Thermoelectric Cooler (TEC) Control Systems Analysis using Solar Energy

Atharv Naik
Student,*Department of Mechanical Engineering,MITSOE , MIT ADT University*
Pune, Maharashtra,India
atharvnaik786@gmail.com

Nishigandha Patel
Professor,*Department of Mechanical Engineering,MITSOE , MIT ADT University*
Pune, Maharashtra,India
nishigandha.patel@mituniversity.edu.in

Sandeep Thorat
Professor,*Department of Mechanical Engineering,MITSOE , MIT ADT University*
Pune, Maharashtra,India
sandeep.thorat@mituniversity.edu.in

***Abstract*— Global demand for renewable energy sources is rising as a result of the negative effects burning fossil fuels has on the environment. Utilizing renewable energy sources, such as solar energy, one of the world's most reliable and clean energy sources with a wide range of applications, can help us curb the trending increase in global electricity consumption. One such application is the cooling effect provided by Thermoelectric Coolers (TECs). Thermoelectric coolers can run on a battery that receives a direct power supply from solar panels. It is possible to obtain experimental efficacy. Solar panels also have the potential to be used as a power source for thermoelectric cooling systems. A single solar module can only generate a certain amount of power; most installations include multiple modules, giving us the opportunity to research power output and efficiency for TEC's. A photovoltaic system, in general, consists of a panel or array of solar modules, a solar inverter, and, on occasion, a battery and/or a solar tracker. This report will primarily concentrate on thermoelectric cooling based on solar cell power output, which can provide cooling in remote applications. The report also includes the possibility of using controllers and sensors to achieve the desired temperature**

Keywords*— Thermoelectric cooler, Solar energy, Temperature Sensor, Photovoltaic system.

I. INTRODUCTION

Electrical energy is a vital necessity in daily life, and the provider must be quick to address any problems that may occur due to the escalating demand for it.[1] One of the problems with electrical energy is the dwindling supply of fossil fuels as a source of energy, which makes it necessary to create new, sustainable alternative energy sources in the modern day.[2] Energy created from raw materials that are readily available, renewable, and reusable is referred to as renewable energy. One type of renewable energy is solar power.[3] Due to its constant availability and the absence of any waste, solar energy has emerged as one of the most significant renewable energy sources[4,5]. On the other hand, environmental aspects like ambient and operational temperatures have a big impact on the effectiveness, productivity, and durability of solar panels.[6,7,8] According to studies, only 15 to 20 percent of the solar radiation that a solar panel absorbs is turned into electricity, with the remainder being lost as heat.[9,10,11] The main energy source that will be essential in supplying the future need for electricity on a worldwide scale is solar energy. For the purpose of harnessing solar energy, modern photovoltaic (PV) systems with high electric conversion efficiency are crucial.[12] In addition, a number of variables, like the strength of the light and the solar panels' operating temperature, affect how much electricity is produced by solar panels. We therefore require a technique that can increase the output power of solar panels.[13] A method for boosting the power produced by a PV system is maximum power point tracking (MPPT).[14] A solar panel is a device that turns solar energy into electrical energy by utilizing the photovoltaic effect.[15] The electrical energy produced is typically used to power devices, with part of it being temporarily stored in batteries. This solar panel system's operations may go on through the afternoon, evening, and even in the rain because it employs a battery. Photovoltaic (PV) technology uses the sun's rays to generate electricity.[16] A renewable energy source that can be utilized as a stand-alone power source is solar photovoltaic technology.[17-19] Integration with the thermoelectric cooler also needs solid-state operation, DC power output, dependability, and durability. [20-22] With a 25-year lifespan, solar photovoltaic systems are taken into consideration. By lowering carbon emissions, the utilization of solar photovoltaic energy and energy optimization promotes long-term sustainability.[23,24] One of the greatest options for a variety of applications, including the refrigeration of food and the storage of medications, is thermoelectric cooling. The Peltier effect states that cooling occurs at a junction of two distinct semiconductors (n-type and p-type) when a direct current is passed across the junction.[25] A thermoelectric cooler (TEC) can absorb and transfer heat from one side to the other when it is electrified.[26] A temperature differential between the two sides of this PN junction builds up as current travels through the electrodes connecting the various semiconductors, as seen in Fig. 1. A single PN junction is capable of forming a whole TEC. To address the demand for cooling space, TECs are always constructed with several PN junctions connected in series. [27-29]-

The high cost and poor energy efficiency of thermoelectric cooling are its principal drawbacks. Despite being discovered in the nineteenth century, the thermoelectric cooling effect did not experience rapid development until the 1950s, when the fundamental physics of thermoelectric materials had been established.[30].A solid-state, noise- and pollution-free device is the thermoelectric (TE) device.[31] We focused on the analysis of a Thermoelectric Cooler (TEC) control system using Solar Energy in this paper.

