PERFORMANCE OF A THERMOELECTRIC MODULE

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Industrial Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"Thermoelectric Power Generation and Heat Pump Cooling"** was prepared by **CHUNG WUI KET** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Industrial Engineering at Universiti Tunku Abdul Rahman.

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Performance of a Thermoelectric Module

ABSTRACT

Thermoelectric (TE) is the direct conversion of temperature difference between the junctions of two dissimilar materials to provide electrical output. This effect was discovered by Thomas Seebeck in 1821. Later, in 1851, Peltier showed the converse is also true. The Seebeck effect could be utilized to generate electricity and the Peltier effect could be utilized as a heat pump for the cooling of semiconductors like LEDs. This paper reports on the performance of TE modules. Thermal characteristics such as the Seebeck coefficient (α_{te}), thermal conductance (K_{te}), internal resistance (R_{te}), power load (P_L) and Coefficient of Performance (COPc), were determined in this study. Experiments were conducted using TE in both power generating (TEG) and in cooling (TEC) modes. The Seebeck coefficient and thermal conductance were found to be quite constant but the internal resistance increased as the temperature increased. The coefficient of performance was found to decrease with power supplied to the TE. Recommendations for future studies were suggested to improve the present study.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Thermoelectric (TE) is the direct conversion of temperature difference between the junctions of two dissimilar materials (thermocouple) to electricity. This incidence was discovered by Thomas Seebeck and is known as the Seebeck effect. In essence a thermoelectric device generates DC voltage when a temperature differential is applied across it. Thus, TE devices are employed to generate electricity or to measure temperature. However, is it possible for a thermoelectric device to be able to be used as temperature controllers to regulate the temperature of objects. In this instance Peltier showed that the converse is also true. A voltage applied between the junctions of the thermocouple creates a temperature difference between them. The direction of heating and cooling is determined by the polarity of the applied voltage which is known as the Peltier effect. In real life applications, the Seeback effect could be utilized to generate electricity and the Peltier effect could be utilized as a heat pump to transfer heat from the cold junction to the hot junction.

A typical TE module is shown schematically in Fig. 1. It consists of several pairs of thermocouple semiconductors and the thermocouples are sandwiched between two ceramic plates so that the surfaces are electrically insulated on both surfaces. Depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. A TE module consists of multiple pairs of thermocouples electrically connected in series and thermally in parallel. TE module can be differentiated into thermoelectric generator (TEG) and thermoelectric heat pump cooler (TEC). TEG could be utilized to generate electricity whereas TEC could be utilized as a heat pump. Thermoelectric modules are able to stabilize the thermal management, regulate the temperature of electronic chips, administers the cooling of small size products, water heating, refrigeration and employ waste heat as a heat source.

An example of where thermoelectric modules could be implemented for heat management are high powered LEDs. Light emitting diodes (LEDs) are rapidly utilized to replace conventional light bulbs due to their high efficiency, environmentally friendly, reliability and perdurable charecteristics. Present day high power LEDs are capable of providing up to 120-150 lm/W with 80 – 90% of the input energy being converted into heat. Thermal management is of critical importance for high power LEDs and provides a challenging task for designers. Poor heat dissipation decreases its lighting efficiency. The higher the LED's operating temperature, the more quickly the light will degrade, and the shorter the useful life will be. Traditional LED chip cooling include the finned metal fins under natural or forced convection. In order to increase their cooling performance, LEDs use a variety of unique heat sink designs and configurations to manage heat.

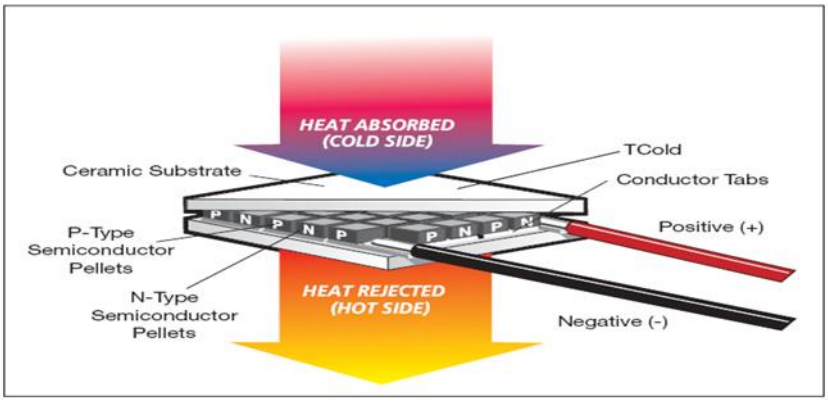


FIGURE 1 CUT –AWAY VIEW OF A TE MODULE

1.2 Problem Statements

Thermal performance of a thermoelectric module depends on the physical properties such as the Seebeck coefficient (α_{te}), the electric resistance (R_{te}) and the thermal conductivity (K_{te}). Manufacturers of thermoelectric modules do not provide this sort of data for their customer or in certain cases the given data are not accurate because of the variation in the process of manufacturing. So in order to determine the performance of a TE device, physical properties of the thermoelectric module are required. An experimental apparatus was fabricated in this study for this purpose. Experimental investigations who were carried out to determine the performance of some TE modules for thermoelectric power generation and heat pump cooling.

1.3 Objectives

The main objective is to investigate the performance of TE modules for power generation and heat pump cooling. The following investigations were carried out to determine:

- Heat sink thermal resistance.
- Characteristics of the TE module.
- Performance of TE modules for power generation and heat pump cooling.

1.4 **Outline of Thesis**

Chapter 1 introduces the working principles and applications of thermoelectric. Literature survey on past works on characterisation of thermoelectric modules, thermoelectric power generation and thermoelectric cooling system are presented in Chapter 2. A theoretical model to determine the performance of a fin heat sink is introduced in Chapter 3. Chapter 4 describes the experimental investigation carried out. The experimental results are discussed in Chapter 5. Suggestions are included for further improvements in Chapter 6. Chapter 7 concludes the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Characterisation of thermoelectric modules

Phillips (2009) carried out various experiments whereby the thermal efficiency of TE characteristic was determined. Utilizing a variable power cartridge heater, thermal power was supplied to a module encased in a insulating container and the temperature difference across the module was calibrated using the type-K thermocouples. Comparing his findings to those that of before him, he found that in relation to the accepted average value of thermal conductivity his results was within 21%, the Seebeck coefficient within 16% and the thermal efficiency of low ΔT within 20%. Thermistors were used to improve the accuracy of measurements like thermal conductivity and Seebeck coefficient.

Another research on characterisation of thermoelectric, Nazri (2007) carried out an experiment whereby the TE characteristics like thermal conductivity, electric resistance, Seeback coefficient, and conductivity are determined. The results were compared with the results given by the manufacturer. Fin, cooling fan with fin, and water cooling jacket are the three different heat sinks that were selected to determine their performance. Optimization of thermoelectric performance is amended by analysing the effect of several settings for the heat sinks.

2.2 Thermoelectric power generation

Niu *et al.* (2008) performed an experimental and theoretical study on low-temperature waste heat thermoelectric generator. The hot and cold fluid flow temperatures, flow rates and power output's load resistance and conversion efficiency were investigated in this study. They found that the power obtained and conversion efficiency were highly effected by the operating conditions.

Rowe *et al.* (1998) carried out investigation on the evaluation of thermoelectric modules for power generation. They investigated the parameters such as the power per area, cost per watt and factor of manufacture quality. They found that with usage of commercially available thermoelement of appropriate length it could effortlessly obtain a cost-per-watt of £4/W. They added on that for better results, a module with optimised geometry with improved MQF will be required.

Nguyen and Pochiraju (2013) performed an experiment to study the characteristics of thermoelectric generator (TEG) which simulates real life energy harvesting applications where a transient heat source will affect the hot surface and the cold surface is cooled through natural convection only. An implementation of Seebeck, Peltier, Thomson, and Joule effects was conducted using finite-difference technique. Thomson effect was found to greatly affect the expected power generation by thermoelectric in their conclusion.

2.3 Thermoelectric cooling and heating

Zhou *et al.* (2011) performed an experimental and theoretical study for the optimization of a thermoelectric cooling (TEC) system which takes into consideration the thermal conductance on the hot and cold sides. They obtained COP of between 0.40- 0.47.

Lee *et al.* (2007) carried out an investigation on the cooling performance of a thermoelectric mirco-cooler. They investigated the effect of parameters such as temperature difference, the current, the thickness of the thermoelectric element and the amount of thermoelectric pairs towards the performance of the cooler. They found that the COP has the highest value when the current applied was at 1.12A. Other than that, a trend of increasing COP could be recorded when the temperature difference decreases or the increase in the thickness of the thermoelectric element.

