Spin Seebeck Effect for Longitudinal Fins Arrangement in Biomedical Application

Usman Masud*, Muhammad Iram Baig*, and Usman Haider**
*University of Engineering and Technology, Taxila, Pakistan
**Consultant, Electrical Engineering, Pakistan

Abstract

Solar power has been one of the forms of renewable energy. With this perspective, we aim to employ it in our biomedical sensor which is designed for human health. The said sensor needs permanent monitoring by the physicians, thereby demanding uninterrupted power in the hospitals. This work is designed to use solar energy as a thermal energy using latent heat storage system. The storage material used in this project is paraffin wax which stores heat as latent heat. Spin Seebeck effect has been utilized in the arrangement such that the stored energy can be continuously supplied to the sensor. Our results show that Phase change materials (PCMs), as underlying heat storing devices are much efficient than sensible heat storage. Our results have shown that the technique is very effective in terms of the sensor's performance, as indicated by the verification of the graphical investigation.

Keywords—biomedical sensors, IEEE transmission protocols, nodes.

I. Introduction

Biomedical sensors [1] are being currently deployed all over the world. On account of recent changes in human lifestyle, life durations have changed across many parts of the world. This implies continuous monitoring of human health. In this connection, our sensor is one of those that is designed to analyze human breath and its constituents [2, 3]. This investigation leads to information about various diseases in human body that helps gain a timely analysis and thereby, an appropriate analysis can be initiated. However, this demands continuous and uninterrupted supply of electricity to the system as it depends on a 24/7 monitoring mechanism.

Solar thermal storage scheme is a new field of research. The purpose of our project is to satisfy the energy criterion not only for the said sensor but also it would pave way regarding the energy shortcomings in the country using renewable source of energy as well as many parts of the world. There are different systems of heat storage with different type of materials. Here we are using solar thermal battery system. We studied different types of fins arrangements such as straight fin arrangement, cross-fin arrangement, T and Y shaped arrangement. All these arrangements were studied earlier and it was found that cross fin configuration gives the maximum output, in particular for the sensor device.

The purpose is to develop a new arrangement of fins for better heat transfer than cross fins arrangement. So finally the three fins are placed at an angle of 120 degree. Here we have used latent heat storage system. The storage material may be quartz, silica, mineral oil and paraffin wax .For better heat transfer paraffin wax has been used as it has high storage capacity. From design point of view an electric geyser is used instead of solar collectors due to shortage of time and to maintain constant supply of heat. Two tanks can be used to store hot and cold fluid separately but this will not be economical. So we used a single storage tank to get high efficient to cost ratio. An electric rod is placed in a tank of steel filled with water. Ac voltage is supplied to the rod which increases the temperature of water gradually. The input to the geyser is a constant power supply so with an increase in time the aquatic temperature rises and begins to flow in the storage tank filled with wax. The copper pipe with fins placed around the wax transfers heat to wax uniformly .When the temperature rises to 45- 60 degree centigrade then wax starts melting and store this thermal energy. One of the best prevalent usages of solar thermal technology has been reported to be solar water heating [4].

Three temperature sensors are used that will sense the level of heat and these temperature values will be displayed on LCD screen. After noting the temperatures on LCD temperature difference can be calculated manually which gives the required results. The complete storage process is divided into three steps.

1. Charging
2. Storing
3. Discharging

However some of these processes may be simultaneous. Frequently it is common to charge the storage media while producing electricity. After completing the storage process we have used thermocouples at various points which will measure the temperature difference and we have displayed various temperature readings on Data Acquisition System (DAS). Moreover digital thermocouples can be used directly. So finally due to difference in temperature at inlet and outlet heat will flow that can be utilized according to requirement.

II. Related Work

The development of alternative energies [5, 6] becomes now a days more important issue, due to the continuous increase in green-house gas emission levels and the fossil fuels climbing prices. The main characteristics of new alternative energy that it must be clean, cheap, and sustainable. Solar energy can be considered as the most appropriate energy possesses these requirements. During the previous years, extensive variation in solar energy equipment has been established through investigation and advancement [7], in particular the practicality and extensive campaign in the past two decades. Based on these assumptions, much of this technology [8] has supposedly reached maturity to quite some extent. This user-friendly interface is suitable for distributed applications.

