of a Temperature-Controlled Car Seat Powered by an Exhaust Thermoelectric Generator. *Journal of Electronic Materials*, 45(3), pp.1529–1539.

Faraji, A.Y. & Akbarzadeh, A., 2013. Design of a compact, portable test system for thermoelectric power generator modules. *Journal of Electronic Materials*, 42(7), pp.1535–1541.

Frobenius, F., 2015. Thermoelectric Generators for the Integration into Automotive Exhaust Systems for Passenger Cars and Commercial Vehicles. *Journal of Electronic Materials*, 45(3), pp.1433–1440.

Goldsmid, H.J., 2010. Review of Thermoelectric Materials. *Introduction to Thermoelectricity*, pp.139–166.

He, W. Wang, S. & Zhang, X., 2016. Influence of different cooling methods on thermoelectric performance of an engine exhaust gas waste heat recovery system q. *Applied Energy*, 162, pp.1251–1258.

He, W., Wang, S. & Zhang, X., 2015. Optimization design method of thermoelectric generator based on exhaust gas parameters for recovery of engine waste heat. *Energy*, 91, pp.1–9.

Holman J.P., 2010. Heat Transfer.McGraw-Hill, pp. 1-725

Hsiao, Y.Y., Chang, W.C. & Chen, S.L., 2010. A mathematic model of thermoelectric module with applications on waste heat recovery from automobile engine. *Energy*, 35(3), pp.1447–1454. Available at: http://dx.doi.org/10.1016/j.energy.2009.11.030.

© COPYRIGHT UPM

Ikoma, K., Munekiyo, M. & Furuya, K., 1998. Thermoelectric Module And Generator For Gasoline Engine Vehicles - Thermoelectrics, 1998. Proceedings ICT 98. XVII International Conference on. , pp.5–8.

Ismail, B.I. & Ahmed, W.H., 2009. Thermoelectric Power Generation Using Waste-Heat Energy as an Alternative Green Technology. , 1(807), pp.27–39.

Ismail, B.I. & Alabdrabalnabi, N., 2014. Design and Perfromance Characteristics of a Portable Solar-Driven Thermoelectric Heat Pump under Thunder Bay Extreme Cold Conditions in Northwestern Ontario, Canada. *Journal of Green Engineering*, 4(2), pp.116–134. Available at: http://www.riverpublishers.com/journal_read_html_article.php?j=JGE/4/2/2.

Kaxiras, E., 2001. *Materials Science*,

Kim, S., 2013. Analysis and modeling of effective temperature differences and electrical parameters of thermoelectric generators. *Applied Energy*, 102, pp.1458–1463. Available at: http://dx.doi.org/10.1016/j.apenergy.2012.09.006.

Kitagawa, K., Komoda, N. & Hayano, H., 1999. Effect of humidity and small air movement on thermal comfort under a radiant cooling ceiling by subjective experiments. *Energy and Buildings*, 30(2), pp.185–193.

Kong, L.B., Hng, H.H. & Boey, F., 2014. *Thermoelectric Effect*, Available at: http://link.springer.com/10.1007/978-3-642-54634-1.

Kossyvakis, D.N., Vossou, C.G. & Hristoforou, E.V., 2015a. Computational and experimental analysis of a commercially available Seebeck module. *Renewable Energy*, 74, pp.1–10. Available at: http://www.sciencedirect.com/science/article/pii/S0960148114004108.

Kossyvakis, D.N. et al., 2015b. Computational and experimental analysis of a commercially available Seebeck module. *Renewable Energy*, 74, pp.1–10. Available at: http://www.sciencedirect.com/science/article/pii/S0960148114004108 [Accessed February 9, 2015].

Lawrence, 2010. Americans using less energy, more renewables _ EurekAlert! Science News.

Leonov, V., 2013. Thermoelectric Energy Harvesting of Human Body Heat for Wearable Sensors. *IEEE Sensors Journal*, 13(c), pp.1–1. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6479224.