Toh *et al.* (2007) carried out studies on optimization of a thermoelectric cooler-heat sink combination for active processor cooling. They analyzed the performance of an off-the-shelf TEC utilized together with a fan-cooled extruded aluminium heat sink in cooling a Pentium processor package and the performance of only the heat sink is compared by using systematic methodology for characterizing and comparing the performance of the TEC enhanced system with that of a heat sink only system. He found that there is also a trade-off for the increase in COP of the TEC for purposes of systems processor cooling.

Zhang (2010) developed a general way in optimizing and evaluating thermoelectric coolers. Based on the TEC thermal balance equations, simplified formulations are derived by TEC pallet level and module level, and analytical solutions for cooling capacity and device temperature. He found that performance parameters and device side thermal resistance realized by a fast selection of heat sink with the present analysis approach.

Riffat *et al.* (2004) carried out investigations on improving the coefficient of performance of thermoelectric cooling system. Maximum heat pumping capacity is achieved by a relatively short thermoelement. Improvements in both COP and heat pumping capacity are extremely important in reducing the contact resistances. An accurate module test measures the basic physical properties of a thermoelectric module and performance curve for the new methodologies of system design and system analysis of high performance thermoelectric cooling system. Multistage thermoelectric modules are used to improve the COP for applications with large temperature difference.

Cosnier *et al.* (2008) carried out investigations on thermoelectric air cooling and air heating system. They found that COP is above 1.5 in air cooling mode and close to 2 in heating mode which required maximal electrical intensity in the range of 4-5A to maintain the small temperatures difference of 5-10 ^{o}C between the hot and cold side of the TE.

Kazmierczak *et al.* (2009) performed an experiment to design a simple and effective heat pump system which can potentially fulfil home cooling and heating requirements. They investigated the effects of the TE power input, number of TE units, rate of fluid flow, and heat sink temperature. They found that lower flow rates can increase the heat sink resistance and temperature across the TE module and potentially cause the system to operate less efficiently.

Luo *et al.* (2005) carried out an experiment on thermoelectric heat pump water heaters. They found that the heating coefficient of a TE heat pump is 1.6, and is more efficient than compared with electrical heating devices under suitable operating condition. In the application of a TE in water heating purposes, it is found that it can save over 40% of power consumption with the TE heat pump as compared to a conventional electric water heater.

Chein *et al.* (2005) performed an experimental and theoretical study on thermoelectric cooler performance for cooling a refrigeration object. TEC hot side was employed with microchannel heat sinks manufactured with etched silicon wafers to dissipate heat. Water temperatures inside tank and at the microchannel heat sink inlet and outlet were analysed in the experiment. The equivalent TEC hot side temperature and microchannel heat sink performance were estimated by utilizing the measured temperature data. They concluded that for low temperature cooled object the TEC current input should be increased and it is critical to reduce the thermal resistance of heat sink in the same time.

In small scale cooling applications, TE coolers only have a COP of 0.5 comparing to COP of large machines of 3.0 to 5.0. Bass et al. (2004) took upon to investigate the performance of a multi-layer quantum well thermoelectric in electronic cooling applications. The TE was required to keep the component at a fixed temperature where it will then pump the excessive heat to a higher temperature which is then rejected. The MQLW which was in the development stages was found to be able to cool the electronic component an increases the CPU's performance.

TE generators with multi-elements require further investigations on its power output and efficiency expressions. Chen et al. (2001) carried out an experiment for this purpose including attention on heat transfer irreversibility in the heat exchangers between the generator and the heat sources. The findings show that there is a direct effect on the heat transfer irreversibility on the performance of a thermoelectric generator. On a final note, the amount of thermoelectric elements has a consequence on the performance as well.

Another research which concludes the importance of Thomson effect on the cooling efficiency of a thermoelectric cooler was carried out by Huang et al. (2004). The research focuses on the temperature distribution of a thermoelectric in relation to the Thomson effect, Joule heating, Fourier's heat conduction and the heat transfer through convection and radiation. It was found that not only the Thomson effect plays an important role but the figure-of-merit of the thermoelectric materials as well.

Taylor et al. (2006) too concluded that a combination of applied current and TE geometry is required to achieve a minimum junction temperature at maximum COP. The focus was on achieving and analytic expression for a TE element geometry which would yield a desirable temperature for electronic cooling applications. A model constructed with a 0.4K/W heat sink with an optimized bismuth-telluride TE module found that a maximum of 100W could be dissipated at a junction temperature of 85°C.

Using finite time thermodynamics and fundamental ideology of thermoelectric generation technology, Gou et al. (2010) created a model of a thermoelectric generator system. The model suffices on a low-temperature waste heat as to simulate industrial conditions. Comparing their findings and theoretical analysis, it shows a possibility of implementing the system for waste heat recovery for industrial purposes. The findings shown an increase in waste heat temperature, number of TE modules in series, expanding heat sink surface area and enhancing cold-side heat transfer capacity can increase the performance of the system.

Leephakpreeda (2011), set out to acquire a simple methodology, in a few steps of measurement, to obtain the parameters of thermoelectric modules. A series of input-output descriptive models were also proposed for a readable representation of linear input-output relation for real cooling/heating purposes. The investigation focused on thermoelectric modules of capacities 45, 60 and 91.2 W. The experimental results obtained an agreement with the simulated results.

CHAPTER 3

THEORETICAL INVESTIGATION

3.1 Theoretical model of fin heat sink

A heat sink is a passive heat exchanger which is employed to remove heat produced by an electronic component. This is to keep device temperature at a certain low level. Heat spreading resistance occurs while a small heat source is in contact with a bigger heat sink surface. The spreading resistance occurrence results is a large temperature slope between the heat source and the boundaries of the heat sink. It impede the heat transfer rate from the hot surface to the boundaries of fins. Fin efficiency is determined by the actual heat transfer from the fin.

3.1.1 Fin efficiency and thermal resistance of fin heat sink for 1-D heat flow.

An isometric view of a conventional rectangular profile straight fin and wall heat sink combination is shown in Fig. 2(a) together with the thermal resistance network in Fig. 2(b). The temperature distribution along the fin is shown in Fig. 2(c). The fin efficiency is given by

$$\eta_{fin} = \frac{\tanh\,(m_{fin}\ L_{fin,c})}{(m_{fin}\ L_{fin,c})} \qquad (1)$$

where

$$m_{fin} = \sqrt{\frac{h_a \, 2\,(W_{fin} + t_{fin})}{k_{fin} \, W_{fin} \, t_{fin}}} \qquad (2)$$

and the corrected fin length

$$L_{fin,c} = L_{fin} + \frac{t_{fin}}{2} \qquad (3)$$

The total heat transfer surface area of the heat sink is given by

$$\Sigma A_{hs} = N_{fin} \, A_{fin} + A_{fin,b} \qquad (4)$$

where the heat transfer surface area of each fin is

$$A_{fin} = (2L_{fin} + t_{fin}) \, W_{fin} \qquad (5)$$

and the total heat transfer surface area of the non-finned or bare portion of the heat sink is

$$A_{fin,b} = (S_{fin} - t_{fin}) \, W_{fin} \, (N_{fin} - 1) \qquad (6)$$

The total surface fin efficiency of a multi fin array is given by

$$\eta_o = 1 - \frac{N_{fin} \, A_{fin}}{\Sigma A_{hs}} (1 - \eta_{fin}) \qquad (7)$$

The total heat transfer rate from the heat sink is given by

$$\dot{q}_h = \eta_o \, h_a \, \Sigma A_{hs} \, (T_b - T_a) \qquad (8)$$

The surface thermal resistance of the fin heat sink is calculated from

$$R_{fin} = \frac{1}{\eta_o \, h_a \, \Sigma A_{hs}} \qquad (9)$$

For a plane wall of thickness Δx_{base}, wall resistance is given by

$$R_{base} = \frac{\Delta x_{base}}{k_{fin} \, S_{fin} \, W_{fin} \, N_{fin}} \qquad (10)$$

The total thermal resistance of the fin heat sink under 1-D heat flow is thus given by

$$R_{f1D} = R_{hs} + R_{base} \qquad (11)$$

A theoretical model for a fin heat sink assembly undergoing 1-D heat flow is shown in Fig. 3(a) together with the associated thermal resistance network in Fig. 3(b). An aluminum block is placed in-between the heat source and the fin heat sink. In the absence of heat spreading effect, the interface temperatures (T_s, T_f and T_{fm}) shown are assumed uniform.