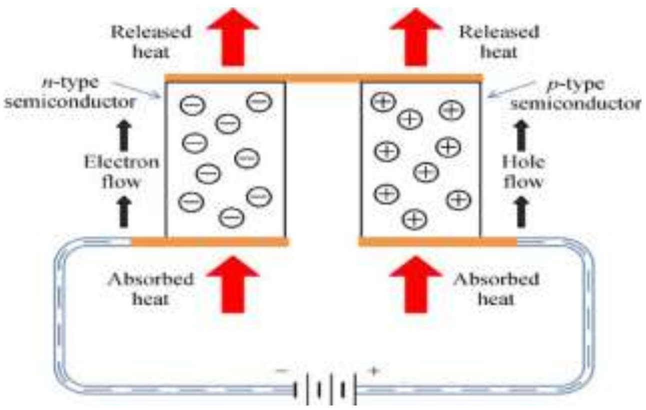

Fig1. TEC's operating principle is depicted schematically

This examination of Thermoelectric Cooler (TEC) control systems using solar energy is based on a review of the relevant literature as well as empirical research that are publicly available across the globe. In order to make our analysis based on the background study, we first gathered pertinent evidence that either supports or refutes the elements described in the introduction section of this work. Our research is divided into the following subject areas:

• Solar-powered Thermoelectric Cooler (TEC) control systems and how they function.

• The electric coolers' operational frameworks, procedures, and applications.

These findings in the aforementioned domains form the basis of our conclusions, which enable future extensions or projections based on requirements or requirements connected to the subject of our study.
subject.

II. THERMOELECTRIC COOLER WORKING PRINCIPLE:

The "Seebeck, Peltier, and Thomson effects" underpin a typical Thermoelectric Module.

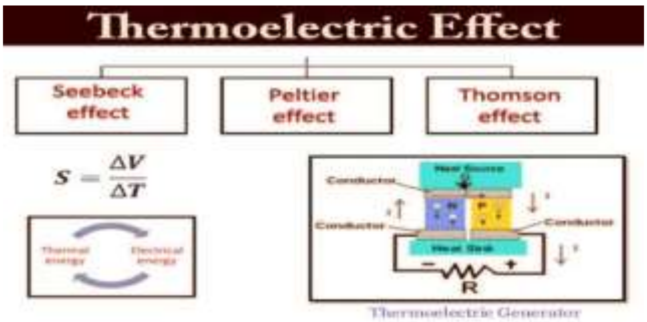

Fig 2. Seebeck Effect

- Seebeck Effect

“When two materials that are different are linked and a temperature differential of exists at the junction, the Seebeck Effect creates a current and potential difference.This study emphasises Peltier's effect also.. [32-33]

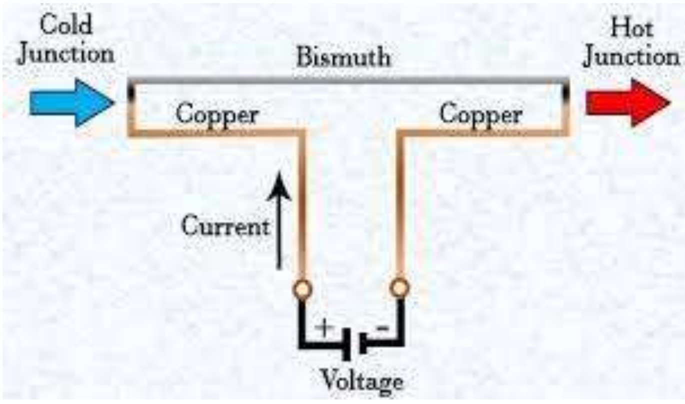

Fig 3. Peltier Effect

V. THERMOELECTRIC MODULE:

Due to their ability to run on electricity produced from waste, thermoelectric refrigerators (TER) are a novel and environmentally friendly alternative that will be essential in overcoming the energy problems of today.[34] Consequently, TER are in high demand [35], especially in underdeveloped nations where the need for freezers with long lifespans and less maintenance is present.[35][36] A form of cooling system called a thermoelectric refrigerator (TER) is used in a variety of products, including machineries, appliances, and medical equipment. The cooling device utilized (TEM) is a thermoelectric module. It is made up of several cold and hot junctions.[37] Electricity is used to heat and cool the residence.