A widespread practice of solar thermal technology is solar water heating [4].Solar energy has a great prospect for buildings, heating and cooling, warming water for home and business uses, culinary, maintaining greenhouses in agricultural harvests, etc. [9]. However, solar energy is sporadic, fluctuant, and available during daytime only. Hence, its applications require active thermal energy to be stored such that the overabundant heat saved throughout sunlight might be kept for future usage when needed. Solar energy needs a heat storage system to be used as a buffer to pacify the alteration of solar incidence. In other words, some form of thermal energy storage becomes important for the most practical consumption of that source of energy.

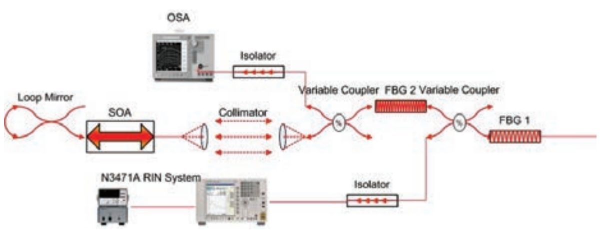

Fig. 1. Experimental setup of the biomedical sensor proposed in [3], with its various components.

III. Methodology

Paraffin wax has been the best used commercial organic heat storing Phase Change Materials (PCMs) [10]. The common sort of paraffin C_nH_{2n+2} is a chain of saturated hydrocarbons having identical features. An increase of C-atoms rises the melting point too. Paraffin amid C5 and C15 remain liquids, whereas the others stay waxy solids. Paraffin waxes have been cheap with modest thermal energy storage density, however, little thermal conductivity, therefore, need great surface area. These materials are able to stock energy by softening at a constant temperature. Paraffin wax has been the finest used commercial organic heat storing PCM [11]. The common paraffin of form C_nH_{2n+2} are saturated hydrocarbons possessing identical features. Increasing the number of C-atoms increases the melting point too. Paraffin between C5 and C15 have been liquids, and the remaining are waxy solids. This material is low-cost and has sufficient thermal energy storage density and little thermal conductivity which necessitates more surface area. These materials are able to stock energy by mechanism of melting at a constant temperature.

The use of maximized thermal conductive fins for thermal storage is a naive and operational approach to make better the melting rate of that PCM within the thermal storing capacity. Conversely, making the quantity more of metallic fins would only improve the effective thermal conductivity of the system and will not make a severe betterment in the total heat transfer coefficient. This property due to expected convection because transfer phenomenon is reduced inside the small fin gap capacity.

As shown in Fig. 1, the biomedical sensor [2] under investigation consists of a Semiconductor Optical Amplifier (SOA) that is responsible for the mainframe laser operation. Then there are two Fibre Bragg Gratings (FBGs) that provide wavelength selection for the sensor to detect the sample in the desired wavelength range. The collimator is where the sample is placed, and loop mirror delivers broadband reflectivity for increased intensity of the laser. Isolators ensure unidirectional flow of light into the specified directions to view the output. Variable couplers help divide the laser light into desired output ratio. The output can be seen on Optical Spectrum Analyzer (OSA) in optical form and Electrical Spectrum Analyzer (ESA) in electrical form. The latter helps diagnose the sensor operation in the form of Relative Intensity Noise (RIN) that is a substantial merit of the sensor in terms of operation and economy. The sensor device works in such a way that the human breath needs to be monitored continuously and this demands nonstop electricity [3]. For this purpose, technical discussions were held and a plan was chartered to employ renewable energy resources.

Thermal energy storage (TES) [12] is accomplished with critically divergent technologies that mutually put up an extensive range of needs. It permits surplus thermal energy to be saved for future use, hours, days or many months later, at individual house, multiuser buildings, locality, towns or even regional quarters depending on the explicit technology [13].The consumption of an underlying heat storage scheme that uses PCMs [14] is an operational mode of keeping thermal energy, as it offers the merits of great energy storage density as well as the isothermal property of that system storage. PCMs are being extensively engaged in latent thermal heat storage arrangements aimed at solar engineering, heat pumps, as well as applications in space-craft with thermal control [15].

As the sensor is an inherent device for the detection and analysis of human breath, numerous parameters need to be adjusted accordingly. Innumerable materials are being explored for the energy storage methods built on the property of solid to liquid phase change. In order to make feasible for the sake of storage of heat, the said materials must fulfill a certain criteria related to their characteristics. Before making a choice, following factors were in particular paid attention.