The thermal resistance of the aluminum block may be determined from

$$R_{al} = \frac{(T_s - T_f)}{P_{EH}} \qquad (12)$$

and the contact resistance from

$$R_{cr} = \frac{(T_f - T_{f\,\mathrm{m}})}{P_{EH}} \qquad (13)$$

In the absence of thermal contact resistance, temperature T_{hs} would be equal to T_{fm}.

The total thermal resistance of this heat sink assembly for 1-D heat flow may be determined from

$$R_{f1D} = \frac{(T_{fm} - T_a)}{P_{EH}} \qquad (14)$$

3.2 Theoretical model of fin heat sink with TE.

Figure 4(a) shows a TE module incorporated together with a fin heat sink. The associated thermal resistance network is shown in Fig. 4(b). Contact resistances are neglected. All interface temperatures are expected to be uniform since the heat flow is 1-dimensional. Hot side (T_h) temperature is equal to heat sink base temperature (T_{fm}). From Fig. 4(b), the thermal resistance of the TE module is given by

$$R_{TE} = \frac{(T_c - T_h)}{P_{EH}} \qquad (15)$$

The effective thermal resistance of the fin heat sink with TE assembly is then given by

$$\Sigma R_{fTE} = R_{TE} + R_{f1D} \qquad (16)$$

where fin resistance (R_{f1D}) is obtained from Eq (14).

The heat transfer rates at the cold and hot sides of the TEC module are given by

$$\dot{q}_c = \alpha_{te}\, I_L\, T_c + \frac{I_L^2\, R_{te}}{2} + K_{te}\, \Delta T_{te} \qquad (17)$$

and

$$\dot{q}_h = \alpha_{te}\, I_L\, T_h - \frac{I_L^2\, R_{te}}{2} + K_{te}\, \Delta T_{te} \qquad (18)$$

where the temperature difference across the TE module is

$$\Delta T_{te} = T_h - T_c \qquad (19)$$

The induced TE voltage is

$$V_{te} = \alpha_{te}\, \Delta T_{te} + I_{te}\, R_{te} \qquad (20)$$

Power developed by the TE module is given by

$$P_L = \dot{q}_h - \dot{q}_c \qquad (21)$$

Substituting Eqns. (17) and (18) into Eqn. (21), we obtain

$$P_L = \alpha_{te}\, I_L\, \Delta T_{te} - I_L^2\, R_{te} \qquad (22)$$

The efficiency of the generator is calculated from

$$\eta_L = \frac{P_L}{\dot{q}_h} \qquad (23)$$

From the resistance network

$$\dot{q}_h = \frac{T_h - T_a}{R_{f1D}} \tag{24}$$

The internal electrical resistance of the TE module can be experimentally represented by

$$R_{te} = a + bT_{mTE} \tag{25}$$

where mean TE temperature

$$T_{mTE} = \frac{(T_h + T_c)}{2} \tag{26}$$

From Eqs. (18), (22) and (23) we obtain

$$T_h = \frac{R_{f1D}\,(b\,I_{te}^2\,T_c - 2\,a\,I_{te}^2 - 4\,K_{te}\,T_c) - 4\,T_a}{R_{f1D}\,(b\,I_{te} + 4\,\alpha_{te}\,I_{te} - 4\,K_{te}) - 4} \tag{27}$$

With specified values of cold surface temperature (T_c) and operating ambient temperature (T_a) together with the characteristics of the TE module, the expected hot side temperature (T_h) can be iterated from Eq. (27) at a given TE current (I_{te}). The TE voltage to be supplied is given by Eq. (20). When no power is provided to the TE, open-circuit (no load) voltage results from the temperature difference imposed on both sides of the module

$$V_{NL} = \alpha_{te}\,\Delta T_{te} \tag{28}$$

Seebeck coefficient is then determined from

$$\alpha_{te} = \frac{V_{NL}}{\Delta T_{te}} \tag{29}$$

and thermal conductance from

$$K_{te} = \frac{P_{EH}}{\Delta T_{te}} \tag{30}$$

With load connected, the output voltage drops as a result of the internal resistance of the TE module. Dividing Eq. (22) by I_L, we obtain the voltage generated across the module when a load is connected to it, viz.,

$$V_L = \alpha_{te}\, \Delta T_{te} - I_L\, R_{te} = V_{NL} - I_L\, R_{te} \tag{31}$$

Rearranging the above, we obtain the current supplied

$$I_L = \frac{1}{R_{te}}(V_{NL} - V_L) \tag{32}$$

The current flow at each TE module is calculated from

$$I_L = \frac{V_L}{R_L} \tag{33}$$

From Eqns. (32) and (33), we obtain

$$V_L = V_{NL}\left(\frac{R_L}{R_{te} + R_L}\right) \tag{34}$$

and internal resistance from

$$R_{te} = R_L \left(\frac{V_{NL}}{V_L} - 1 \right) \tag{35}$$

Heat transfer rate at the cold side of the TEC module is expressed as

$$\dot{q}_c = \alpha_{te}\ I_{te}\ T_c - \frac{I_{te}^2\ R_{te}}{2} - K_{te}\ \Delta T_{te} \tag{36}$$

and the heat rejection rate at the hot side

$$\dot{q}_h = \alpha_{te}\ I_{te}\ T_h + \frac{I_{te}^2\ R_{te}}{2} - K_{te}\ \Delta T_{te} \tag{37}$$

where the temperature difference between the cold and hot sides is defined as

$$\Delta T_{te} = T_h - T_c \tag{38}$$

Power supplied to the TE module is given by

$$P_{te} = \dot{q}_h - \dot{q}_c \tag{39}$$

Substituting Eqns. (36) and (37) into Eqn. (38), we obtain

$$P_{te} = \alpha_{te}\ I_{te}\ \Delta T_{te} + I_{te}^2\ R_{te} \tag{40}$$

The voltage impressed across the TE module under load condition is given by

$$V_{te} = \alpha_{te}\ \Delta T_{te} + I_{te}\ R_{te} \tag{41}$$

and the current supplied is

$$I_{te} = \frac{1}{R_{te}} (V_{te} - \alpha_{te}\ \Delta T_{te}) \qquad (42)$$

The coefficient of performance for cooling is defined as

$$COP_c = \frac{\dot{q}_c}{P_{te}} \qquad (43)$$

Rewriting Eqn. (41) gives

$$R_{te} = \frac{(V_{te} - \alpha_{te}\ \Delta T_{te})}{I_{te}} \qquad (44)$$

Assuming perfect insulation with no heat loss, the heat transfer rate ($\dot{q}_c$) at the cold side of the TE is equal to the power (P_{EH}) supplied by the electrical heater.

Eqn. (36) can be rewritten as

$$T_h = \frac{(\alpha_{te}\ I_{te}\ T_c + K_{te}\ T_c - P_{EH} - I_{te}^2\ R_{te} / 2)}{K_{te}} \qquad (45)$$

The thermal resistance network for a fin heat sink incorporated with a TE module is shown in Fig. 4(b). The heat transfer rates across the surfaces can be written in terms of the interface temperature differences and resistances, viz.,

$$\dot{q}_c = \frac{(T_s - T_c)}{R_{cr}} \qquad (46)$$

$$\dot{q}_h = \frac{(T_h - T_a)}{R_f} \qquad (47)$$

Substituting ($\dot{q}_h$) from Eqn. (47) into Eqn. (37) we obtain

$$T_h[1+R_f\ [(K_{te}-\alpha_{te}\ I_{te})]-K_{te}\ R_f\ T_c=R_f\ \frac{I_{te}^2\ R_{te}}{2}+T_a \quad (48)$$

Eqns. (45) and (48) are quadratic equations which can be solved to give T_h and I_{te} given T_a, T_c and R_f.

