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# The Effect of Nanofluid Usage on Electricity Consumption in Thermoelectric Refrigeration Application: An Experimental Study

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## ABSTRACT

This study investigates the effects of nanofluid use in thermoelectric refrigerators on electricity consumption. A water-cooled block was placed on the hot surface of the TEC, and a water-to-air heat exchanger was added to the refrigeration cycle in order to cool the coolant. By adding 1% by mass of three distinct nanoparticles to the fluid, the temperature differences of the cooled cabinet were tested at three distinct outdoor temperatures. In addition, to measure the cabinet's performance when loaded, 1 litre of water was left in the cabinet, and the tests were repeated. In the case where water without nanoparticle addition, which is the reference case, was used as the coolant, the measurement was made for 1 hour, and the final temperature of the cooled cabinet was determined. Then the times to obtain the same cooled cabinet temperature using various nanoparticles were observed. It has been observed that energy savings are achieved in all nanofluid use cases compared to the reference situation. It has been observed that the temperature of the cooled cabinet drops to the lower temperatures earlier in cases where nanofluid was used. For this reason, this study is essential in terms of the efficient use of energy resources.

# Termoelektrik Buzdolabı Uygulamalarında Nanoakışkan Kullanımının Elektrik Tüketimi Üzerindeki Etkisi: Deneysel Bir Çalışma

## ÖZ

Bu çalışmada, termoelektrik soğutucularda nanoakışkan kullanımının elektrik tüketimi üzerindeki etkileri araştırılmıştır. Bu amaçla tasarlanan sistemde TEC'in sıcak tarafına su soğutmalı blok yerleştirilmiş ve soğutucu akışkanın ısısını almak için sisteme sudan havaya ısı eşanjörü eklenmiştir. Akışkana kütlece %1 oranında üç farklı nanopartikül eklenerek soğutucu kabinin sıcaklık farkları üç farklı dış ortam sıcaklığında test edilmiştir. Ayrıca soğutucu kabinin dolu olması durumundaki performansını ölçmek için kabine 1 litre su bırakılmış ve testler tekrarlanmıştır. Soğutma sıvısı olarak referans durum olan nanopartikül ilavesiz su kullanılması durumunda 1 saat boyunca ölçüm yapılmış ve soğutucu kabinin son sıcaklığı belirlenmiştir. Daha sonra çeşitli nanopartiküller kullanılarak aynı soğutucu kabin sıcaklığının elde edildiği zamanlar gözlemlenmiştir. Yüksüz koşullarda aynı soğutma kabini sıcaklığına ulaşmak için tüketilen enerji miktarı karşılaştırıldığında, referans duruma göre en yüksek iyileştirme $Al_2O_3$-Su nanoakışkanı ile %57 olarak hesaplanmıştır. Yüklü koşullarda, 18 °C ortam sıcaklığında $Al_2O_3$-Su nanoakışkanı kullanıldığında enerji tüketiminde en yüksek iyileşme %50 olarak elde edilmiştir. Referans duruma göre tüm nanoakışkan kullanım durumlarında enerji tasarrufu sağlandığı gözlenmiştir. Nanoakışkan kullanıldığı durumlarda soğutucu kabin sıcaklığının su ile soğutmaya göre aynı sürelerde daha düşük sıcaklıklara düştüğü, yani daha az enerji tükettiği gözlenmiştir. Bu nedenle bu çalışma enerji kaynaklarının verimli kullanılması açısından önemlidir

