Indonesian Journal of Electrical Engineering and Computer Science
Vol. 29, No. 3, March 2023, pp. 1374~1381
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v29.i3.pp1374-1381

Experimental investigation of hybrid thermoelectric evaporative air-cooling system for crickets rearing process

Peeradapath Parametpisit[1], Piyapat Panmuang[2], Amornthep Sonsilphong[3], Chaiyong Soemphol[1]
[1]Research Unit for Computational Electromagnetics and Optical Systems (CEMOS), Department of Electrical Engineering, Faculty of Engineering, Mahasarakham University, Kantarawichai, Thailand
[2]Faculty of Technical Educationg, Rajamangala University of Technology Isan Khonkaen Campus, Khonkaen, Thailand
[3]Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khonkaen Campus, Khonkaen, Thailand

Article Info

Article history:

Received Sep 25, 2022
Revised Oct 27, 2022
Accepted Oct 29, 2022

Keywords:

Cricket farming
Evaporative air-cooling
Peltier effect
Temperature control
Thermoelectric cooler

ABSTRACT

Due to the effects of the change in temperature that have resulted in dramatic changes in the livelihoods of crickets. Hence, the implementation of cooling technologies is an important factor for alleviating these negative consequences. This research presents the experimentally investigate the feasibility of employing a thermoelectric cooler in combination with an evaporative air-cooling system for two-spotted cricket (gryllus bimaculatus) rearing process. The proposed cooling system has been installed to reduce the temperature that appropriate for the cricket rearing. The experimental results show that the product air temperature of cricket rearing pens with thermoelectric evaporative air-cooling system decreases form ambient air. The average temperature of the cricket rearing pens with thermoelectric evaporative air-cooling system is 29.66 °C, with the highest temperature at 31.40 °C. While the average temperature of the cricket rearing pens without thermoelectric evaporative air-cooling system is 33.75 °C, with the highest temperature at 37.10 °C. Furthermore, this research also shows that this proposed system can improve cricket survival rate. The crickets that reared in the prototype system have a survival rate of 88.5%, while survival rate of crickets in an uncontrolled pen is 67.2%. This paper provides a potential of applying thermoelectric evaporative air-cooling for cricket farming.

Corresponding Author:

Chaiyong Soemphol
Research Unit for Computational Electromagnetics and Optical Systems (CEMOS)
Department of Electrical Engineering, Faculty of Engineering, Mahasarakham University
Kantarawichai, Maha Sarakham, 44150, Thailand
Email: chaiyong.s@msu.ac.th

1. INTRODUCTION

According to the report, the world's population is expected to increase to 8.5 billion in 2030, 9.7 billion in 2050 and 10.4 billion in 2100, respectively [1]. It is a causing concern about insufficient food in the future thus there is an urgent need for alternative nutrient sources and edible insects are promising and potential choice [2]. Cricket is one of most important choice that has been suggested as an excellent food source, resolving the scarcity of food in the future [3]. It has been postulated that crickets generally contain high-quality nutrients, which are easily digestible and more bio-available than those available from plant and animal food sources [4], [5]. In addition, it has been reported that cricket production requires a small area and crickets can be reared at high density so the production may be cost and area-effective compared with production of other animals [6]. Thus, cricket farming as an alternative to produce food and feed is an interesting topic in the current context of around the world.

Nowadays, there is also growing interest to do cricket farming in Thailand. It is estimated that there are over 22,000 cricket farms scattered thought Thailand, especially in the north-eastern of Thailand [7]. Most of the farmers in Thailand preferred to breed house crickets (Acheta domesticus) and two-spotted crickets (Gryllus bimaculatus) [8]. However, the effects of global warming have resulted in dramatic changes in the livelihoods of cricket farmers not only in Thailand, but all over the world. Temperature has been shown to have an important effect on crickets' survival and their metabolism. It has been reported that small changes in temperature have large effects on reproduction, whereas large changes in moisture have very small effects on reproduction [9]. The optimal survival rate of crickets is maintained when the temperature is between 28-32 °C [10]. Too low temperature the crickets will grow slowly. On the other hand, too high temperature will result in a lower survival rate, and individuals raised at the higher temperature reached the final mount faster but it has a reduced lifespan than individuals reared at the lower temperature [11], [12]. This problem has had a profound impact on the Thailand cricket farming sector. Especially when the summer temperature rises, it will find high death rates among the crickets. Moreover, heat generation inside the cricket pens is an important issue, because it may be the cause of the disease and many deaths of crickets.