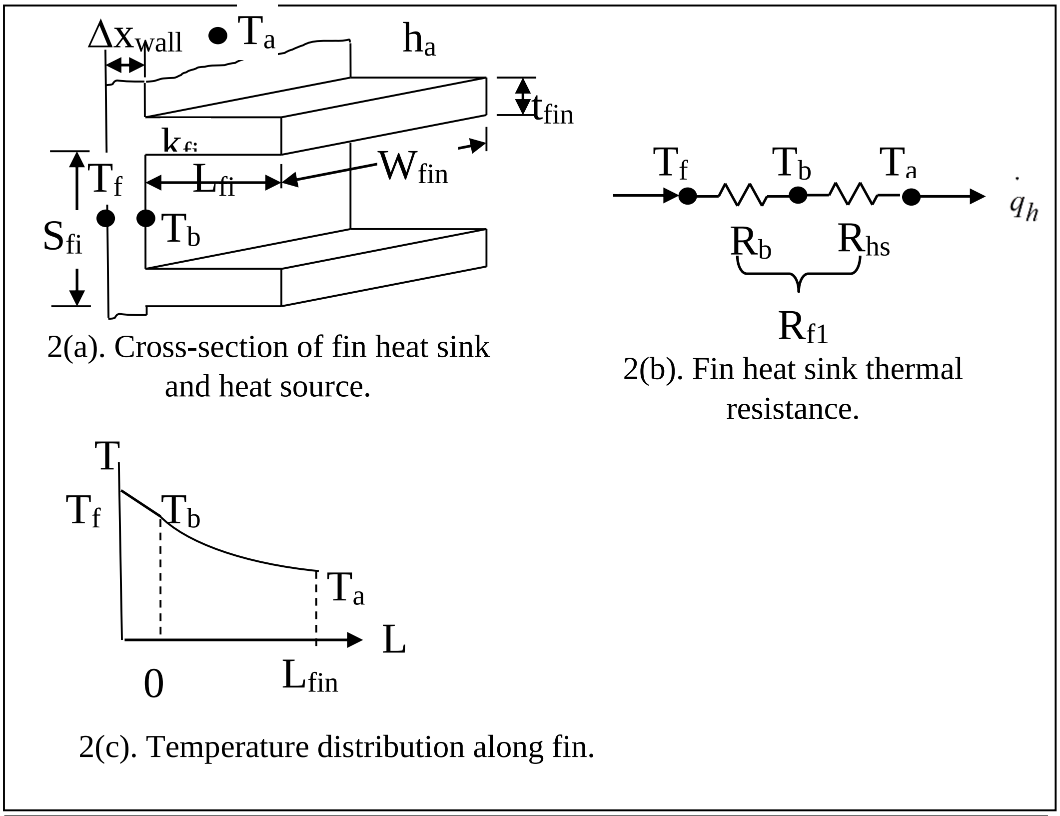
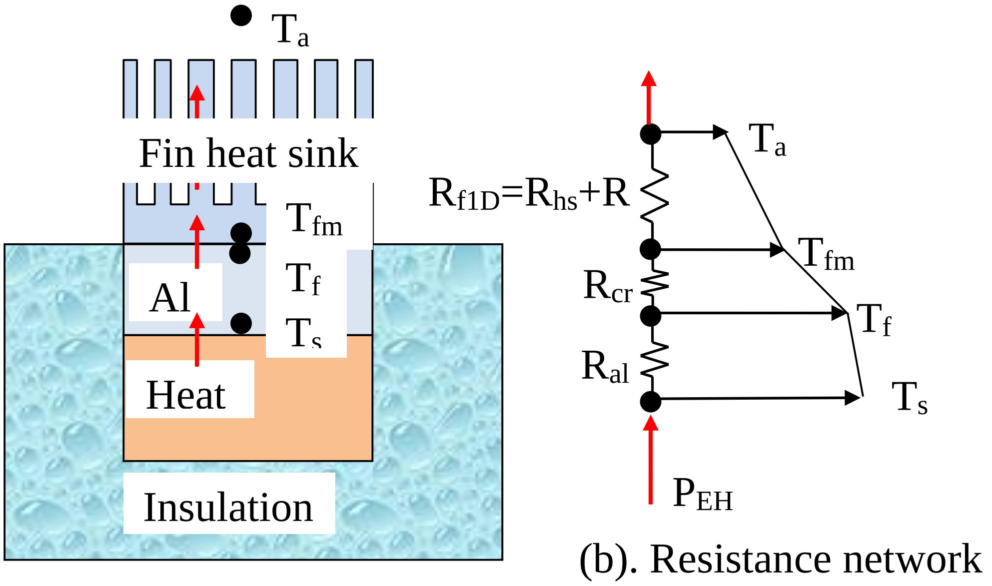
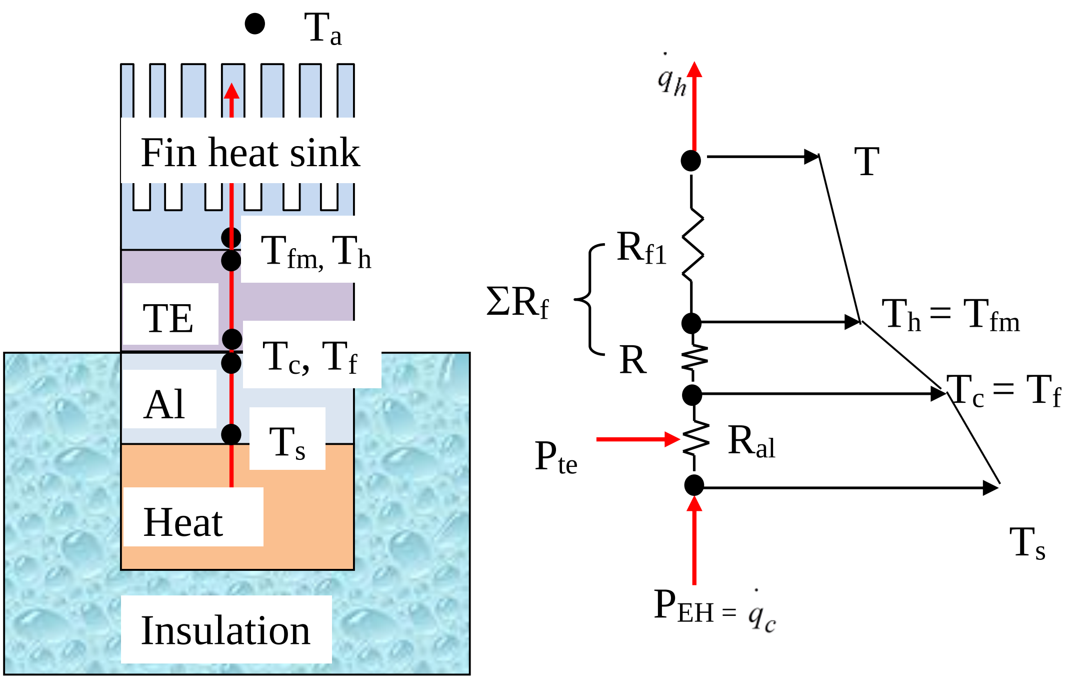


FIGURE 2 THERMAL RESISTANCE OF RECTANGULAR PROFILE FIN HEAT SINK



(a). Cross-section of fin heat sink. (b). Resistance network of fin heat sink.

FIGURE 3 THERMAL RESISTANCE NETWORK OF FIN HEAT SINK FOR 1-D HEAT FLOW



(a). Cross-section of fin heat sink with TE. (b). Resistance network of fin heat sink with TE.

FIGURE 4 THERMAL RESISTANCE NETWORK OF FIN HEAT SINK WITH TE FOR 1-D HEAT FLOW

CHAPTER 4

EXPERIMENTAL INVESTIGATION

4.1 Experimental apparatus

A photograph of the experimental apparatus is shown in Figure 5. The experimental apparatus consisted of a thermoelectric module, aluminum block, electric heating element, AC power supply, DC power supply, digital multimeter, data logger, thermocouple, insulation materials and aluminum fin heat sink.

4.1.1 TE module

The thermoelectric module used in this experiment is HT8, 12, F2, 4040 from Laird Technologies. This TE module is assembled with proprietary solder construction, Bismuth Telluride semiconductor material and thermally conductive Aluminium Oxide ceramics. Practical usages of the TE modules are on larger heat-pumping applications and high temperature power generation with maximum operating temperatures of 175^{o}C. This TE module has dimensions of 44 x 40 x 4 mm as shown in Figure 6.

4.1.2 Aluminium block

The aluminium block is used to measure the temperature of TE cold side (T_c) and temperature of heating element (T_s). There are two thermocouples which were located at the 1.5 mm deep grooves on the centre of the aluminium block surface which is in contact with the cold side of TE and surface of the heating element to obtain a temperature measurement. Location of the thermocouple on the block surface shown in Figure 7.

4.1.3 Electrical resistance heating element

An electric heating element with a maximum power rating of 50 W was employed to provide heat to the TE module. The amount of power supplied was adjusted according to temperature needed.

4.1.4 AC Power Supply

The AC power supply used has a maximum output voltage of 240V to supply power to electrical heating element to supply high temperature at the hot side of the thermoelectric module. The amount of power supplied can be adjusted.