The quality of thermoelectric materials is generally determined by their inherent qualities, which are used to select thermoelectric modules.[39] The performance of a module is based on a material attribute called the Seebeck coefficient. For thermoelectric devices, low thermal conductivity materials are necessary to minimize parasitic heat flow across each leg.[40] Nanostructures provide autonomous regulation of electron and phonon transport.[41] Due to the boundary scattering phenomena, the thermal conductivity of nanomaterials is extremely low. Thermoelectric materials also make superior electrical conductors.[40] It will be discovered that the ideal range for semiconductor materials' electrical resistivity lies between 10-3 m and 10-2 m.[39] The variation in resistivity depends on the charge carrier concentration and the charge carrier's mean free route as a result of surface scattering and reflection.[42]

IV. METHODS FOR ENHANCING THE PERFORMANCE OF THE COOLING SYSTEM

When The cooling power output and cooling COP of the system, as well as the functionality of the thermoelectric modules and the heat sink design, must all be taken into account when building a thermoelectric cooling system. As a result, COP and cooling capacity must be balanced when constructing a thermoelectric cooling system. [43-51]

VI. RELATED WORK

1. Cheng and Lin, 2005 [52] The physical parameters of thermal elements were tuned using genetic algorithms.
2. Chakraborty et al. (2006) [53] The cooling cycle of a thermal element was illustrated using temperature-entropy analysis.
3. Zhang (2010) [54] A general, uncomplicated method for optimizing thermoelectric coolers was presented in place of the frequently utilized iterative process.
4. Lee (2013) [55] introduced new dimensionless groups to symbolize crucial thermoelectric device parameters..

VII. APPLICATIONS OF THERMOELECTRIC COOLING:

As technology develops, more and more fresh uses appear. There are numerous thermoelectric cooling applications available today. To start, small enclosures, portable iceboxes, beverage can coolers, and picnic baskets are all cooled using thermoelectric cooling systems in the civil market.[56] Second, it has been applied to the cooling of integrated circuit chips or laser diodes in scientific, laboratory, and medical equipment. Third, the use of thermoelectric cooling systems for industrial temperature management, electronic device cooling, and other heat dissipation applications has increased. [57-59]

Fig 4. Some Examples of Thermoelectric Cooling Applications

Sark (2011) [60] This method was found to boost efficiency for roof integrated PV-TE modules by up to 23% while increasing annual energy generation by 11.7% to 14.7% utilizing commercially available thermoelectric materials. The production of thermoelectric power is the technological area of this application. On the other hand, the thermoelectric module helps to cool the photovoltaic panels.

VIII. CONCLUSION

In terms of material developments, modeling strategies, theoretical underpinnings, and practical applications, this paper examines how thermoelectric cooling has changed over the previous ten years. For power generation or cooling, thermoelectric devices are utilized in this work since they are environmentally beneficial. Utilizing TE systems can help the world meet its promise to reduce pollution and enhance energy conservation.

The use of TE systems can help the world meet its commitment to improve energy efficiency and reduce pollution.

Self-cooling instruments are another use for thermoelectric modules, especially in small setups where thermoelectric cooling is more efficient than traditional systems. Semiconductors, ceramics (high temperature), and polymers are some of the thermoelectric materials available, each with its own set of properties (flexibility). Because of their high ZT values, Bi-Te alloys are commonly used in thermoelectric modules. Furthermore, TECs' advantages would emphasize their importance in future cooling technologies. Some of the papers suggest that Proposal of a transient cooling concept involving the introduction of a thermal mass and Theoretical proof that transient cooling works. This study has made a significant contribution to the concept's demonstration. It's important to note that the study's example constrains our interpretation.

The capabilities, guiding principles, and TEG module requirements to operate the utilized TEC at peak efficiency throughout most of the year are examined in this study. The heat demand of TEG systems is usually met with low-cost/free resources. TEG systems, in addition to PV panels, are used to produce solar energy. It should be noted that recouping capital in TEG systems takes approximately 6-8 years. As a result, it is critical to reduce thermoelectric material costs.

Thermoelectric cooling applications, on the other hand, are not limited to these fields.