Evaporative air-cooling system is one of a simply available method to reduce the ambient temperature. The evaporative air-cooling systems has several advantages such as: lowering the outside temperature, energy savings, low-cost installation and maintenance, environmentally friendly and elimination of the greenhouse effect and static electricity in the environment. It is very useful for small air-cooling system. This method is appropriate for cooling the indoor air with small area such as mobile homes, single family housing and industrial warehouse [13]. It has been found that evaporative air-cooling system can be applied in agriculture. It is especially used for reducing the temperature in greenhouses for growing plants and raising pigs or chickens [14]. It can archieve numerous advantages for farms, it not only saves energy, but also guarantees the plants or animals well being [15]. It can reduce animal stress, make the animal grow faster, weight gain, less sickness, decreased feeding time as well as can increase the density of animals in the house. However, the performance of this system still needs to be developed to allow for a wider range of applications.

A thermoelectric (TE) device is a device that converts heat energy into electrical energy or, on the other hand, a thermoelectric can also convert from electrical energy to heat energy. Currently, thermoelectric has been increasingly applied to various cooling equipments. Thermoelectric coolers (TECs) are commonly used in a small-size refrigeration system or in portable cooler box for cold storage as well as a water cooling system [16], [17]. This devive offer many advantages such as small in size, portable, noiseless, environmentally friendly and economical compared to conventional cooling systems. They have been utilized in various applications for example air-conditioning [18], [19], electronic device cooling [20], batteries cooling [21]-[23] and medical science [24]-[26]. Moreover, it has been reported that the thermoelectric cooling system can be used to improve the cooling performance of an evaporative air-cooling systems [13], [27], [28].

In this work, we present experimentally investigate the feasibility of to reduce the temperature in crickets pens by employing a thermoelectric cooler in combination with an evaporative air cooling system for cricket farming. Following sections will explain the design of thermoelectric evaporative air-cooling system. The temperature in cricket pens with and without this proposed system are presented in the results. Moreover, the survival rate of two-spotted crickets has also been reported in section 4. Such results demonstrate the practicability of proposed thermoelectric evaporative air-cooling system for the crickets rearing process.

2. RESEARCH METHOD

Crickets are cold blooded nocturnal insects of the order Orthoptera. There are many different species of cricket, however each species has the same three key life cycle stages; egg, nymph, and adult as demonstrated in Figure 1. It has been reported that house cricket (Acheta domesticus) and two-spotted cricket (Gryllus bimaculatus) are most common cricket species farmed in Thailand. The length of the production cycle depends on the species of cricket, temperature and the purpose of raising it. In current cricket farming systems for food, the production cycle from hatching to harvest is 35 and 55 days for two-spotted crickets and house cricket, respectively [5]. Generally, crickets can be reared in various housing structures. However, the most key elements can be externally controlled given that the location chosen to setup a farm should be free from flooding, able to be shaded and not exposed to direct sun light. The water used to feed must be clean and free from contamination. The most important and least controllable factor is the climate's temperature and it has been found that most of crickets thrive when the temperature is between 28-32 °C. In this research, the TE evaporative air-cooling system is proposed to use for controlling the temperature in cricket rearing pens. The temperature in cricket rearing pens will be controlled within the appropriate range for crickets to grow. Two-spotted crickets (Gryllus bimaculatus) are selected to be reared in cricket pens with proposed system. The farming conditions will be simulated to be the same as the real culture as in all agricultural ventures including that of traditional Thai cricket farming. This prototype system consists of three main subsystems; first, the evaporative air-cooling system, second, thermoelectric cooler system and the last system is two cricket pens.