**Anahtar Kelimeler:** Termoelektrik Soğutma, Nanoakışkanlar, Alan Soğutma, Enerji tüketimi

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# 1. Introduction

The noisy and vibrating studies of conventional compression cooling systems have led researchers to search for new cooling systems that will eliminate noise pollution [1]. In this context, thermoelectric devices are a major alternative to conventional cooling systems due to their advantages like silent and vibration-free operation, not containing moving parts and providing sustainable energy conversion [2]. In general, thermoelectric devices are classified as thermoelectric coolers (TECs) and thermoelectric generators (TEGs). TEGs, convert heat into electricity with the Seebeck effect. TECs, on the other hand, are the phenomenon of heat withdrawal from an environment by the Peltier effect and these devices are named Peltier. The Peltier effect is based on the principle that a circuit is formed between two P and N-type semiconductor materials and a temperature difference occurs between the surfaces when an electric current is applied [3]. TECs do not contain any refrigerants harmful to the environment. They can also be custom designed and manufactured for any cooling capacity or size. Thanks to these advantages, TECs make them widely used in various fields such as the food industry, aerospace industry, microelectronic systems, laser diodes, telecommunications, superconducting systems and medical devices [4]. However, TECs have a significant disadvantage due to their low coefficient of efficiency (COP) values compared to conventional cooling systems, especially at large cooling loads [5]. For this reason, researchers are working to increase the COP values of TECs. It is possible to increase the cooling power obtained from the cold side, especially by keeping the hot side temperature of TECs at very low values. For this purpose, fins are used on the hot surfaces of TECs [6]. Zhu and Yu [7] investigated the effect of heat sink optimization on the performance of thermoelectric devices. They used the entropy generation minimization method to optimise of TEC system. A mathematical model was prepared, and the total entropy generation rate was considered as an optimization objective function. According to the results of the theoretical study, they demonstrated that the cooling performance of TECs can be increased with suitable heat sink optimization. Zhu et al. [8] conducted a theoretical study to examine optimal heat sink dimensions. With the proper optimizing of heat sink dimensions, the highest coefficient of performance and the lowest cold side temperature can be achieved. In recent years, it has been achieved to reduce the hot surface temperatures even more with the help of a fluid circulating on these surfaces. Dizaji et al. [9] carried out an empirical study to examine the cooling performance of an air-water based thermoelectric system. They used a water-cooled block on the hot side of Peltier for the purpose of adjusting at constant temperature for the different climatic conditions and different flow rates. The empirical results showed that the temperature of the cold surface of Peltier can be further decreased by controlling hot side temperatures at lower values. In order to further enhance the quantity of heat removed from the hot surface of Peltier, it is a more economical and efficient solution to prefer nanofluids with much better thermal performances instead of the base liquid as a fluid [10]. Nanofluids are obtained by homogeneously dispersing nanoparticles in base liquids such as water, ethylene glycol, and kerosene. They provide much higher thermal conductivity than conventional refrigerants [11]. There are many studies in the literature to discharge larger amounts of heat from the hot surface of Peltier using nanofluids or different systems. Wiriyasart et al. [12] examined the effect of using ferrofluid and nanofluid on heat transfer rates in thermoelectric modules. For this purpose, they prepared $Fe_3O_4$ ferrofluid and $TiO_2$ nanofluid at the 0.015% and 0.005% concentration ratios, respectively and they used a dummy battery pack as a heat load by filling it with water at a constant temperature. The results revealed that using nanofluid and ferrofluid ensured an increase of the Peltier effect by decreasing the Fourier effect. In addition, the maximum heat transfer rate was observed 11.17% higher than water and 12.57% higher than nanofluids for ferrofluids at the same concentration ratio. Lin et al. [13] carried out an empirical study to examine the thermal behaviour of light-emitting diodes (LEDs) with a system combining a TEC. They used water and TiO2 as coolant and measured LED substrate temperature at distinct nanofluid concentration ratios and TEC power. The results revealed that with the use of nanofluids instead of water, it is possible to reduce the LED substrate temperature up to 18.5°C and to reduce the thermal resistance by 42.4%. Sohel et al. [14] examined the thermal performance of a mini channel heat sink. In the experimental study, $Al_2O_3$-Water nanofluids were used as refrigerant at distinct Reynold numbers and volume ratios and the thermal performance values obtained in the case of using $Al_2O_3$-Water nanofluids compared with values obtained in the case of using pure water. The experimental results showed that instead of pure water, using of $Al_2O_3$-Water nanofluids ensures considerable increment in heat transfer performances for TEC applications. Mohammadian and Zhang [15] conducted an empirical work to evaluate the effect of using nanofluids on performance parameters in TEC applications. They prepared a thermoelectric cooling system containing two micro-channel heat exchangers installed on both surfaces of the Peltier. The experimental results revealed that the COP value and total entropy production decrease at high Reynolds numbers with the decrease in particle size. Ahmed et al. [16] investigated cooling applications of electronic devices through TEC used with nanofluids. In their experimental study, they observed the thermal performance of the system by using $Al_2O_3$-Water nanofluid at various volume concentrations to remove more heat from the hot surface of the TEC. According to the results, with the use of 0.2% $Al_2O_3$-Water nanofluids, they achieved a 40% improvement in the COP value of the system. Nanofluids are used as an efficient method in cases where heat is required to be removed from the heat sinks, apart from TECs [17]. Peyghambarzadeh et al. [18] experimentally examined the thermal performance of $Al_2O_3$-Water and CuO-Water nanofluids in a heat sink under constant heat flux and laminar flow conditions. Compared to the base fluid, the heat transfer coefficient enhanced up to 49% and 27% for the 1% volume of $Al_2O_3$-Water and 0.2% volume of CuO-Water nanofluids, respectively. Naphon and Nakharintr [19] studied heat transfer properties of $TiO_2$-Water nanofluids in comparison with de-ionized water. In their study, heat flux ratio, Reynolds number and inlet temperatures were considered. As a result of the study, they achieved that $TiO_2$-Water nanofluids have better thermal performance than the de-ionized water. In an experimental study, Rimbault et al. [20] investigated the thermal behaviour of CuO-Water nanofluids at different volume fractions inside a microchannel heat sink. Experiments were conducted for both turbulent and laminar flow conditions. According to the experimental results, CuO -Water nanofluids showed highly better thermal performance than pure water.