A. Thermal properties:

A change in phase changes and drastically impacts temperature fitted with the application, as well as high variation in enthalpy close to the working temperature and sufficient thermal conductivity in either liquid or solid phase. This can play havoc, as the chemical reactions generated of the material with the analyzed substance in this way can yield to falsification of results, as well as generate unwanted health effects.

B. Physical properties:

With the advent of nanotechnology, there are numerous things that have been important to the structure of the device sooner or later during the operation of the device. Variation in low/high density, as well as minor/under-cooling can yield to undesirable consequences.

C. Chemical properties,

The stability and absence of phase separation depends on compatibility with various sorts of environments and container materials and non-toxicity. This might in turn yield non-flammability outcome which is very significant not only for the biomedical setup but is also echo friendly.

Material	Ceramic	Concrete
Density (kg/cubic meter)	3,500	2,750
Specific Heat (J/Kg.K)	8,66	9,16
Thermal Conductivity(W/mK)	1.35	1
Coefficient of thermal expansion(*1*/K)	11.8	9.3

Table 1. Properties of concrete and ceramic material[16].

Factors	Amount
Density [kg/m3]	Solid - 8,80 or liquid - 7,60
Specific heat [kJ/kg K]	Solid - 2.9 or liquid - 2.2
Thermal conductivity [W/m K]	2×10^{-1}
Melting temperature	47
Latent heat [kJ/kg]	140
Thermal expansion [K-1]	1×10^{-3}

Table2.Thermo-physical parameters of paraffin wax [16].

D. Economic features

The biomedical sensor has been destined for people who have crossed their 50's which explains the reason and motivation to engage components in the near infrared wavelength range [3]. This in turn yields a lot of consumers that highlights the economic factor therein. Best efforts have been made to ensure low cost of the sensor, and therefore paraffin seems to be an optimal material in this case.

E. Abundance

The properties of different storage materials were studied that resulted in the fact that PCMs appear to be the finest among their competitors in terms of availability which is an important parameter for the biomedical sensor's durability and maintenance.

In all phase changing materials paraffin wax was found practically well due to its great heat capacity over a narrow temperature range. Paraffin wax stores energy once it changes phase to liquid from solid (when it melts) and releases energy by changing from liquid to solid (when it freezes).

Due to low melting temperature of paraffin wax we used a single storage tank. The tank was made of steel and covered with insulation to eliminate heat loss. To make the flow of water in reverse direction we used a dc water circulating pump. The output result can be shown in different ways, three different thermo couples can be used and a single data acquisition system (DAS) with the output on monitor screen can be used. For simplicity we used a LCD displaying the different temperatures at a time by using PIC microcontroller.

With the development of technology and by studying of various shapes of fins cross fin arrangement was developed. Cross-fin shape has shown more natural convective response at the top surface of fins with the increase in horizontal and vertical area. However recent studies have shown that cross-fin configuration does not show good results at the lower regions of process. So it is necessary that an advance and more efficient system with the proper fins geometry to increase the efficiency of solar thermal storage system must be developed.

Finally attempts have been made to develop an efficient fin arrangement in the said storage system. We have explored our best to keep these fins in proper geometry for getting maximum efficiency more than other types of configurations of fins discussed above.

We used a paraffin wax having temperature range from 45 to 60°C. So this type of wax can easily be melted at low temperature and output can be obtained in less time. In other studies other PCM materials have used like mineral oil, fatty acids and salts etc. But the melting temperatures of those materials are more than wax. Electrical conductivity of these materials is also lower than this. In short wax is best in all respects then other materials. In order to make the system efficient we developed fins on the copper pipe. There are many fins arrangements but we used three fins at an angle of 120 degree apart from each other. The reason to choose this arrangement of fins was that all other fins arrangements i.e. Straight-shaped, T-shaped, Y-shaped and Cross shaped were studied earlier. For the sake of convenience and completeness, some important properties of wax are outlined in table 2.

The design procedure is elaborated in the following.

1) Structure and Isolation of Storage Tank

The paraffin wax is placed inside the storage tank made up of acrylic material in which a copper pipe with fins is placed. The hot water flows inside the copper the copper tube and heat is transferred to the wax by natural conduction and convection processes [9]. The tank is made up of acrylic material instead of plastic or glass as this material provide high insulation strength and saves the heat to flow out of tank. Due to this the heat transfer rate increases and wax melts in less time and stores energy for a long time.