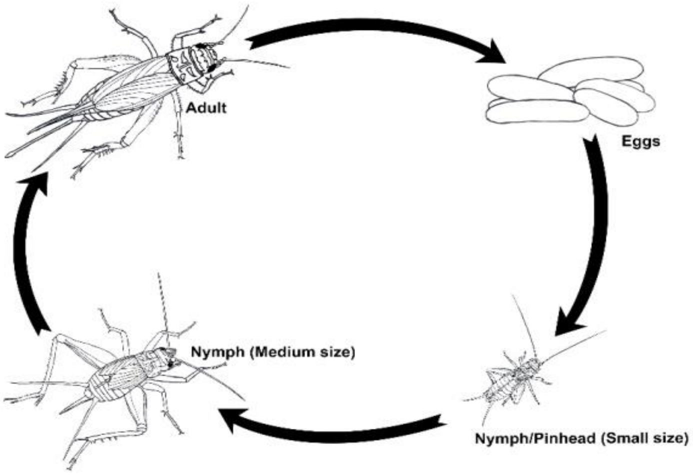
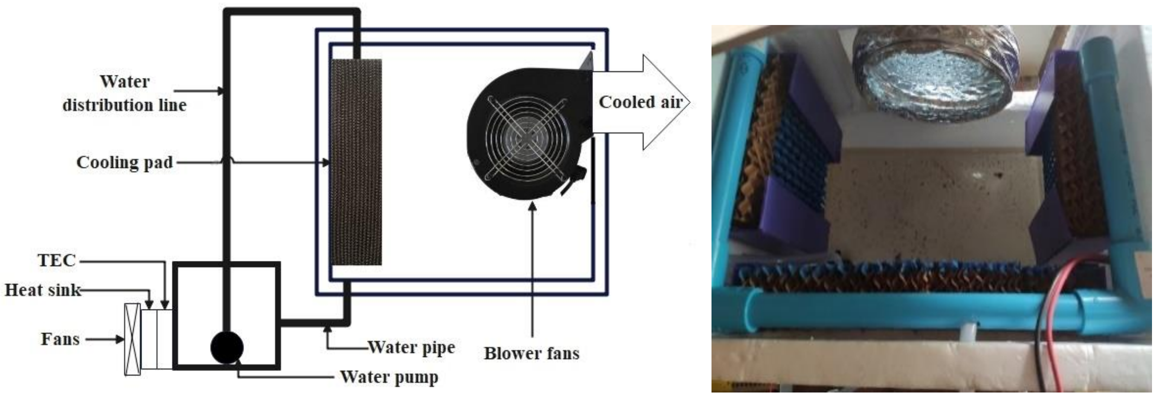


Figure 1. Life cyecle of crickets

The proposed thermoelectric evaporative air-cooling system for crickets rearing is presented in Figure 2. The evaporative air-cooling system consists of a cooling chamber, cooling pad and blower fan as demonstrated in Figure 2(a). The cooling is as cold insulated that made of foam box with 2 cm of thickness as shown in Figure 2(b). Cooling pads are installed on three sides of the box. There is a water pipes above of cooling pad that used to transport cold water generated by the thermoelectric cooling system. The cooling process of this system is based on an adiabatic saturation process. The air (inlet) with a controlled temperature is sucked into the cooling pad and water is sprayed on top of the cooling pad. Water passes to the whole area of the cooling pad. After air passes the cooling pad (evaporative cooling system), the air temperature decreases.