In the present study, the effects of nanofluid usage in thermoelectric refrigerator applications on electricity consumption and cooling times are investigated. In the TEC system used in the thermoelectric cooling cabinet specially designed and produced for the study, a cooling block was used on the hot surface of the Peltier, and it was planned to remove more heat from the surface by circulating different nanofluids in various concentrations. The experiments were repeated for certain periods, both for the situation where the inside of the cabinet is empty and by leaving a certain amount of product to be cooled inside the cabinet and decreases in the indoor temperature of the cabinet were watched.

The aim of this study is to increase the quantity of heat removed by the hot surface of the Peltier and thus provide improvements in cooling power. When this situation occurs, it is expected that the cooling cabinet temperature will reach the lower temperatures earlier, and therefore faster product cooling will take place. As a result of this, less energy will be consumed especially in portable product cooling applications (picnic type refrigerators, in-car refrigerators, organ and drug transport boxes). In this respect, this study is important in terms of the efficient use of energy resources.

In the study, nanofluids, which are frequently used in cooling applications, were preferred. The nanoparticles used are easily supplied and there is precise information about their thermal and physical properties in the literature. In addition, they are suitable for comparison with each other and with other nanofluids in the literature in terms of thermal conductivity values. For these reasons, these nanofluids were preferred in this study. In addition, in order to observe the effect of mixing ratios, the tests were repeated at three different mixing ratios by mass.

## 2. Material

### 2.1. Preparation of Nanofluids

In the system, silicon dioxide ($SiO_2$), aluminium oxide ($Al_2O_3$) and titanium dioxide ($TiO_2$) nanoparticles were prepared by a two-step method with water at 1% concentration ratios. The properties of the nanoparticles used in the system are shown in Table 1 and their preparation is shown in figure 1.

Table 1. Characteristics of nanoparticles used in study

| **Particle** | **Size (nm)** | **Phase** | **Surface Area ($m^2/g$)** | **Colour** | **Purity (%)** |
|---|---|---|---|---|---|
| *Aluminium Oxide* | 78 | Gamma | >20 | White | 99,55 |
| *Silicon Dioxide* | 55-75 | Amorphous | 150-550 | White | 98,5 |
| *Titanium Dioxide* | 38 | Anatase | 55 | White | 99,55 |

Figure 1. Preparation of nanofluids

## 2.2. Preparation of TEC System

A TEC1-12715 model single stage TEC with 15 volts and 10 amperes power was used in the system. An aluminium ingot was adhered to the cold surface of TEC with thermal paste. Then, the other surface of the aluminium ingot was coated with thermal paste and the aluminium fin was combined with this surface. An aluminium water-cooled block was adhered to the hot side of the Peltier with the help of thermal paste. Then, an aluminium fin was attached to the other surface of this block with the same method. To accelerate the heat dissipation from the aluminium fins, 12 V, 1 A fans were used on both fins. Schematic description of the TEC system was shown in figure 2.

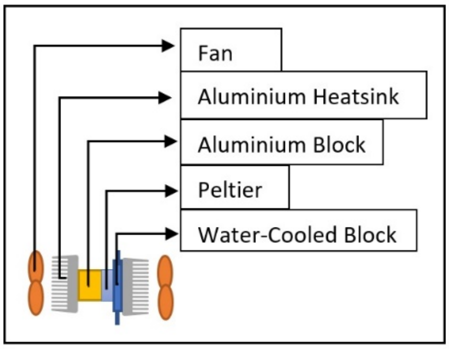


Figure 2. Schematic description of TEC systems

## 2.2. Preparation of Cooled Cabinet

First, a cabinet of 1.8 mm thick MDF material was produced with inner dimensions of 30 cm width, 30 cm depth, and 40 cm height. Later, a 60 mm larger cabinet was produced from this cabinet in all directions, and the smaller one was placed inside the larger one, and the 60 mm gaps in between were filled with XPS foam on the backside and polyurethane foam on the other sides. On the front, a frame made of PVC material is used. The production of the cooled cabinet was shown in Figure 3.