4.1.5 DC Power Supply

MicroMate Adjustable DC Power Supply VPS15-40 was used to supply power to TE module. This power supply has a maximum potential difference of 15V and maximum amperage of 40A.

4.1.6 Multimeters

Multimeters were used to measure the voltage of the AC power supply, alternating current flowing into the electrical heating element, the direct current produced by the TE module, the voltage of the DC power supply and direct current flowing into the TE module.

4.1.7 Data Logger

Data Logger GRAPHTEC GL820 with total of 20 channels are used where 8 channels are used to measure temperatures at respective position as shown in Figure 10 and 2 channel is used for voltage measurement.

4.1.8 Thermocouple wires

Type T thermocouples were used in this experiment. The wires are made up of copper and constantan with tolerance of $\pm 0.5^{o}$C.

4.1.9 Insulation material

Insulation materials include gasket paper, cock board, rock wool and box were used in this experiment to minimise heat loss to the ambient. The insulation consisted of a composite layer of 10 mm thick cork board and 95 mm thick rock wool.

4.1.10 Aluminium fin heat sink

A heat sink is a thermal heat transfer device that used to distribute heat from a high temperature heat source to ambient. The heat sink has dimensions of 45 x 45 mm with a 10 mm thick base.

4.2 Experimental Procedure

4.2.1 The effects of the heat sink

Figure 8 shows the experimental set up to determine the effectiveness of the heat sink used. An electric heating element and heat sink was employed as to simulate heat generation and dissipation. The heat sink was placed on top of heating element and the entire set up was fixed down with a G-clamp. Thermal insulation materials like cork boards and rock wools were wrapped around the heating element to ensure heat flow in one dimension, towards the heat sink, and prevent large heat loss towards its surrounding. The thickness of thermal insulation was approximately 100mm. An Alternating Current (AC) power supply was used to power up the heating element and measured with an AC voltmeter and ammeter to obtain an actual reading of the power supplied. There were in total four runs in this experiment, all runs were performed with the heat sink under natural convection. The power inputs to the heating element used for every run was 10W, 15W and 20W. The results from Run A1 to A4 are shown in Table 1 and plotted in Figure 11. T_{f1}, T_{f2}, T_{f3}, and T_{f4} are the temperature readings at the base of the fin of the heat sink which is the heat produced from the heating element with T_f as the average temperature reading. Thermocouples inserted at the grooves of fin heat sink to measure the surface temperature on hot side of the heating element. Insulation temperature (T_{ins}) and ambient temperature (T_a) were measured by another two thermocouples located at the end of thermal insulation and surrounding of the insulation. All thermocouple probes were connected and logged by data logger. Locations of thermocouple are shown in Figure 8.

4.2.2Characterisation of the TE module

Figure 9 shows the experimental setup for the characterisation of TE module and TE power generator (TEG) mode. A TE module and aluminium block were added in between the heat sink and heating element in the experimental setup. The aluminium block located between the TE module and heating element. TE module (HT8.12.F2.4040) from Laird Technologies were used. The data logger records two set of potential readings, which are V_{ref} and V_L. V_{ref} was used to determine the current produce by the TE as it flows through a resistor. V_L determines the voltage potential produce by the TE. The no load voltage (V_{NL}) was recorded before any load resistance was applied to the circuit. A total six of 1Ω resistors were added as load, R_L in run B1, B2 and B3 while nine of 1Ω resistors were used in Run B4 to B9. The first resistor was meant as a reference resistor (R_{ref}) and the voltage (V_{ref}) was recorded for indicate current flow (I_L) at the TE module by calculation. The experiment was run under natural convection with 5W, 7.5W and 10W power input to the heating element. A voltmeter was connected to the thermoelectric module for measuring voltage generated when it perform as power generation mode (TEG). Results of the Seebeck coefficient and thermal conductance against mean temperature are shown in Figure 12.

4.2.3 Performance of the TE module for power generation

The experiment of TEG was similar with the experiment 4.2.2 Characterisation of the TE module. P_{EH} were adjusted to 3 different values which were 5W, 7.5W and 10W. The changeable resistor values were set to nine different values which were start from 1Ω with the increment of one resistor each time until 9Ω for run B4 to B9. While six of 1Ω resistors were used in Run B1, B2 and B3 with increment of 1Ω. The first resistor was procedure as reference resistor, R_{ref} and the voltage, V_{ref} was recorded for indicate current flow, I_L at the thermoelectric module by calculation using Ohm's Law. A voltmeter was connected to the thermoelectric module for measuring voltage generated when it perform as power generation mode (TEG). The power generated by TE module HT8 are shown in Figure 14, Figure 15, Figure 16 and Figure 17.

4.2.4 Performance of the TE module for cooling

The experimental apparatus set up is similar to the set up shown in Figure 9 but differs slightly as the TE receives power input from a DC power supply so that the TE could be used as TEC mode. Three runs will performed with the same power input (10W) to the electrical heating element and there were three different voltage input to the TEC, which were 4V, 6 V and 8V in Run B1, B2 and B3 while 2V, 4V and 6V in Run B4 to B9. The current input readings were taken to determine the power input to the TEC. The voltage input and temperature readings are recorded by the data logger.

4.3 Experimental Results

All the graphs were plotted in this section based on the results obtained from the experiment. The main results obtained from the experiment including Seebeck coefficient of TE (α_{te}), thermal conductivity of TE (k_{te}), electrical resistance of TE (R_{te}), power generated by TE(P_L) and coefficient of performance (COP_c).

Figure 11 plotted the graphs that show the amount of time taken for the electrical heating element to reach steady state. Total 4 experimental runs were conducted which are Run A1, Run A2, Run A3 and Run A4 represents the steady state time required when electrical heating element powers (P_{EH}) were 10W, 15W and 20W respectively. The data collected at steady state will be used to calculate the required result.

Figure 12 reviewed the graphs that show Seebeck coefficient of TE (α_{te}) and thermal conductance of TE (K_{te}) of HT8#1, HT8#2 and HT8#3 against the mean temperature of TE (T_m).

Figure 13 presents the graphs that shows internal resistance, R_{te} against mean temperature of TE (T_m) when load resistance (R_L) were 1.08Ω, 2.16Ω, 3.24Ω, 4.32Ω, 5.40Ω, 6.48Ω, 7.48Ω, 8.64Ω and 9.72Ω.

Figure 14 to 17 presents the graphs that shows power generated (P_L) against load resistance (R_L) of HT8#1, HT8#2 and HT8#3. Seven resistors were used for all three power input which 5W, 7.5W and 10W in Run B1, B2 and B3.A total of nine resistors were used in Run B4 to Run B9 for all three power input (5W, 7.5W and 10W).

Figure 18 to 26 plotted the graphs that show the change in temperature and voltage against time for Run B1 to B9 in 5W, 7.5W and 10W power input respectively. Seven resistors were used for all three power input which 5W, 7.5W and 10W in Run B1, B2 and B3.Total of nine resistors were used in Run B4 to Run B9 for all three power input (5W, 7.5W and 10W).

Figure 27 to Figure 35 represents the changes in temperature of different parts of the TEC for Run C1 to C9 in 5W, 7.5W and 10W power input respectively. Three voltage inputs were used for all three power input, which were 4V, 6V and 8V in Run C1, C2 and C3 while 2V, 4V and 6V in Run C4 to Run C9.

Figure 36 to Figure 44 plots the changes in temperature of different probes of the TEC for Run C1 to C9 in 5W, 7.5W and 10W power input respectively. Three voltage inputs were used for all three power input, which were 4V, 6V and 8V in Run C1, C2 and C3 while 2V, 4V and 6V in Run C4 to Run C9.

Figure 45, 46 and 47 shows the power supplied to TE (P_{te}) and coefficient of performance (COP_C) against the current (A). The coefficient of performance shows the capability of the cooler in pumping heat.