(a) (b)

Figure 2. The proposed thermoelectric evaporative air-cooling system (a) diagram of a combined thermoelectric evaporative air cooler and (b) fabricated evaporative air cooler

For the second part, the thermoelectric cooling system is used to generate a cooled water that feed to an evaporative air-cooling system. The thermoelectric cooling system is based on the Peltier effect. This system is made of thermoelectric modules, fin heat exchangers and fan. The thermoelectric modules have two sides, and when a direct current (DC) electric current flows through the device, this makes one plate cold and the other hot. In this work, thermoelectric cooler module TEC1-12715 is used and its specification is shown in Table 1. The cold side of thermoelectric is attached with one of the aluminium container walls and the hot side is attached with aluminum heat sink and fan, respectively. Heat sink and fan are used to accelerate heat transfer at the hot side and silicon glue is used to connect between them.

Table 1. Thermoelectric cooler TEC1-12715 specifications

Parameters	Value
Type of module	Peltier
Max. operating voltage	15.4 V
Max. operating current	15 A
Max. Cooling Power	136 W
Max. Operating Tem.	90 °C
Tem. Difference Max	70 °C
Resistance	750 mΩ
Body dimensions	50×50×3.8 mm

A completed prototype of thermoelectric evaporative air-cooling for cricket farming is demonstrated in Figure 3. Gypsum board is used to make rearing pens and the egg pan are arranged to absorb moisture in the rearing pens. To isolate the crickets in a safe and secure environment that will optimize growth, a net is placed over the rearing pens. The principal operation of the proposed prototype is the conversion of sensible heat of the hot air to the latent heat of water vaporization by inducing the air in direct contact with the water circulated from the aluminum container through the cooling pad by using a water pump, which results in a decrease in air temperature. The purpose of a thermoelectric cooling installation is to remove the perceived heat from the water in the container to further improve its air-cooling capacity. The cooling air which occurs from this system will be sent into the rearing pens by an internal blower fan.

Furthermore, node MCU ESP8266 is used as a microcontroller unit to control and monitor the operation of this system. A basic digital temperature and humidity DHT11 sensor is used to mearsure the temperature in crickets rearing pens. The temperature is controled between 28-32 °C, if the temperature is below 28 °C, the thermostat will automatically cut off. On the other hand, if the temperature is higher than 32 °C, it will start up automatically by the interaction between temperature control unit and relay. Note that, in this work relative humidity is not regulated.

Figure 3. A completed prototype of thermoelectric evaporative air-cooling for cricket farming

3. EXPERIMENTAL SETUP

The experiments were carried out in order to evaluate the air-cooling performance of the prototype system and survival rate of crickets. A comparative experiment was conducted between the cricket pen with and without thermoelectric evaporative air-cooling system. As we know that house crickets have three stages in their life cycle: egg, nymph, and adult. In this work, after the cricket eggs will be being for the hatch, the nymph will begin to nursery period of 14 days. After that, the 14 days old of 800 field crickets (Gryllus bimaculatus) were selected to rear in experiment. These crickets' sample were divided into two equal sub-groups; the first group comprising of 400 crickets are raised a in a prototype of TE evaporative air-cooling system and the second group comprising of the remaining 400 crickets were raised without the proposed system as shown in Figure 4. The crickets of both groups will be reared for 15 days period. The rearing conditions such as food and water to feed for cricket of both groups are the same. The daily temperature and survival rate will be recorded.