Leonov, V., Van Hoof, C. & Vullers, R.J.M., 2009. Thermoelectric and hybrid generators in wearable devices and clothes. *Proceedings - 2009 6th International Workshop on Wearable and Implantable Body Sensor Networks, BSN 2009*, pp.195–200.

© COPYRIGHT UPM

Leonov, J.S. & Vullers, R.J., 2010. Calculated Performance Characteristics of Micromachined the mopiles in Wearable Devices. , pp.391–396.

Liang, X., Tian, H. & Wang, Y., 2014. Comparison and parameter optimization of a two-stage thermoelectric generator using high temperature exhaust of internal combustion engine. *Applied Energy*, 130, pp.190–199. Available at: http://dx.doi.org/10.1016/j.apenergy.2014.05.048.

Lombardo, N., Knudson, C. & Ozanich, R., 2014. Automotive Waste Heat Conversion to Electric Power using Skutterudite, TAGS, PbTe and BiTe. *Ieee*, pp.1–6.

Mahlia, T.M., Masjuki, H.H. & Amalina, M.A., 2004. Cost-benefit analysis of implementing minimum energy efficiency standards for household refrigerator-freezers in Malaysia. *Energy Policy*, 32(16), pp.1819–1824.

Mani, M. & Pillai, R., 2010. Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. *Renewable and Sustainable Energy Reviews*, 14(9), pp.3124–3131. Available at: http://dx.doi.org/10.1016/j.rser.2010.07.065.

Massaguer, E., Montoro, L. & Gonzalez, J.R., 2015. Modeling analysis of longitudinal thermoelectric energy harvester in low temperature waste heat recovery applications. *Applied Energy*, 140, pp.184–195. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0306261914012549.

Mateeva, N., 1998. Correlation of Seebeck coefficient and electric conductivity in polyaniline and polypyrrole. *Journal of Applied Physics*, 83(1998), pp.3111–3117.

Matiko, J.W., Grabhamet, N.J. & Beeby, S. P., 2014. Review of the application of energy harvesting in buildings. *Measurement Science & Technology*, 25(1), p.012002. Available at: <Go to ISI>://WOS:000328687400003.

Mekhilef, S., Saidur, R. & Kamalisarvestani, M., 2012. Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. *Renewable and Sustainable Energy Reviews*, 16(5), pp.2920–2925. Available at: http://dx.doi.org/10.1016/j.rser.2012.02.012.

Merkisz, J., 2014. The Analysis of Exhaust Gas Thermal Energy Recovery Through a TEG Generator in City Traffic Conditions Reproduced on a Dynamic Engine Test Bed. *Journal of Electronic Materials*, 44(6), pp.1704–1715.

Miao, L., 2015. Experimental Performance of a Solar Thermoelectric Cogenerator Comprising Thermoelectric Modules and Parabolic Trough Concentrator without Evacuated Tube. *Journal of Electronic Materials*, 44(6), pp.1972–1983. Available at: http://link.springer.com/10.1007/s11664-015-3626-7.

Min, G. & Rowe, D.M., 2000. Improved model for calculating the coe • cient of performance of a Peltier module. , 41, pp.163–171.

© COPYRIGHT UPM

Ming, T., Wu, Y. & Peng, C., 2015. Thermal analysis on a segmented thermoelectric generator. *Energy*, 80, pp.388–399. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360544214013504.

Muhieldeen, M.W., 2010. Potential of using polyethylene single bubble insulation to reduce cooling load of of a leture hall.

Multi-Meter, D.E., 2016. Digital Multimeters DT830 Series Digital Multimeters.

Nochetto, H., Taylor, P. & Maddux, J.R., 2013. High Temperature Thermoelectric Materials for Waste Heat Regeneration. , (January).

Omer, S. A. & Infield, D.G., 2000. Design and thermal analysis of a two stage solar concentrator for combined heat and thermoelectric power generation. *Energy Conversion and Management*, 41(7), pp.737–756.

Orr, B., Singh, B. & Tan, L., 2014. Electricity generation from an exhaust heat recovery system utilising thermoelectric cells and heat pipes. *Applied Thermal Engineering*, 73(1), pp.588–597.