2) Controller Configuration

A PIC microcontroller 16f877 [17] is connected with the LCD where pins 1-4 are used as analogue to digital converter circuit that are connected with thermistors. Pins 13 and 14 are connected to the clock generator with the clock frequency of 4MHz. Pin 1 is grounded and 2 is connected with 5 volts supply. The pin 21 and 22 of controller are connected with pi 4 and 6 of LCD. From ADC circuit the data flows in binary numbers that is received on LCD from pin 11-14.

3) Circuit Design

In order to complete the design of the entire circuit, various components have been incorporated. This is done in order to avoid problems like short-circuiting, and fluctuation in voltages, numerous devices have been incorporated. In this regard, resistors of different ratings are used for different purposes. Mainly the resistance used is 220Ω a few variable resistors are also used having rating 10 ohms. Capacitors of different ratings including 10 microfarad and 27 microfarad are employed. Besides, thermistors are also used whose one end is connected with 5 volt and other is grounded. These thermistors are connected to pin 1-4 of PIC controller. As the resistance normally rises with the rise in temperature but the resistance of thermistors declines with rise in temperature. This choice of components is not only beneficial in various technical ways, but also is very beneficial in terms of economy, as the sensor mechanism has been destined for the general public.

4) Experimental Results

The experiment was performed in such a systematic manner that the temperature was recorded at different levels within the container. This is necessary in order that the device performs satisfactory and no significant fluctuations hinder the functioning of the sensor at any time. It is found that the level of heat at the lowermost portion of the storage tank is high, a moderate temperature is observed at the middle and finally, a low temperature at the uppermost part of the tank is documented. For instance, the melting temperature of wax was found to be 48°C. Similarly other parameters actually calculated during the experiment are given in table 3.

Temperature	Readings
T_a	321 K
T_b	308 K
T_c	302 K
$\Delta T = T_a - T_b$	13 K
$\Delta T = T_b - T_c$	6 K
$\Delta T = T_a - T_c$	19 K

Table 3. Average temperature record maintained in the container.

The temperature difference can be converted directly into electrical energy by Seebeck effect [18] by connecting thermoelectric generator. Accordingly the relationship can be expressed mathematically as

$$V = \alpha \Delta T, \quad (1)$$

where, V is the voltage difference between two dissimilar metals, α is Seebeck co-efficient, ΔT is the change in temperature between hot and cold junctions. The voltages generated by Seebeck effect are minor, typically only a few μV (millionth fraction of a Volt) per kelvin of temperature difference present at the junction. When this difference in temperature becomes significant, some Seebeck-effect devices are capable to produce a few mV (thousandth fraction of a Volt). Numerous devices like this can be connected to rise the voltage outcome or in parallel to intensify the utmost deliverable current in series. Big arrangements of Seebeck-effect equipment can offer valuable, modest electrical power in case a great temperature difference is kept across the said junctions.

This phenomenon is accountable for the behaviour of thermocouples that are engaged to measure nearly the differences in temperature or to actuate electronic switching devices that are able to turn big systems on and off. This competency is used in thermoelectric cooling machinery. Frequently used thermocouple metal combinations consist of constantan/iron, constantan/copper, constantan/alumel and constantan/chromel.

By using the equation provided above, the respective values of three different voltages as $V1$, $V2$ and $V3$, which are from bottom to top respectively, have been calculated. This has been in complete agreement with the postulations of spin Seebeck effect [19, 20].

To check the performance of the device, measurements were taken in terms of RIN. The results are shown in Figs. 2 and 3. To cross check the quality of the supplemental mechanism, the same value of RIN was sent across the network and seen at the receiver end. The results were remarkably impressive, as the average difference in the graphical output was 0.08% on average. No offshoots or change in slope were found at the receiver side, and was confirmed by the physicians.

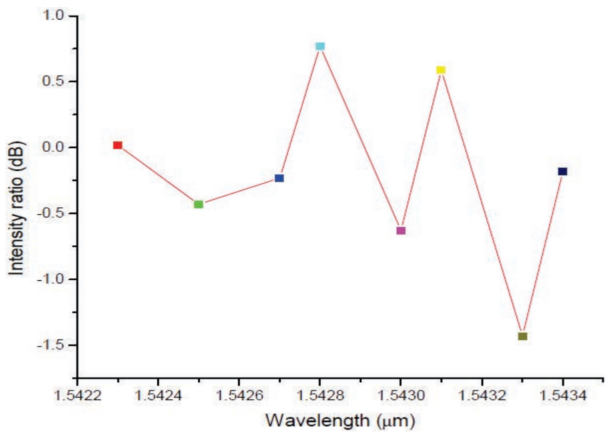

Fig. 2. The value of RIN acknowledged at the receiver's side which is precisely the same as the one at the sender's side, with an average error of 0.08% between the two.