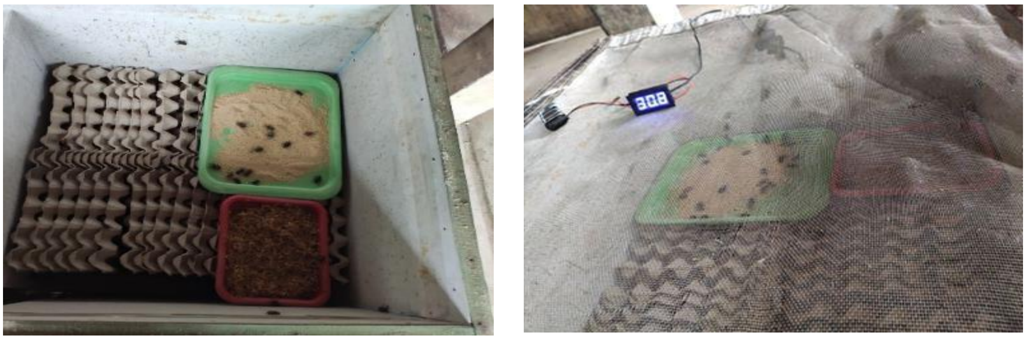


Figure 4. The crickets in the this experimental rearing pens

4. RESULTS AND DISCUSSION

4.1. Daily temperature of crickets rearing pens

The comparison between temperature of two pens over a 15-day period has been shown in Table 2 and Figure 5. It has been found that the average temperature of the cricket rearing pens with TE evaporative air-cooling system is 29.66 °C, with the highest temperature at 31.4 °C. While cricket rearing pens without TE evaporative air-cooling system had an average temperature of 33.75 °C, with the highest temperature at 37.1 °C. The TE evaporative air-cooling system work effectively even ambient air temperature inside the cricket pens reaches 35-40 °C, which is inappropriate for the cricket rearing. The proposed system can reduce the higher ambient air temperature in the cricket rearing pens to the appropriate temperature for cricket rearing within temperature range of 28-32 °C.

Table 2. Maximum temperature in crickets rearing pens

Day	Pens with TE evaporative air-cooling system	Pens without TE evaporative air-cooling system	Different temperature
1	28.2	31.8	3.6
2	28.1	30.2	2.1
3	29.4	33.5	4.1
4	31.4	37.1	5.7
5	28.1	30.8	2.7
6	30.6	35.2	4.6
7	31.7	37.1	5.4
8	30.9	35.6	4.7
9	30.7	35.8	5.1
10	29.1	32.7	3.6
11	30.3	35.1	4.8
12	30.9	35.6	4.7
13	30.7	35.6	4.9
14	30.3	35.1	4.8
15	28.5	29.1	0.6
Ave	29.66	33.75	4.09

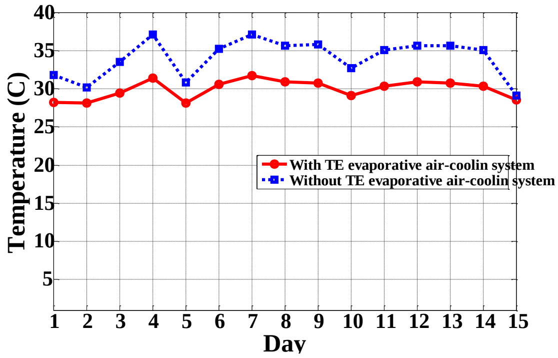


Figure 5. Temperature comparison between the two crickets rearing pens over a 15-day period

4.2. Survival rate of crickets

Generally, dead crickets can be sources of disease, so each day all dead crickets observed in the pens should be quickly removed. In this work, the dead crickets are eliminated and the daily recorded of number of dead crickets is demonstrated in Table 3. Based on the results in Table 3, it is found that crickets reared in the pens with TE evaporative air-cooling system have lower daily dead rates than crickets reared in non-temperature-controlled pens. Total number of dead crickets are 46 crickets and 131 crickets for pens with and without TE evaporative air-cooling system, respectively.

Moreover, Table 4. presents the survival rate of crickets of both pens. The number of survival crickets are 354 and 269 for cricket in the pens with TE evaporative air-cooling system and without TE evaporative air-cooling system, respectively. The survival rate of crickets in pens with TE evaporative air-cooling system is 88.50%, while another pens has a survival rate of 67.25%. From the results, it has been shown that the temperature-controlled pens have a higher occupancy rate than non-temperature-controlled pens at 21.25%. The Survival rates depend on the suitability of the temperature used to feed.