Figure 3. The production of the cooled cabinet

## 3. Method

First, the prepared TEC system was mounted from the front cover of the refrigerator cabinet. K-type thermocouples are placed in suitable places to measure cabin temperature, cooled product temperature, outdoor temperature, refrigerant temperature, and heatsink temperatures. One end of the heat exchanger is connected to the water-cooled block in the TEC assembly with a transparent hose. The other end of the water-cooled block is connected to the circulation pump with a transparent hose. The other end of the heat exchanger is connected to the mini fluid pool in which the circulation pump is located. Thus, the refrigerant coming to the heat exchanger by taking heat from the water-cooled block will leave its excess heat to the environment and go to the fluid pool, and from there it will return to the water-cooled block again with the circulation pump. The schematic diagram of the system is demonstrated in figure 4. Experiments were first carried out without adding nanoparticles, using 600 ml of water as a refrigerant, both for the loaded and unloaded conditions, and the results were accepted as the reference situation to be compared with the situations using nanofluids. Then, experiments were repeated with nanofluids ($Al_2O_3$-Water, $TiO_2$-Water, and $SiO_2$-Water) prepared, both for the unloaded state and for the loaded state. In addition, the temperature of the conditioning room in which the experimental setup is located was adjusted to 18, 24 and 30 °C with the help of an air conditioner, and all tests were repeated at three different outdoor temperatures for loaded and unloaded conditions, and the effect of outdoor conditions on the cooling power was observed.

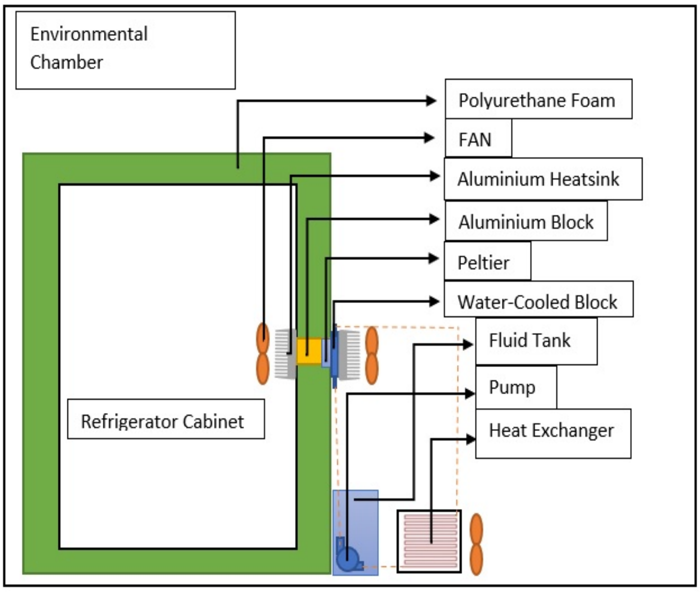


Figure 4. The schematic diagram of the TEC system

Test times were determined as 1 hour. In the case of using water without nanoparticle addition as the refrigerant, the temperature of the cooled cabin was measured after 1 hour, and it was observed in how many minutes the same cabin temperature was reached when nanofluids were used.

## 4. Results

Peltier with a power of 15 V 10 A was used in the system.

$$W = V \times I \quad (1)$$

W=15 X 10 =150 W=0.15 kW

### 4.1. Without Load Conditions

In the case of using water without nanoparticle addition as a refrigerant (reference case) without load conditions at 18 °C ambient temperature, the temperature of the cooled cabin decreased to 1.7 °C at the end of 3600 seconds. The same temperature value was obtained the fastest in 1560 seconds when $Al_2O_3$-Water nanofluid was used. It has been observed that faster cooling occurs in cases where $TiO_2$-

Water and $SiO_2$-Water are used compared to the reference case. As shown in Figure 5, 540 kWs energy is required in the reference case to reduce the cooled cabinet temperature to 1.7 °C, while this value is 234 kWs when $Al_2O_3$-Water nanofluid is used.

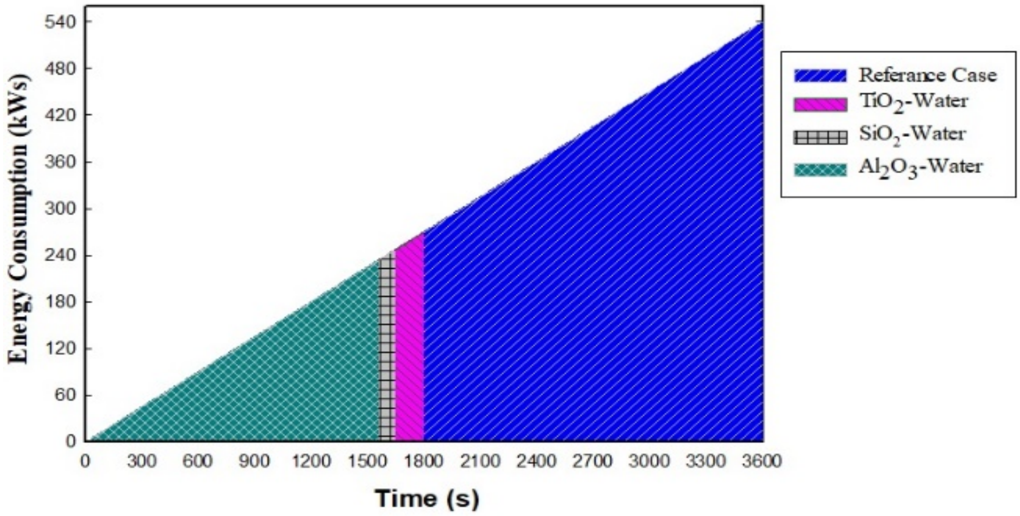


Figure 5. Comparison of electricity consumption at 18 °C ambient temperature without load conditions