REFERENCES

[1] M. A. Greeen, Solar Cells Opertaing Principles, Technology and System Applications, New Jersey: Prentice-Hall, 1982.

[2] M. Ikbal, Interkoneksi Sistem Photovoltaic dengan Grid", Bandung: Program studi teknik elektro ITB, 2008.

[3] S. Nema, R. K. Nema, and G. Agnihotri, "Matlab Simulink Based Study of Photovoltaic Cells Modules Array and Their Experimental Verification," International Journal of Energy and Environment, 1 (3), 487-500, 2010.

[4] Tesio, U., Guelpa, E., Verda, V. 2020. Integration of thermochemical energy storage in concentrated solar power. Part 1: Energy and economic analysis/optimization. Energy Conversion and Management: X. 6. 100039.

[5] Kaveh M, Karami H, Jahanbakhshi A. Investigation of mass transfer, thermodynamics, and greenhouse gases properties in pennyroyal drying. J Food Process Eng 2020;43(8). https://doi.org/10.1111/jfpe.v43.810.1111/jfpe.13446.

[6] Popovici CG, Hudis¸teanu SV, Mateescu TD, Chereches¸ N-C. Efficiency improvement of photovoltaic panels by using air cooled heat sinks. Energy Procedia 2016;85: 425–32.

[7] Alghool DM, Elmekkawy TY, Haouari M, Elomri A. Optimization of design and operation of solar assisted district cooling systems. Energy Conversion and Management: X 2020;6:100028.

[8] Mata-Torres C, Palenzuela P, Alarc´on-Padilla DC, Zurita A, Cardemil JM, Escobar RA. Multi-objective optimization of a Concentrating Solar Power+ Photovoltaic+ Multi-Effect Distillation plant: Understanding the impact of the solar irradiation and the plant location. Energy Convers Manage 2021;X:100088.

[9] Emam M, Ookawara S, Ahmed M. Performance study and analysis of an inclined concentrated photovoltaicphase change material system. Sol Energy 2017;150: 229–45.

[10] Cioccolanti L, Tascioni R, Pirro M, Arteconi A. Development of a hardware-in-the-loop simulator for small-scale concentrated solar combined heat and power system. Energy Conversion and Management: X 2020;8:100056.

[11] Dos Santos SAA, Torres JPN, Fernandes CA, Lameirinhas RAM. The impact of aging of solar cells on the performance of photovoltaic panels. Energy Conversion and Management: X 2021;10:100082.

[12] R. Sangdot and H. Patel, "A Review on Photovoltaic Panel Cooling Using Heat Pipe," International Journal of Scientific Development and Research, vol. 1, pp.573-576, 2016.

[13] A. Rafi, and M. Rif'an, Perancangan Sistem Penjejak Matahari Berbasis Mikrocontroller dan Sensor Cahaya, Skripsi, 2007.

[14] P. Rudito., Pengaturan PWM (Pulse Width Modulation) dengan PLC, Universitas Brawijaya, 2012.

[15] B. Abdellahi., Performance Optimization of the PV Pumping System, Abdelmalek Essaadi University, Marocco, 2018.

[16] T. S. Haruno, Pompa dan Kompresor, Jakarta: Pradnya Paramita, 2000.

[17] L. Plegari and R. Rizzo, Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking, Renewable Power, 2010.

[18] Nadimuthu, L.P.R., Victor, K., Performance Analysis and Optimization of Solar-Powered E-Rickshaw For Environmental Sustainability In Rural Transportation, Environmental Science and Pollution Research, 28 (2021), pp. 34278-34289. https://doi.org/10.1007/s11356-021-12894-x

[19] Selvaraj, D.A., Victor, K., Design and Performance of Solar PV Integrated Domestic Vapor Absorption Refrigeration System, International Journal of Photoenergy, 2021 (2021), pp. 6655113. https://doi.org/10.1155/2021/6655113

[20] Chopade, S., et al., Bench Marking of Grid Tied Solar Roof Top Photovoltaic System: A Case Comparison, International Journal of Engineering & Technology; Vol 7, No 2.33 (2018): Special Issue 33, (2018), https://doi.org/10.14419/ijet.v7i2.33.14832

[21] Lalith, Pankaj Raj.G.N., et al., Hybrid Photovoltaic-Thermal Systems: Innovative CHP approach, Proceedings, Proceedings of the 4th International Conference on Electrical Energy Systems, ICEES 2018, 2018, pp. 726-730. https://doi.org/10.1109/ICEES.2018.8442352