Table 3. Number of daed crickets

Day	Dead crickets reared in pens with TE evaporative air-cooling system	Dead crickets reared in pens without TE evaporative air-cooling system
1	5	10
2	3	9
3	4	11
4	2	15
5	4	8
6	1	6
7	6	10
8	3	8
9	3	8
10	4	6
11	2	7
12	3	9
13	1	10
14	3	8
15	2	6
Total	46	131

Table 4. Crickets' survival rate

	crickets raised in pens with TE evaporative air-cooling system	crickets raised in pens without TE evaporative air-cooling system	Different between two rearing pens
Number of survive crickets	354	269	85
Survival rate	88.50%	67.25%	21.25%

5. CONCLUSION

The TE evaporative cooling air-system for cricket farming has been fabricated and tested in this work. The experimental results show that the proposed system can reduce the higher ambient air temperature in the cricket rearing pens to be appropriate temperature for cricket rearing. The average temperature of the cricket rearing pens with TE evaporative air-cooling system is 29.66 °C, with the highest temperature at 31.4 °C. While cricket rearing pens without TE evaporative air-cooling system had an average temperature of 33.75 °C, with the highest temperature at 37.1 °C. The average reduced temperature of the cricket rearing pens with TE evaporative air-cooling system is 4.09 °C, when compared to ambient temperature in the pens without this system. In addition, from the ability of the propsed system to be able to control the temperature suitable for crickets rearing, it also can improve the survival rate of crickets. The survival rate of crickets reared in the proposed system is increased by up to 21.25%. Thus, from the results it can be concluded that this proposed TE evaporative air-cooling system is one of the alternatives that can be used to control the temperature that appropriate for the cricket rearing process.

ACKNOWLEDGEMENTS

We would like to thank Faculty of Engineering, Mahasarakham University, Thailand for the financial supported.

REFERENCES

[1] United Nations Department of Economic and Social Affairs, Population Division, "World population prospects 2022: summary of results," *UN DESA/POP/2022/TR/NO. 3*, New York, 2022.

[2] R. O. Araque and E. E. Montenegro, "Edible insects: A food alternative for the sustainable development of the planet," *Int. J. of Gast. and Food Sci.*, vol. 23, 100304, Apr. 2021, doi: 10.1016/j.ijgfs.2021.100304.

[3] K. W. Lange and Y. Nakamura, "Edible insects as future food: chances and challenges," *J. of Future Foods*, vol. 1, no.1, pp. 38-46, Sep. 2021, doi: 10.1016/j.jfutfo.2021.10.001.

[4] D. K. Murugu, *et al.*, "From farm to fork: crickets as alternative source of protein, minerals, and vitamins," *Front Nutr*., vol. 8:704002, 2021, doi: 10.3389/fnut.2021.704002.

[5] A. Baiano, "Cricket farming edible insects: An overview on nutritional characteristics, safety, farming, production technologies, regulatory framework, and socio-economic and ethical implications," *Trends in Food Sci. & Tech.*, pp. 35-50, 2020, doi: 10.1016/j.tifs.2020.03.040.

[6] P. Miech, J. E. Lindberg, Å. Berggren, T. Chhay, B. Khieu, and A. Jansson, "Growth and survival of reared cambodian field crickets (Teleogryllus testaceus) fed weeds and agricultural and food industry by-products," *J. of Ins. as Food and Feed*, vol. 2, no. 4, pp. 285-292, Sep. 2016, doi: 10.3920/JIFF2016.0028.

[7] A. Halloran, Y. Hanboonsong, N. Roos, and S. Bruun, "Life cycle assessment of cricket farming in north-eastern Thailand," *J. of Clea. Prod*., vol. 156, pp. 83-94, July 2017, doi: 10.1016/j.jclepro.2017.04.017.

[8] P. Chumpasuk and Y. Sriwaranun, "Production and marketing management of cricket farm in KhonKaen, Kalasin and Maha Sarakham provinces," *Khon Kaen Agr. J.* vol. 42, no. 4, pp. 547-554, 2014.