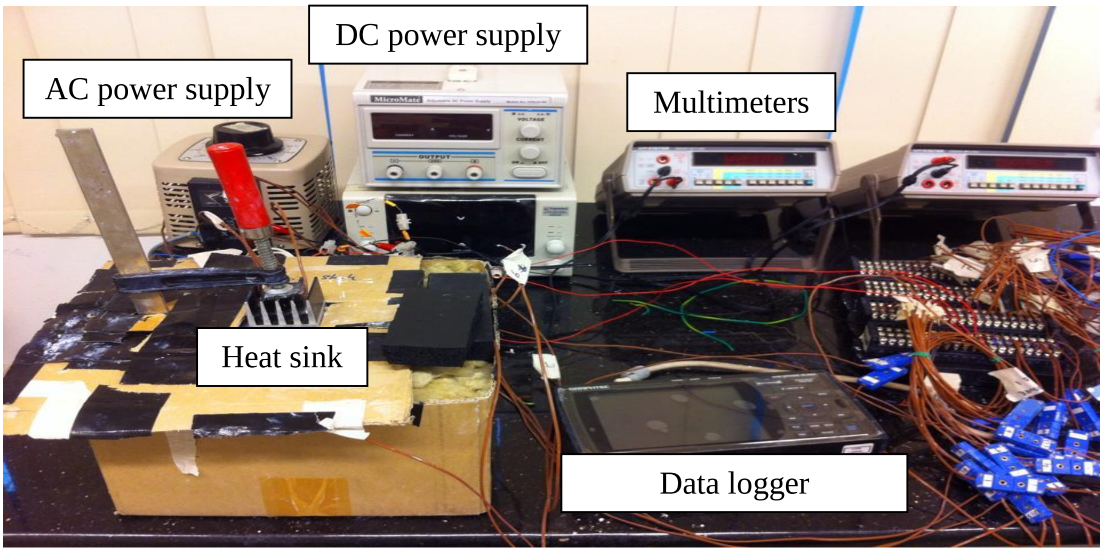


FIGURE 5 EXPERIMENTAL APPARATUS

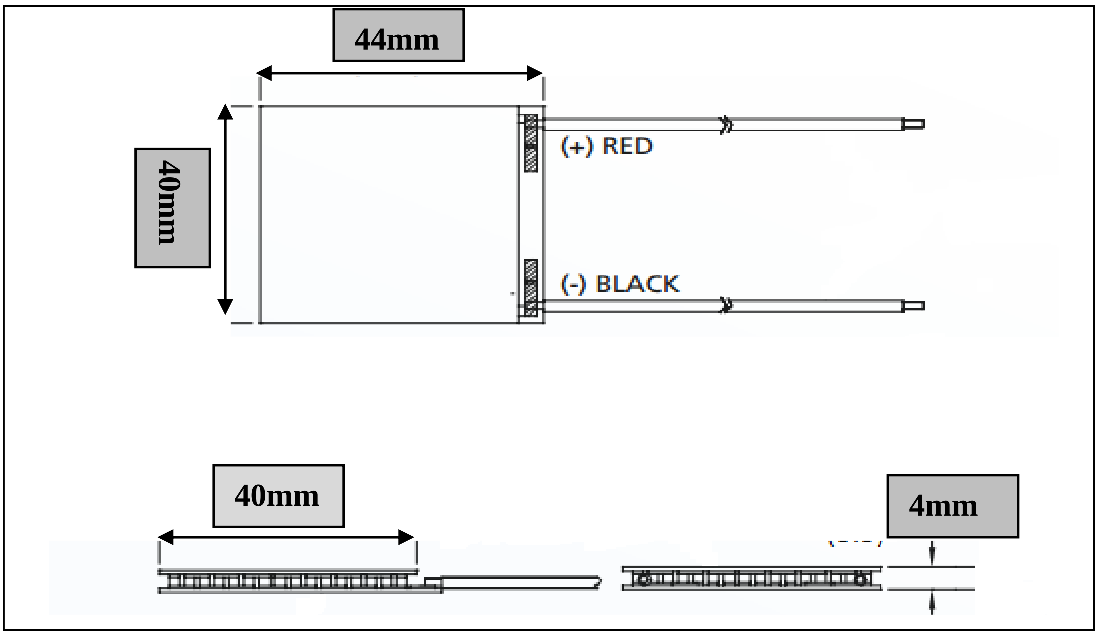


FIGURE 6 DIMENSIONS OF LAIRD TE HT8, 12, F2, 4040 MODULE

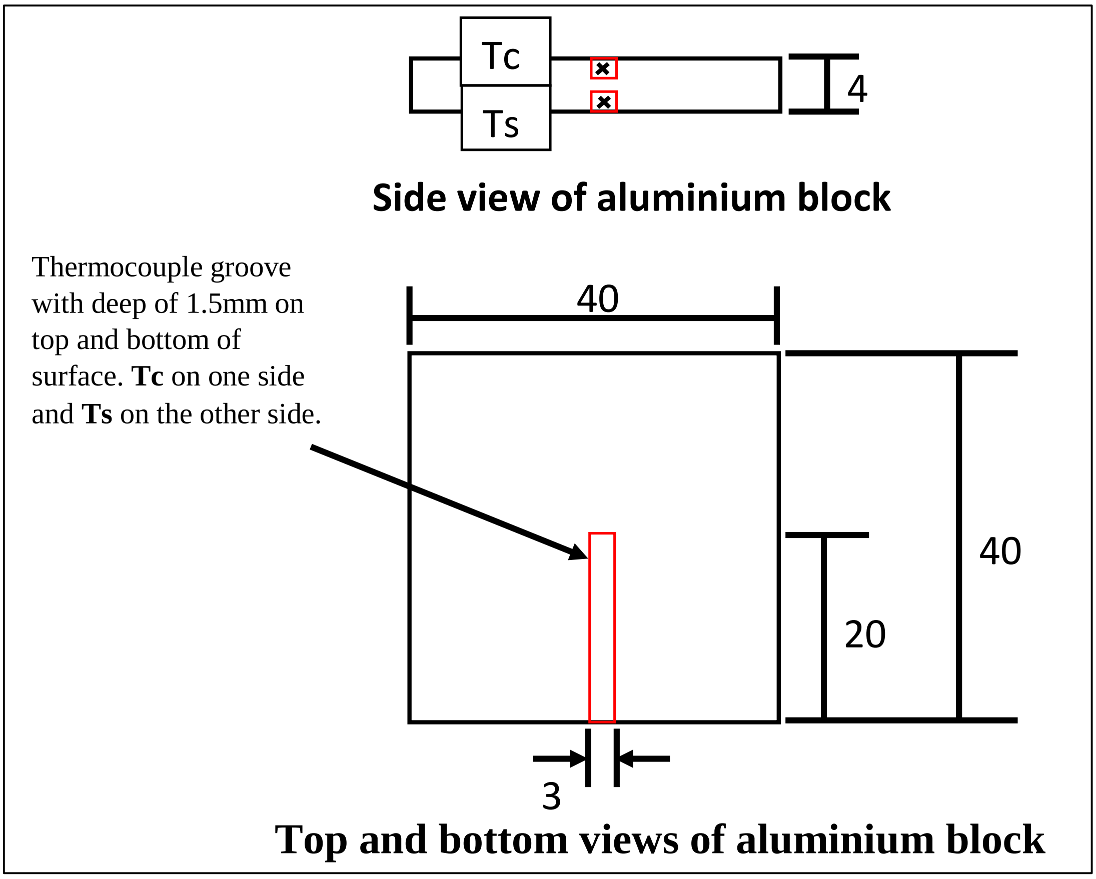


FIGURE 7 LOCATIONS OF THERMOCOUPLE IN ALUMINIUM BLOCK

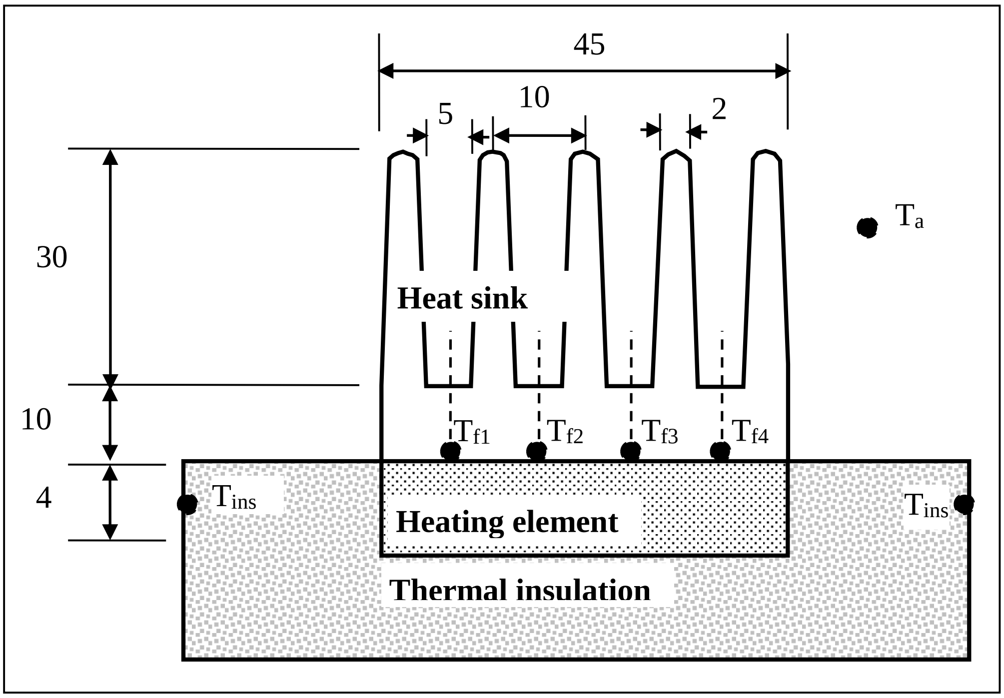