For the 24 °C ambient temperature conditions, the temperature of the cooled cabin decreased to 1.3 °C at the end of 3600 seconds. The same temperature value was obtained the fastest in 2130 seconds when $Al_2O_3$-Water nanofluid was used. It has been observed that faster cooling occurs in cases where $TiO_2$-Water and $SiO_2$-Water are used compared to the reference case. As seen in Figure 6, 319.5 kWs of energy was consumed in the case where the temperature value at the end of the reference state is reached the fastest with nanofluids.

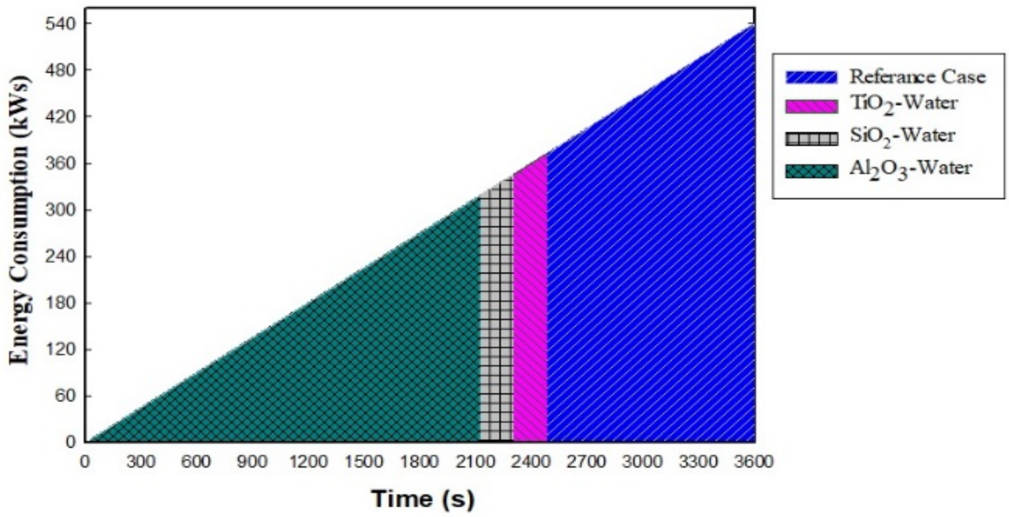


Figure 6. Comparison of electricity consumption at 24 °C ambient temperature without load conditions

For the 30 °C ambient temperature conditions, the temperature of the cooled cabin decreased to 6.6 °C at the end of 3600 seconds. The same temperature value was obtained the fastest in 2700 seconds when $Al_2O_3$-Water nanofluid was used. It has been observed that faster cooling occurs in cases where $TiO_2$-Water and $SiO_2$-Water are used compared to the reference case. As seen in Figure 7 405 kWs of energy was consumed in the case where the temperature value at the end of the reference state is reached the fastest with nanofluids.

## 4.2. With Load Conditions

In the reference case at loaded conditions at 30 °C ambient temperature, the temperature of the cooled cabin decreased to 11 °C at the end of 3600 seconds. The same temperature value was obtained the fastest in 2190 seconds when $Al_2O_3$-Water nanofluid was used. It has been observed that faster cooling occurs in cases where $TiO_2$-Water and $SiO_2$-Water are used compared to the case of reference case. As shown in Figure 8, 540 kWs energy is required in the reference case to reduce the cooled cabinet temperature to 1.7 °C, while this value is 328.5 kWs when $Al_2O_3$-Water nanofluid was used.