[22] Lalith Pankaj Raj Nadimuthu, G.N., et al., Fast Thermal Degradation of Biomass Using Scrapped Solar Cell With Special Focus On Photovoltaic (PV) Waste Disposal, in: Waste Valorisation and Recycling, Springer Singapore, 2019, pp. 349-361. https://doi.org/10.1007/978-981-13-2784-1_33

[23] Lalith Pankaj Raj, N., Kirubakaran, V., Energy Efficiency Enhancement and Climate Change Mitigations Of SMEs Through Grid Interactive Solar Photovoltaic System, International Journal of Photoenergy, (2021). https://doi.org/10.1155/2021/6651717

[24] Ram kumar, R., et al., Performance analysis of Solar water heater by using TiO2 nanofluids, Materials Today Proceedings, 21 (2020), 1, pp. 817-819. https://doi.org/10.1016/j.matpr.2019.07.251

[25] Threlkeld JL. Thermal environmental engineering. Prentice-Hall; 1962 [Chapter 6]

[26] He J, Tritt T M. Advances in thermoelectric materials research: Looking back and moving forward. Science, 2017, 357(6358): eaak9997

[27] Chowdhury I, Prasher R, Lofgreen K, Chrysler G, Narasimhan S, Mahajan R, Koester D, Alley R, Venkatasubramanian R. On-chip cooling by superlattice-based thin-film thermoelectrics. Nature Nanotechnology, 2009, 4(4): 235–238

[28] Zhao D, Tan G. A review of thermoelectric cooling: Materials, modeling and applications. Applied Thermal Engineering, 2014, 66 (1–2): 15–24

[29] Kim S J, Lee H E, Choi H, Kim Y, We J H, Shin J S, Lee K J, Cho B J. High-performance flexible thermoelectric power generator using laser multiscanning lift-off process. ACS Nano, 2016, 10(12): 10851–10857

[30] M.S. Dresselhaus et al, New directions for low-dimensional thermoelectric materials, Advanced Materials, Vol. 19, 1043-1053, 2007

[31] Alghoul, M. A., Shahahmadi, S. A., Yeganeh, B., Asim, N., Elbreki, A. M., Sopian, K., et al. (2018). A review of thermoelectric power generation systems: roles of existing test rigs/ prototypes and their associated cooling units on output performance. Energy Conversion and Management, 174, 138–156.

[32] Mizusaki, Junichiro, et al. "Electronic Conductivity, Seebeck Coefficient, and Defect Structure of La1ǦxSrxFeO3 (x= 0. l, 0.25)." Journal of the American Ceramic Society 66.4 (1983): 247-252

[33] Pérez–Aparicio, J. L., Palma, R., & Taylor, R. L. (2012). Finite element analysis and material sensitivity of Peltier thermoelectric cells coolers. International Journal of Heat and Mass Transfer, 55(4), 1363-1374.

[34] T. M. Tritt and M. A. Subramanian, "Thermoelectric materials, phenomena and applications: a bird's eye view," J. Mat. Sci., vol.31, pp. 188–98, 2006. https://doi.org/10.1557/mrs2006.44.

[35] H. Sofrata, "Heat rejection alternatives for thermoelectric refrigerators,"J. Energy Convt. Manage., vol. 37, pp. 269–80, 1996.

[36] S. Godfrey, "An introduction to thermoelectric coolers," Articles,Coolers, Design, TECs, Test & Meas., available at: https://www.electronics-cooling.com/1996/09/an introduction-tothermoelectric-coolers/ (accessed 15 July 2020).

[37] X. F. Zheng, C. X. Liu, Y. Y. Yan, and Q. Wang, "A review of thermoelectric research – recent developments and potentials for sustainable and renewable energy applications," J. Renew. Sust. Energy Rev., vol. 32, pp. 486–503, 2013. https://doi.org/10.1016/j.rser.2013.12.053.

[38] A. C. Sulaiman, N. A. Mohd Anin, M. H. Basha, M. S. Abdul Majid, N. F. Mohd Nasir, and Z. Zaman, "Cooling performance of thermoelectric cooling (TEC) and applications: a review," in MATEC Web of Conferences, vol. 22, 03021, 2018, https://doi.org/10.1051/matecconf/201822503021.