FIGURE 8 EXPERIMENTAL SET UP TO DETERMINE THERMAL RESISTANCE OF FIN HEAT SINK UNDER 1-D HEAT FLOW

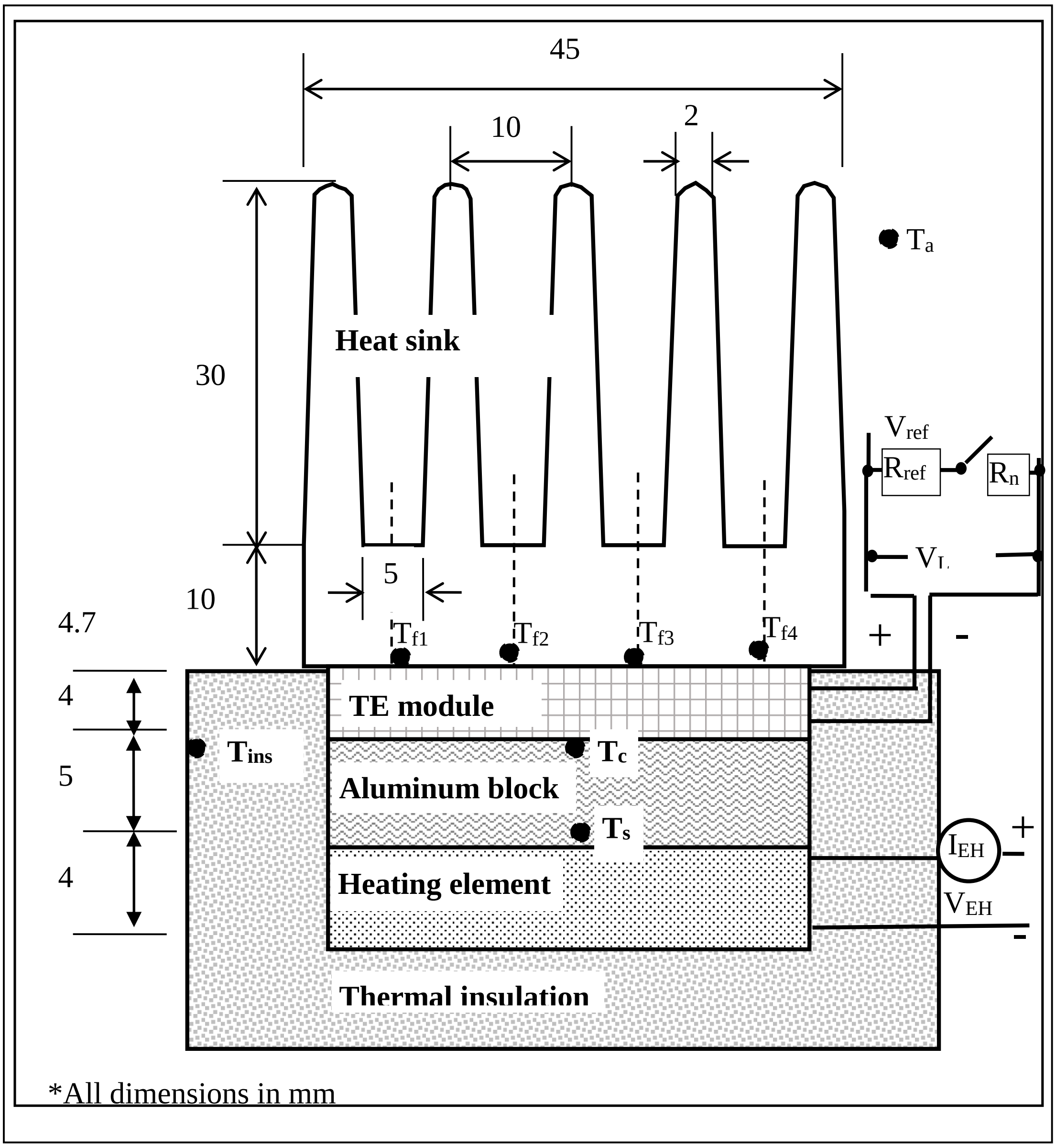
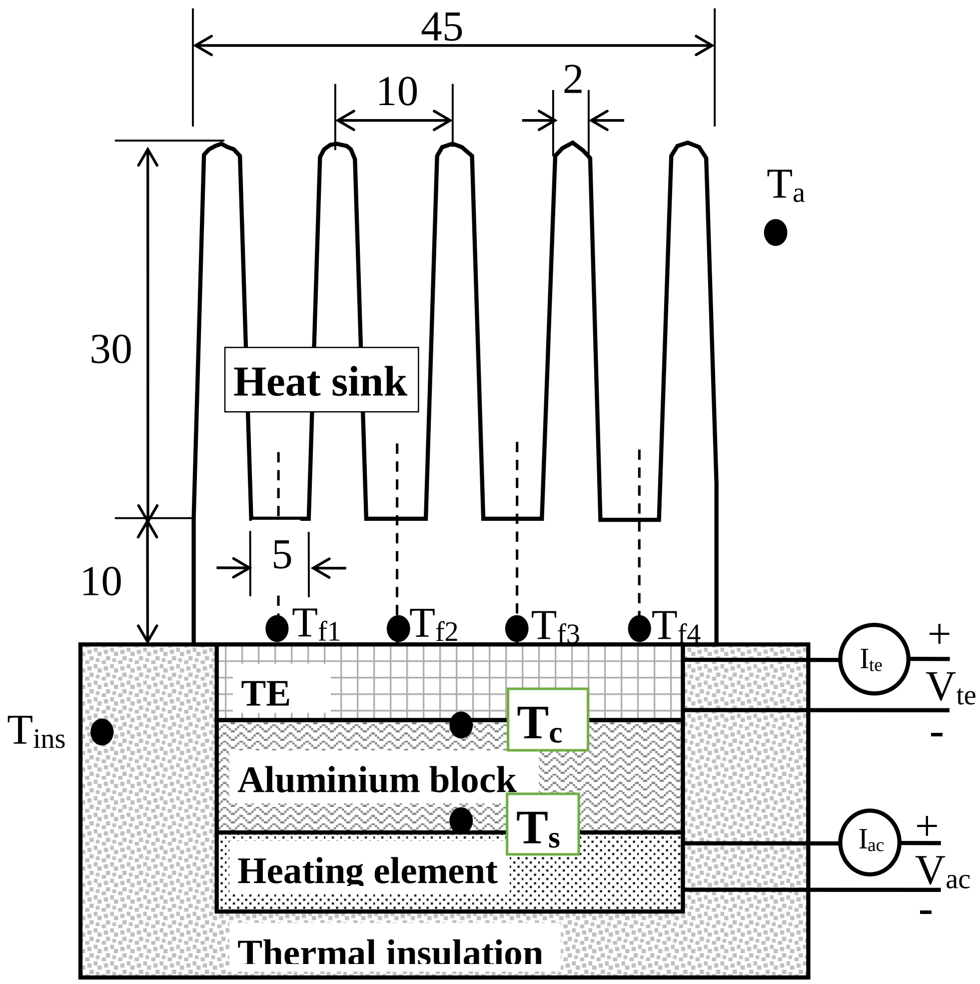
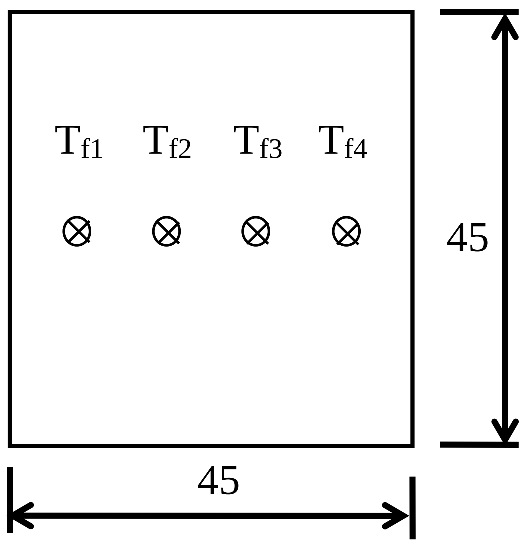


FIGURE 9 EXPERIMENTAL SET UP IN TEG MODE



(a) Experimental setup.