[9] R. Singh, P. Prathibha, and M. Jain, " Effect of temperature on life-history traits and mating calls of a field cricket," *J. of Ther. Bio.*, vol. 93, pp. 102740, Oct. 2020, doi: 10.1016/j.jtherbio.2020.102740.

[10] A. Hanboonsong and P. Durst, "Guidance on sustainable cricket farming – A practical manual," Bangkok, FAO, 2020.

[11] D. T. Booth and K. Kiddell, "Temperature and the energetics of development in the house cricket (Acheta domesticus)," *J. Ins. Phys.*, vol. 53, no. 9, pp. 950-953, Sep. 2007, doi: 10.1016/j.jinsphys.2007.03.009.

[12] R. B. Srygley, "Effects of temperature and moisture on Mormon cricket reproduction with implications for responses to climate change," *J. Ins. Phys*., vol. 65, pp. 57-62, June 2014, doi: 10.1016/j.jinsphys.2014.05.005.

[13] S. Jiajitsawat, "A portable hybrid thermoelectric-direct evaporative air cooling system," *N. U. J. : Sci. and Tech. (NUJST)*, vol. 20, no. 1, pp. 1-8, July 2012.

[14] S. K. A. Khalid, N. S. C. Dan, N. A. Samsudin, M. S. Aripin, and N. A. A. Nordin, "Autonomous coop cooling system using renewable energy and water recycling," *Indonesian J. of Elec. Eng. and Com. Sci.*, vol. 13, no. 3, pp. 1303-1310, Mar. 2019, doi: 10.11591/ijeecs.v13.i3.pp1303-1310.

[15] D. Godyń, P. Herbut, S. Angrecka, and F. M. Corrêa Vieira, "Use of different cooling methods in pig facilities to alleviate the effects of heat stress—A review," *Animals*, vol. 10, no. 9, p. 1459, Aug. 2020, doi: 10.3390/ani10091459.

[16] M. P. Jagadeesh, S. Harish, M. K. N. Pravin, M. Prakash, and P. Sathiyaraj, "Water cooling system by using Peltier;" *Int. J. of Eng. Sci. and Com.*, vol. 12, no. 6, pp. 29594- 29599, June 2022.

[17] A. Al- Rubaye, K. Al-Farhany, and K. Al-Chlaihawi, "Performance of a portable thermoelectric water cooling system," *Int. J. of Mec. Eng. and Tec.*, vol. 9, no. 8, pp. 277-285, Aug. 2018.

[18] A. F. Moazzez, G. Najafi, B. Ghobadian, and S. S. Hoseini, "Numerical simulation and experimental investigation of air cooling system using thermoelectric cooling system," *J. Therm. Anal. Calorim.*, vol. 139, pp. 2553–2563, 2020, doi: 10.1007/s10973-019-08899-x.

[19] X. Ma, H. Zhao, X. Zhao, G. Li, and S. Shittu, "Building integrated thermoelectric air conditioners—A potentially fully environmentally friendly solution in building services," *Future Cities and Envi.*, vol. 5, no. 1, p. 12, Nov. 2019, doi: 10.5334/fce.76.

[20] M. Zebarjadi, "Electronic cooling using thermoelectric devices," *Appl. Phys. Lett.*, vol. 106, p. 203506, May 2015, doi: 10.1063/1.4921457.

[21] Y. Lyu, A. R. M. Siddique, S. A. Gadsden, and S. Mahmud, "Experimental investigation of thermoelectric cooling for a new battery pack design in a copper holder," *Res. in Eng.*, vol. 10, pp. 100214, June 2021, doi: 10.1016/j.rineng.2021.100214.

[22] L. Spitthoff1, A. F. Gunnarshaug, D. Bedeaux, O. Burheim, and S. Kjelstrup, "Peltier effects in lithium-ion battery modeling," *J. Chem. Phys.*, vol. 154, p. 114705, Mar. 2021, doi: 10.1063/5.0038168.