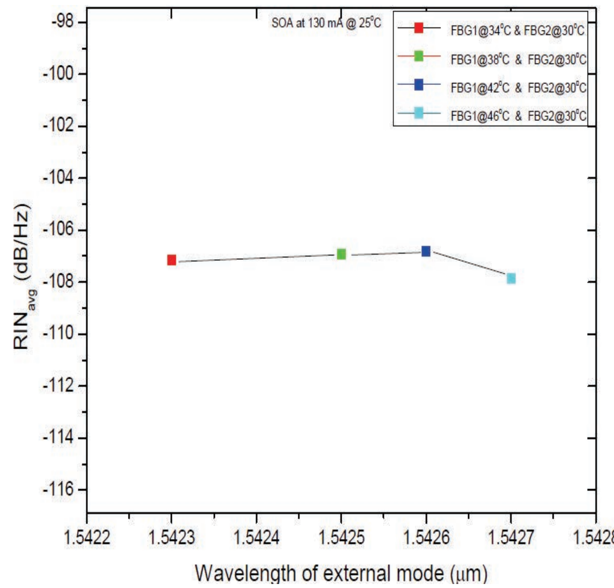

Fig. 3. Another value of average RIN when both modes are in equilibrium state.

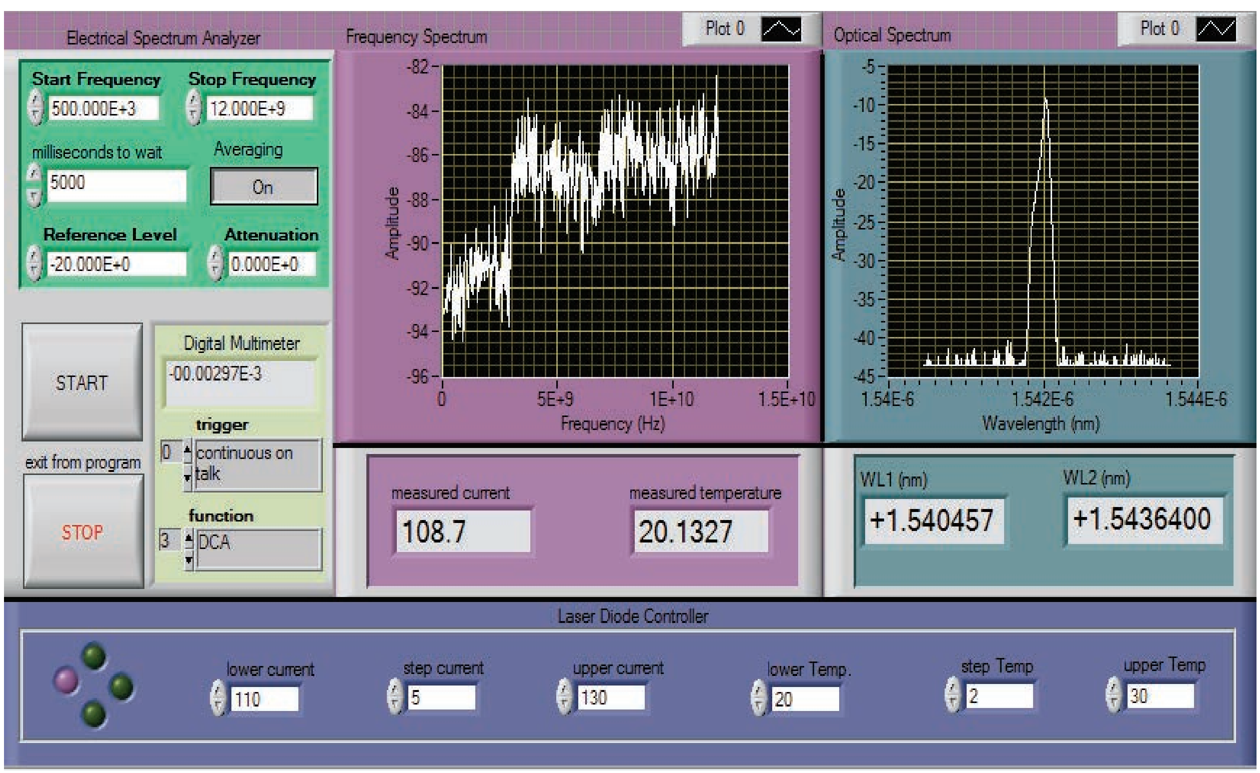

Fig. 4. Controlling mechanism of the setup with Labview. The start and stop frequencies are indicated, along with amplitude spectra. These values are recorded at the receiver end. This justifies that of the control scheme for the entire setup is feasible and implies its efficient prospects for future usage.