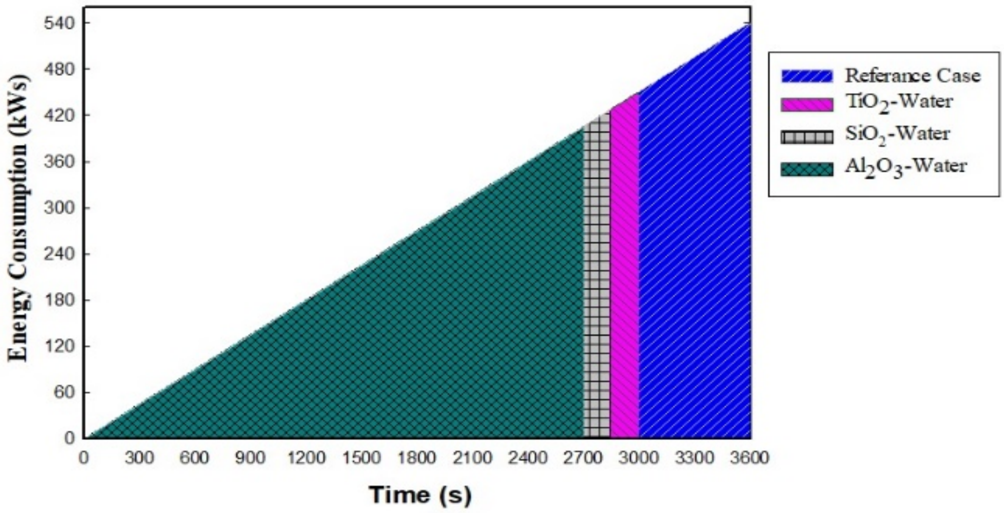


Figure 7. Comparison of electricity consumption without load conditions at 30 °C ambient temperature

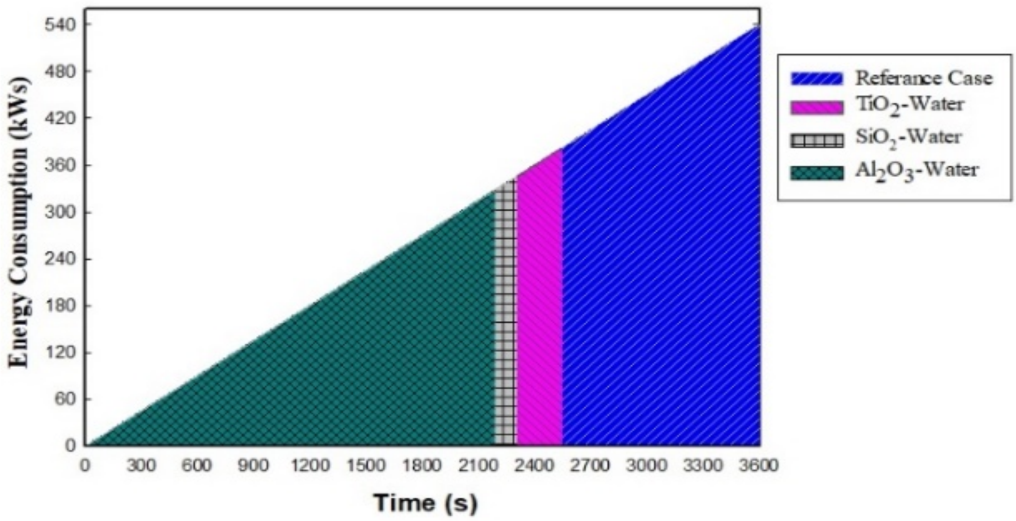


Figure 8. Comparison of electricity consumption with load conditions at 30 °C ambient temperature

For the 24 °C ambient temperature and reference case, the temperature of the cooled cabin decreased to 8.5 °C at the end of 3600 seconds. The same temperature value was obtained the fastest in 1920 seconds when $Al_2O_3$-Water nanofluid was used. As seen in Figure 9, 288 kWs of energy was consumed in the case where the temperature value at the end of the reference state is reached the fastest with nanofluids.

For the 18 °C ambient temperature and reference case, the temperature of the cooled cabin decreased to 5.8 °C at the end of 3600 seconds. The same temperature value was obtained the fastest in 1800 seconds when $Al_2O_3$-Water nanofluid was used. As seen in Figure 10, 270 kWs of energy was consumed in the case where the temperature value at the end of the reference state is reached the fastest with nanofluids.