[23] P. Suksusron, S. Wiriyasart, and P. Naphon, "Electrical vehicle battery cooling by thermoelectric cooling module", *SWU. Eng. J*, vol. 16, no. 1, pp. 50–58, Mar. 2021.

[24] Z. Slanina, M. Uhlik, and V. Sladecek, "Cooling device with peltier element for medical applications," *IFAC-PapersOnLine*, vol. 51, no. 6, p. 54-59, 2018, doi: 10.1016/j.ifacol.2018.07.129.

[25] L. Anatychuk, L. Vikhor, M. Kotsur, R. Kobylianskyi, and T. Kadeniuk, "Optimal control of time dependence of temperature in thermoelectric devices for medical purposes," *Int. J. of Thermo.*, vol. 39, p. 108, Aug. 2018, doi: 10.1007/s10765-018-2430-z.

[26] S. H. Zaferani, M. W. Sams, R. Ghomashchi, Z. G. Chen, "Thermoelectric coolers as thermal management systems for medical applications: Design, optimization, and advancement," *Nano Energy*, vol. 90, p. 106572, Dec. 2021, doi: j.nanoen.2021.106572.

[27] Y. Zhou, T. Zhang, F. Wang, and Y. Yu, "Performance analysis of a novel thermoelectric assisted indirect evaporative cooling system," *Energy*, vol. 162, pp. 299-308, Nov. 2018, doi: j.energy.2018.08.013.

[28] Y. Zhou, T. Zhang, F. Wang, and Y. Yu, "Numerical study and optimization of a combined thermoelectric assisted indirect evaporative cooling system," *J. of Ther. Sci.*, vol. 29, pp. 1345–1354, Oct. 2020, doi: 10.1007/s11630-020-1362-7.

BIOGRAPHIES OF AUTHORS

Peeradapath Parametpisit was born in Maha Sarakham Province, Thailand. She received her Bachelor's Degree in Engineering (Electrical Engineering) from Mahasarakham University in 2021. Ms. Peeradapath have been spending years as an Electrical Engineer experience in farm sector of Thailand. Her research interests include System development, material development of renewable energy, solar systems and cyber physical system. She can be contacted at email: prdp.tunya@gmail.com.

Piyapat Panmuang was born in Khonkaen province Thailand. He received his bachelor degree in Electrical Engineering from Khon Kaen University, Thailand and his master degree and Ph.D. in Electrical and Computer Engineering from Mahasarakham University, Thailand. He is currently a lecturer at the Faculty of Industrial Education, Rajamangala University of Technology Isan Khonkaen Campus, Khonkaen, Thailand. His research interest includes thermoelectric, solar energy, renewable energy conversion, and power electronics. He can be contacted at email: piyapat.pa@rmuti.ac.th.

Amornthep Sonsilphong was born in Khonkaen province Thailand. He received his bachelor degree in Electrical Engineering with first-class honors from Khon Kaen University, Thailand in 2010. He also received his master degree and Ph.D. in Electrical Engineering from Khon Kaen University, Thailand. He is currently a lecturer at the Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khonkaen Campus, Khonkaen, Thailand. His research interest includes metamaterials, chirality, micro nano-fabrications and nanocircuits, automation control systems, 3D printing and design and biomedical Engineering. He can be contacted at email: a.sonsilphong@gmail.com.

Chaiyong Soemphol was born in Surin Province, Thailand. He received his B.Eng. in Electrical Engineering with second-class honors from Khon Kaen University, Thailand in 2011. He also received his Ph.D. in Electrical Engineering from Khon Kaen University, Thailand in 2017. Since 2018, he has been with the Department of Electrical Engineering, Faculty of Engineering, Mahasarakham University, Maha Sarakham, Thailand as a Lecturer. His research interests include compact microstrip devices, metamaterial applications for RF, microwave sensor, wireless power transfer systems, reneable energy and electromechanical energy conversion. He can be contacted at email: chaiyong.s@msu.ac.th.