[39] Hamid, M., et al., A Review on Thermoelectric Renewable Energy : Principle Parameters That Affect Their Performance, Renewable and Sustainable Energy Reviews, 30 (2014), pp. 337-355. https://doi.org/10.1016/j.rser.2013.10.027

[40] Toberer, E.S., et al., Advances in Thermal Conductivity, Annual Review of Materials Research, 42 (2012), 1, pp. 179-209. https://doi.org/10.1146/annurev-matsci-070511-155040

[41] Nakamura, Y., Nanostructure Design for Drastic Reduction of Thermal Conductivity While Preserving High Electrical Conductivity, Science and Technology of Advanced Materials, 19 (2018), 1, pp. 31-43. https://doi.org/10.1080/14686996.2017.1413918

[42] Damodara Das, V., Gopal Ganesan, P., Thickness and Temperature Effects on Thermoelectric Power And Electrical Resistivity Of (Bi0.25Sb0.75)2Te3thin Films, Materials Chemistry and Physics, 57 (1998), 1, pp. 57-66

[43] G. Fraisse, M. Lazard, C. Goupil, J.Y. Serrat, Study of a thermoelement's behavior through a modeling based on electrical analogy, International Journal of Heat and Mass Transfer, 53 (2010) 3503-3512

[44] Jing-Hui Meng, Xiao-Dong Wang, Xin-Xin Zhang, Transient modeling and dynamic characteristics of thermoelectric cooler, Applied Energy, 108 (2013) 340-348

[45] Reiyu Chein, Guanming Huang, Thermoelectric cooler application in electronic cooling, Applied Thermal Engineering, 24 (2004) 2207-2217

[46] Yuanyuan Zhou, Jianlin Yu, Design optimization of thermoelectric cooling systems for applications in electronic devices, International Journal of Refrigeration, 35 (2012) 1139-1144

[47] Chin-Hsiang Cheng, Shu-Yu Huang, Tsung-Chieh Cheng, A three-dimensional theoretical model for predicting transient thermal behavior of thermoelectric coolers, International Journal of Heat and Mass Transfer, 53 (2010) 2001-2011

[48] Reiyu Chein, Guanming Huang, Thermoelectric cooler application in electronic cooling, Applied Thermal Engineering, 24 (2004) 2207-2217

[49] Reiyu Chein, Yehong Chen, Performance of thermoelectric cooler integrated with microchannel heat sinks, International Journal of Refrigeration, 28 (2005) 828-839

[50] Performance analysis of thermoelectric pellets with non-constant cross section, 7th European Workshop on Thermoelectrics, Pamplona, Spain, 2002

[51] HoSung Lee, Thermal design: heat sinks, thermoelectrics, heat pipes, compact heat exchangers, and solar cells. Published by John Wiley & Sons, Inc, USA, 2010

[52] Yi-Hsiang Cheng, Wei-Keng Lin, Geometric optimization of thermoelectric coolers in a confined volume using genetic algorithms, Applied Thermal Engineering, 25 (2005) 2983-2997

[53] A. Chakraborty et al., Thermodynamic modeling of a solid state thermoelectric cooling device: Temperature-entropy analysis, International Journal of Heat and Mass Transfer, 49 (2006) 3547-3554

[54] H.Y. Zhang, A general approach in evaluating and optimizing thermoelectric coolers, International Journal of Refrigeration, 33(2010) 1187-1196

[55] Hosung Lee, Optimal design of thermoelectric devices with dimensional analysis, Applied Energy, 106 (2013) 79-88

[56] Luciana W. da Silva, Massoud Kaviany, Micro-thermoelectric cooler: interfacial effects on thermal and electrical transport, International Journal of Heat and Mass Transfer, 47 (2004) 2417-2435

[57] D. Astrain, J.G. Vian, M. Dominguez, Increase of COP in the thermoelectric refrigeration by the optimization of heat dissipation, Applied Thermal Engineering, 23 (2003) 2183-2200

[58] Nandy Putra et al., The characterization of a cascade thermoelectric cooler in a cryosurgery device, Cryogenics, 50 (2010) 759-764

[59] K. Mansour, Y. Qiu, C.J. Hill, A. Soibel, R.Q. Yang, Mid-infrared interband cascade lasers at thermoelectric cooler temperatures, Electronics Letters, Volume 42, Issue 18, 31 August 2006, p. 1034 – 1036

[60] W.G.J.H.M. van Sark, Feasibility of photovoltaic – thermoelectric hybrid modules, Applied Energy, 88 (2011) 2785-2790