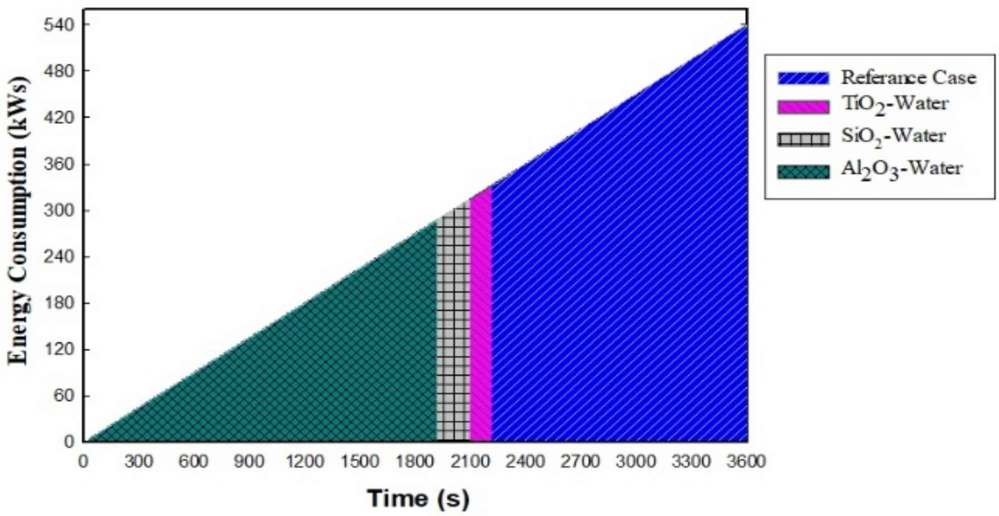


Figure 9. Comparison of electricity consumption with load conditions at 24 °C ambient temperature

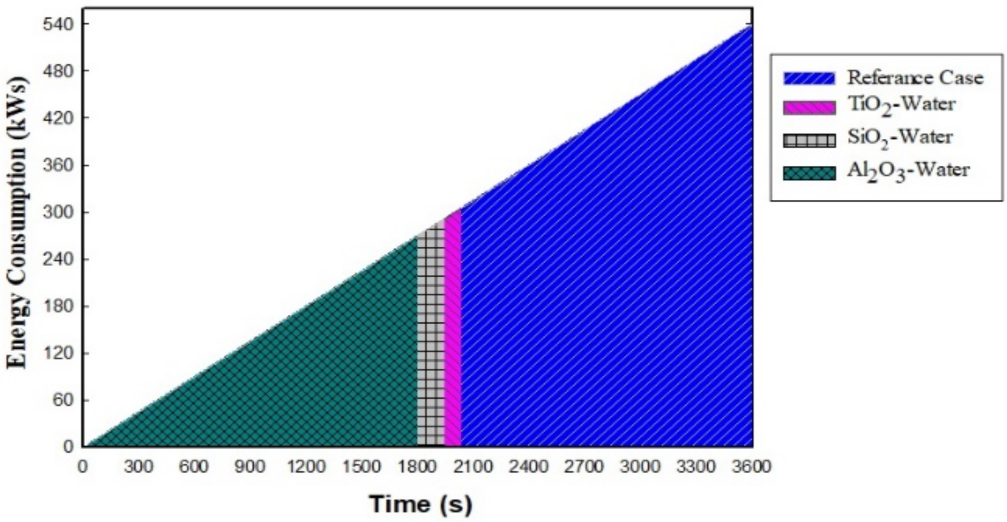


Figure 10. Comparison of electricity consumption with load conditions at 18 °C ambient temperature

## 5. Conclusion

In the present study, the effect of nanofluid usage in thermoelectric refrigerators on electricity consumption was investigated. According to the results obtained from the study, in the case of using nanofluid instead of water as a refrigerant in the system, the cooling cabinet temperatures can reach the lower values earlier. This situation provides significant advantages in terms of efficient use of energy resources, especially in applications that do not work continuously but are required to cool the product quickly (such as picnic type refrigerators, vehicle glovebox coolers, organ, and drug transport boxes).

## Conflict of Interest Statement

The authors declare that there is no conflict of interest

## References

[1] Y. He, R. Li, Y. Fan, Y. Zheng, and G. Chen, "Study on the performance of a solid-state thermoelectric refrigeration system equipped with ionic wind fans for ultra-quiet operation," *International Journal of Refrigeration*, vol. 130, pp. 441–451, 2021. doi:10.1016/j.ijrefrig.2021.06.017

[2] E. Cuce, T. Guclu, and P. M. Cuce, "Improving thermal performance of thermoelectric coolers (TECs) through a nanofluid driven water to air heat exchanger design: An experimental research," *Energy Conversion and Management,* vol. 214, pp. 112893, 2020. doi:10.1016/j.enconman.2020.112893

[3] T. Guclu and E. Cuce, "Thermoelectric Coolers (TECs): From Theory to Practice," *Journal of Electronic Material*, vol. 48, no. 1, pp. 211–230, 2019. doi:10.1007/s11664-018-6753-0

[4] X. D. Wang, Q. H. Wang, and J. L. Xu, "Performance analysis of two-stage TECs (thermoelectric coolers) using a three-dimensional heat-electricity coupled model," *Energy*, vol. 65, pp. 419–429, 2014. doi:10.1016/j.energy.2013.10.047

[5] J. Yu and B. Wang, "Enhancing the maximum coefficient of performance of thermoelectric cooling modules using internally cascaded thermoelectric couples," *International Journal of Refrigeration*, vol. 32, no. 1, pp. 32–39, 2009. doi:10.1016/j.ijrefrig.2008.08.006