Apart from finding these differences, the whole setup has been mechanized by LabView. This means that the system that already existed before was controlled by LabView, and the supplemental setup is also able to be controlled by the said software. This opens vistas for including the biomedical sensor in handheld devices in a more realistic way.

5) Conclusion

Our supposition of systematic arrangement of fins to be engaged for biomedical sensor operation was brilliant as the heat transfer rate of this arrangement was found to be maximum, as this was a new research regarding fins configuration with optimum result. So finally it has been concluded with evidence that for better heat transfer, efficiency, high conductivity and stability all other types of fins arrangement can be replaced to some extent by the fins arrangement used in our project.

Secondly due to the use of acrylic material for storage tank the heat energy remained inside the tank and the loss of heat energy was minimum which increase the overall efficiency of latent heat storage system using low melting paraffin wax.

As an extension to the present work, it would be interesting to collaborate the protocols of wireless networks like IEEE 802 algorithms. This would make interesting outlooks for the existing setup as the entire system would be mechanized and controlled by LabView. Another proposition is to see if the mechanized system can be optimized by a built in hardware scheme, and negotiations with the respective vendor National Instruments are on way in this connection.

6) References

[1] P. A. Serra, Advances in Bioengineering, 2015.

[2] H. Hillmer, "Sensor Process and Device for determining a Physical Value". Patent DE10 2004 037 519B4, 30 July 2004.

[3] U. Masud, Investigations on highly sensitive optical semiconductor laser based sensorics for medical and environmental applications - 'The Nanonose', Kassel University Press, 2015.

[4] P. a. M. A. Purohit, "CDM potential of solar water heating systems in India," *Solar Energy,* vol. 82, no. 9, pp. 799--811, 2008.

[5] C. Demski, A. Spence and N. Pidgeon, "Effects of exemplar scenarios on public preferences for energy futures using the my2050 scenario-building tool," *Nature Energy,* no. 2, 13 March 2017.

[6] Y. Hu and H. Cheng, "Displacement efficiency of alternative energy and trans-provincial imported electricity in China," *Nature Communications,* 17 February 2017.

[7] C. Wang, S. Zhang, W. Yan, R. Wang, J. Liu and Y. Wang, "Evaluating renewable natural resources flow and net primary productivity with a GIS-Emergy approach: A case study of Hokkaido, Japan," Nature Scientific Reports, 18 November 2016.

[8] D. Kang, J. L. Young, H. Lim, W. E. Klein, H. Chen, Y. Xi, B. Gai, T. G. Deutsch and J. Yoon, "Printed assemblies of GaAs photoelectrodes with decoupled optical and reactive interfaces for unassisted solar water splitting," *Nature Energy,* vol. 2, 27 March 2017.

[9] Y. Q. a. R. S. Cui, "Review on Phase Change Materials for Building Applications," in *{Applied Mechanics and Materials*, vol. 71, 2011, pp. 1958--1962.

[10] S. E. Kalnæs and B. P. Jelle, "Phase change materials and products for building applications: A state-of-the-art review and future research opportunities," *Energy and Buildings,* vol. 94, 1 May 2015.

[11] R. Baetens, B. P. Jellea and A. Gustavsen, "Phase change materials for building applications: A state-of-the-art review," *Elsevier Energy and Buildings,* vol. 42, no. 9, p. 1361–1368, 10 April 2010.

[12] B. Mathiesen, H. Lund, D. Connolly, H. Wenzel, P. Østergaard, B. Möller, S. Nielsen, I. Ridjan, P. Karnøe, K. Sperling and F. Hvelplund, "Smart Energy Systems for coherent 100% renewable energy and transport solutions," *Applied Energy,* vol. 145, p. 139–54, 2015.

[13] A. Ter-Gazarian, Energy Storage for Power Systems, London: Peter Peregrinus Ltd. (on behalf of Institution of Electrical Engineers, UK), 1994.