Riffat, S.B. & Ma, X., 2003. Thermoelectrics: A review of present and potential applications. *Applied Thermal Engineering*, 23(8), pp.913–935.

Rowe, D.M., 1995a. CRC Handbook of Thermoelectrics. *New York*, 16(1-4), pp.1251–1256. Available at: http://www.crcnetbase.com/doi/book/10.1201/9781420049718.

Rowe, D.M., 1995b. *CRC Handbook of Thermoelectrics - Google Books*,

Rowe, D.M., 2006. Thermoelectrics Handbook Macro to Nano.

Rowe, D.M., Thomas, G. & Smith, J., 2011. Weight penalty incurred in thermoelectric recovery of automobile exhaust heat. *Journal of Electronic Materials*, 40(5), pp.784–788.

Rowe, D.M. & Cardiff, 2006. Review thermoelectric waste heat recovery as a renewable energy source, 1(1), pp.13–23.

Shu, G., Liang, Y. & Wei, H., 2013. A review of waste heat recovery on two-stroke IC engine aboard ships. *Renewable and Sustainable Energy Reviews*, 19, pp.385–401. Available at: http://dx.doi.org/10.1016/j.rser.2012.11.034.

Sun, X., Liang, X. & Shu, G., 2014. Comparison of the two-stage and traditional single-stage thermoelectric generator in recovering the waste heat of the high temperature exhaust gas of internal combustion engine. *Applied Energy*, pp.489–498. Available at: http://dx.doi.org/10.1016/j.energy.2014.09.032.

Thermoelectic, 2011. Thermoelectric Power Generation. , (January).

© COPYRIGHT UPM

Wang, T., Zhang, Y. & Peng, Z., 2011. A review of researches on thermal exhaust heat recovery with Rankine cycle. *Renewable and Sustainable Energy Reviews*, 15(6), pp.2862–2871.

Wang, Y., Dai, C. & Wang, S., 2013. Theoretical analysis of a thermoelectric generator using exhaust gas of vehicles as heat source. *Applied Energy*, 112, pp.1171–1180. Available at: http://dx.doi.org/10.1016/j.apenergy.2013.01.018.

Weng, C.-C. & Huang, M.-J., 2013. A simulation study of automotive waste heat recovery using a thermoelectric power generator. *International Journal of Thermal Sciences*, 71, pp.302–309. Available at: http://www.sciencedirect.com/science/article/pii/S1290072913000756.

Wong, C.L. Uhlenbrook, S. & Jamil, A.B., 2011. Development of a gridded daily hydrometeorological data set for Peninsular Malaysia. *Hydrological Processes*, 25(7), pp.1009–1020.

Wong, C.L., Venneker, R.& Jamil, A.M., 2009. Variability of rainfall in Peninsular Malaysia. *Hydrology and Earth System Sciences Discussions*, 6(4), pp.5471–5503.

Yazawa, K. & Shakouri, A., 2011. Cost-efficiency trade-off and the design of thermoelectric power generators. *Environmental science & technology*, 45(17), pp.7548–53. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21793542.

Zhang, G. & Yong-wei, Z., 2015. Strain effects on thermoelectric properties of two-dimensional materials. *Mechanics of Materials*, 91, pp.382–398. Available at: http://dx.doi.org/10.1016/j.mechmat.2015.03.009.

© COPYRIGHT UPM

BIODATA OF STUDENT

Hanaa Kadhim Kareem Alsabahi was born in Baghdad, Iraq. She got her Bechelor's degree in Mechanical Engineering from "Almustansrya Universiti" (Iraq) in 1994. The author is Chief Engineer in Ministry of Electricity (Iraq). The author is currently doing her Master research with thesis in University Putra Malaysia.

© COPYRIGHT UPM

PUBLICATION

Alsabahi, H. K., Adam, N. M., As, A., & Alkhakani, A. J. (2015). Review of Potential Thermoelectric Energy Harvesting Using Seebeck Effect. *IJERT*, *4*(11), 173–177.

© COPYRIGHT UPM