[6] R. Chein and Y. Chen, "Performances of thermoelectric cooler integrated with microchannel heat sinks," *International Journal of Refrigeration*, vol. 28, no. 6, pp. 828–839, 2005. doi:10.1016/j.ijrefrig.2005.02.001

[7] L. Zhu and J. Yu, "Optimization of heat sink of thermoelectric cooler using entropy generation analysis," *International Journal of Thermal Science*, vol. 118, pp. 168–175, 2017. doi:10.1016/j.ijthermalsci.2017.04.015

[8] L. Zhu, H. Tan, and J. Yu, "Analysis on optimal heat exchanger size of thermoelectric cooler for electronic cooling applications," *Energy Conversion and Management*, vol. 76, pp. 685–690, 2013. doi:10.1016/j.enconman.2013.08.014

[9] H. Sadighi Dizaji, S. Jafarmadar, S. Khalilarya, and A. Moosavi, "An exhaustive experimental study of a novel air-water based thermoelectric cooling unit," *Applied Energy*, vol. 181, pp. 357–366, 2016. doi:10.1016/j.apenergy.2016.08.074

[10] M. Gupta, V. Singh, R. Kumar, and Z. Said, "A review on thermophysical properties of nanofluids and heat transfer applications," *Renewable and Sustainable Energy Reviews*, vol. 74, pp. 638–670, 2017. doi:10.1016/j.rser.2017.02.073

[11] E. Cuce, P. M. Cuce, T. Guclu, and A. B. Besir, "On the Use of Nanofluids in Solar Energy Applications," *Journal of Thermal Science*, vol. 29, no. 3, pp. 513–534, 2020. doi:10.1007/s11630-020-1269-3

[12] S. Wiriyasart, P. Suksusron, C. Hommalee, A. Siricharoenpanich, and P. Naphon, "Heat transfer enhancement of thermoelectric cooling module with nanofluid and ferrofluid as base fluids," *Case Studies Thermal Engineering*, vol. 24, no. February, p. 100877, 2021. doi:10.1016/j.csite.2021.100877

[13] X. Lin, S. Mo, B. Mo, L. Jia, Y. Chen, and Z. Cheng, "Thermal management of high-power LED based on thermoelectric cooler and nanofluid-cooled microchannel heat sink," *Applied Thermal Engineering*, vol. 172, p. 115165, 2020. doi:10.1016/j.applthermaleng.2020.115165

[14] M. R. Sohel, S. S. Khaleduzzaman, R. Saidur, A. Hepbasli, M. F. M. Sabri, and I. M. Mahbubul, "An experimental investigation of heat transfer enhancement of a minichannel heat sink using Al2O3-H2O nanofluid," *International Journal of Heat Mass Transfer*, vol. 74, pp. 164–172, 2014. doi:10.1016/j.ijheatmasstransfer.2014.03.010

[15] S. K. Mohammadian and Y. Zhang, "Analysis of nanofluid effects on thermoelectric cooling by micro-pin-fin heat exchangers," *Applied Thermal Engineering*, vol. 70, no. 1, pp. 282–290, 2014. doi:10.1016/j.applthermaleng.2014.05.010

[16] N. Ahammed, L. G. Asirvatham, and S. Wongwises, "Thermoelectric cooling of electronic devices with nanofluid in a multiport minichannel heat exchanger," *Experimental Thermal and Fluid Science*, vol. 74, pp. 81–90, 2016. doi:10.1016/j.expthermflusci.2015.11.023

[17] M. Khoshvaght-Aliabadi and M. Sahamiyan, "Performance of nanofluid flow in corrugated minichannels heat sink (CMCHS)," *Energy Conversion and Management*, vol. 108, pp. 297–308, 2016. doi:10.1016/j.enconman.2015.11.026

[18] S. M. Peyghambarzadeh, S. H. Hashemabadi, A. R. Chabi, and M. Salimi, "Performance of water based CuO and Al2O3 nanofluids in a Cu-Be alloy heat sink with rectangular microchannels," *Energy Conversion and Management*, vol. 86, pp. 28–38, 2014. doi:10.1016/j.enconman.2014.05.013

[19] P. Naphon and L. Nakharintr, "Heat transfer of nanofluids in the mini-rectangular fin heat sinks," *International Communications in Heat Mass Transfer*, vol. 40, no. 1, pp. 25–31, 2013. doi:10.1016/j.icheatmasstransfer.2012.10.012

[20] B. Rimbault, C. T. Nguyen, and N. Galanis, "Experimental investigation of CuO-water nanofluid flow and heat transfer inside a microchannel heat sink," *International Journal of Thermal Science*, vol. 84, pp. 275–292, 2014. doi:10.1016/j.ijthermalsci.2014.05.025