[14] M. Kenisarin and K. Mahkamov, "Solar energy storage using phase change materials," *Renewable and Sustainable Energy Reviews,* vol. 11, no. 9, pp. 1913-1965, 2007.

[15] D. Zhou, C. Zhao and Y. Tian, "Review on thermal energy storage with phase change materials (PCMs) in building applications," *Elsevier Applied Energy,* vol. 92, p. 593–605, April 2012.

[16] C. Book, "Paraffin wax(8002-74-2)," J & K SCIENTIFIC Ltd., [Online]. Available: http://www.chemicalbook.com/ProductMSDSDetailCB2854418_EN.htm. [Accessed 11 January 2017].

[17] C. T. (Vysakh), "Introduction to PIC 16F877," 12 January 2011. [Online]. Available: http://www.circuitstoday.com/introduction-to-pic-16f877. [Accessed 23 March 2017].

[18] D. Rowe, Thermoelectrics Handbook: Macro to Nano, CRC Press, 2010.

[19] J. Kimling, G.-M. Choi, J. T. Brangham, T. Matalla-Wagner, T. Huebner, T. Kuschel, F. Yang and D. G. Cahill, "Picosecond Spin Seebeck Effect," *Physics Review Letters,* vol. 118, 1 February 2017.

[20] H. Adachi, K.-i. Uchida, E. Saitoh and S. Maekawa, "Theory of the spin Seebeck effect (Reports on Progress in Physics)," *Reports on Progress in Physics,* vol. 76, no. 3, 2013.

[21] R. M. L. a. M. V. P. Gerard L. Coté, "Emerging Biomedical Sensing Technologies and Their Applications," *IEEE Sensors Journal,* vol. 3, no. 3, June 2003.

[22] A. Meier, "Cooperative Diversity in Wireless Networks," University of Edinburgh, March 2004.

[23] D. Zagar and K. Grgic, "IPv6 Security Threats and Possible Solutions," in *World Automation Congress*, Budapest, 24-26 July 2006.

[24] U. Masud and M. I. Baig, "Cooperative diversity in wireless networks: A timing perspective," in *6th IEEE ICET*, 2010.

[25] W. Brunner and H. Paul, "Theory of intracavity absorption spectroscopy," *Journal of Optical and Quantum Electronics,* vol. 10, pp. 139-151, 1978.

[26] L. F. a. N. K. J. Mills, "Firms' Off-Balance Sheet and Hybrid Debt Financing: Evidence from Their Book-Tax Reporting Differences," *Journal of Accounting Research,* vol. 43, no. 2, pp. 251--282, 2005.

[27] R. a. S. N. S. N. Senthilkumar, "Experimental Investigation of Solar Water Heater Using Phase Change Material," *International Journal of Research in Advent Technology,* vol. 2, no. 7, pp. 1----87, 2014.

[28] J. J. a. K. L. D. Tomlinson, "Thermal energy storage," *Mechanical Engineering,* vol. 112, no. 9, p. 68, 1990.

[29] Sharma, A. Tyagi, V. Chen and D. CR Buddhi, "Review on thermal energy storage with phase change materials and applications," *Renewable and Sustainable energy reviews,* vol. 13, no. 2, pp. 318--345, 2009.

QUOTATIONS

- There is no charm equal to tenderness of heart.

  Jane Austen

- If you cannot do great things, do small things in a great way.

  Napoleon Hill

- It is far better to be alone, than to be in bad company.

  George Washington

- If opportunity doesn't knock, build a door.

  Milton Berle

- Money can't buy you happiness, but it helps you look for it in a lot more places.

  Milton Berle

- Don't judge each day by the harvest you reap but by the seeds that you plant.

  Robert Louis Stevenson

- Try to be a rainbow in someone's cloud.

  Maya Angelou

- When you reach the end of your rope, tie a knot in it and hang on.

  Franklin D. Roosevelt

- Every day is a good day to be alive, whether the sun's shining or not.

  Marty Robbins

- Silence is golden when you can't think of a good answer.

  Muhammad Ali

- No one can make you feel inferior without your consent.

  —Eleanor Roosevelt

- Plant your garden and decorate your own soul, instead of waiting for someone to bring you flowers.

- —Jose Luis Borges

  Love all, trust a few, do wrong to none.

- –William Shakespeare

  The power of imagination makes us infinite.

  ~John Muir

- The best dreams happen when you're awake.

  ~Cherie Gilderbloom