(b) Location of thermocouples at bottom of heat sink.

*All dimensions in mm

FIGURE 10 TEC EXPERIMENTAL SETUP AND LOCATION OF THERMOCOUPLES

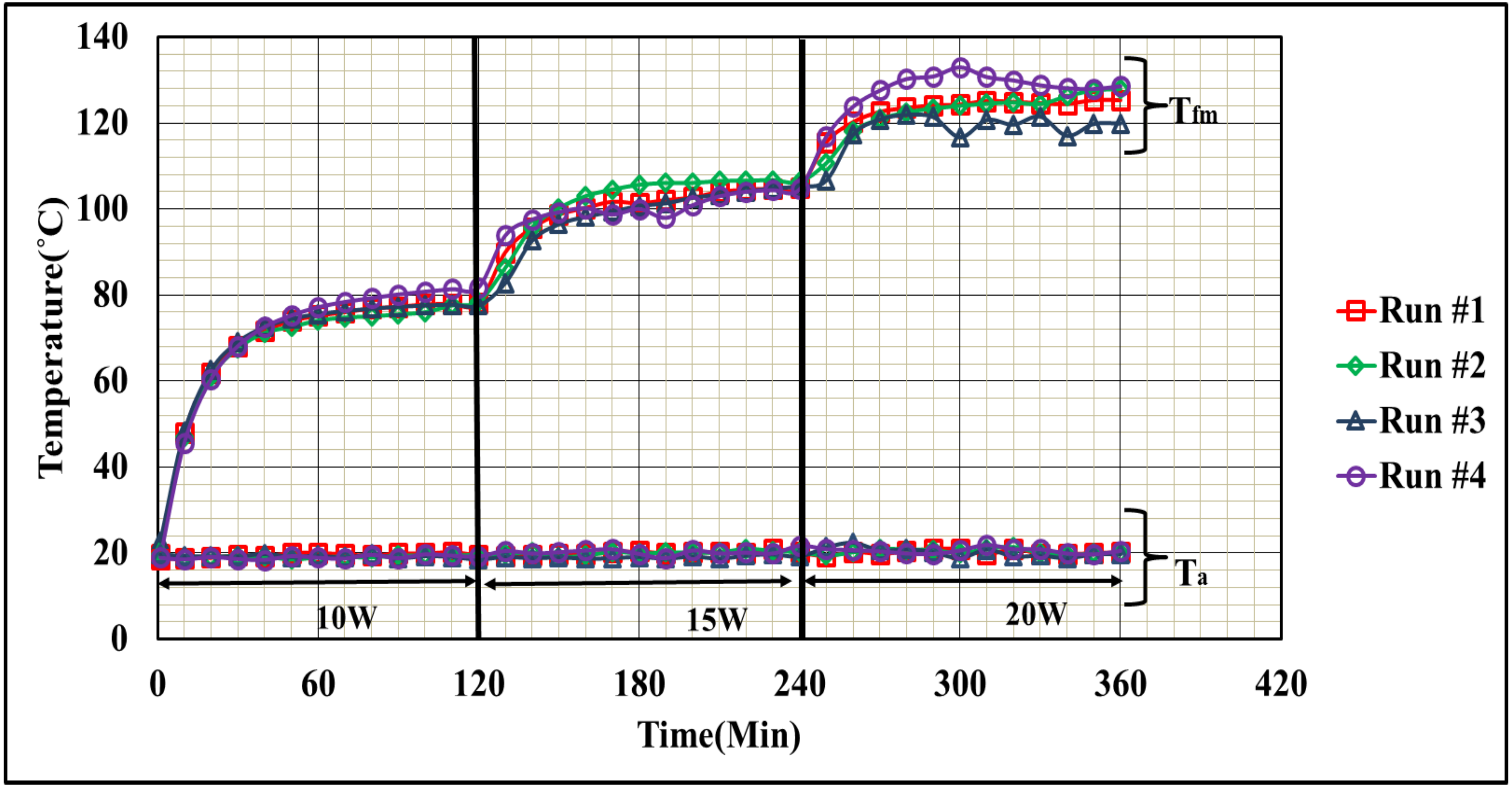


FIGURE 11 TRANSIENT TEMPERATURE RESULTS FOR RUN A1, A2, A3 AND A4

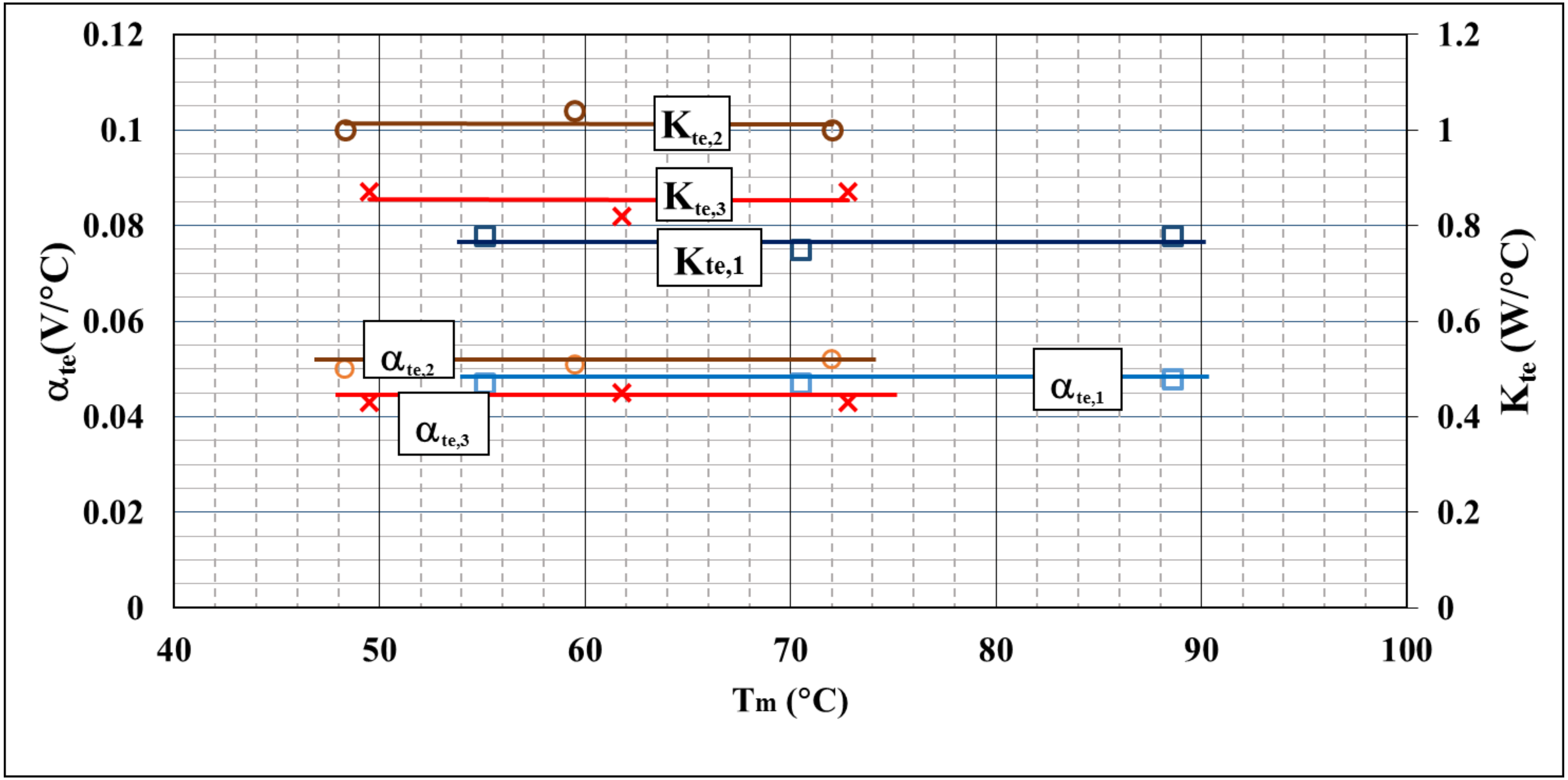


FIGURE 12 SEEBECK COEFFICIENT AND THERMAL CONDUCTANCE OF HT8#1, HT8#2 AND HT8#3

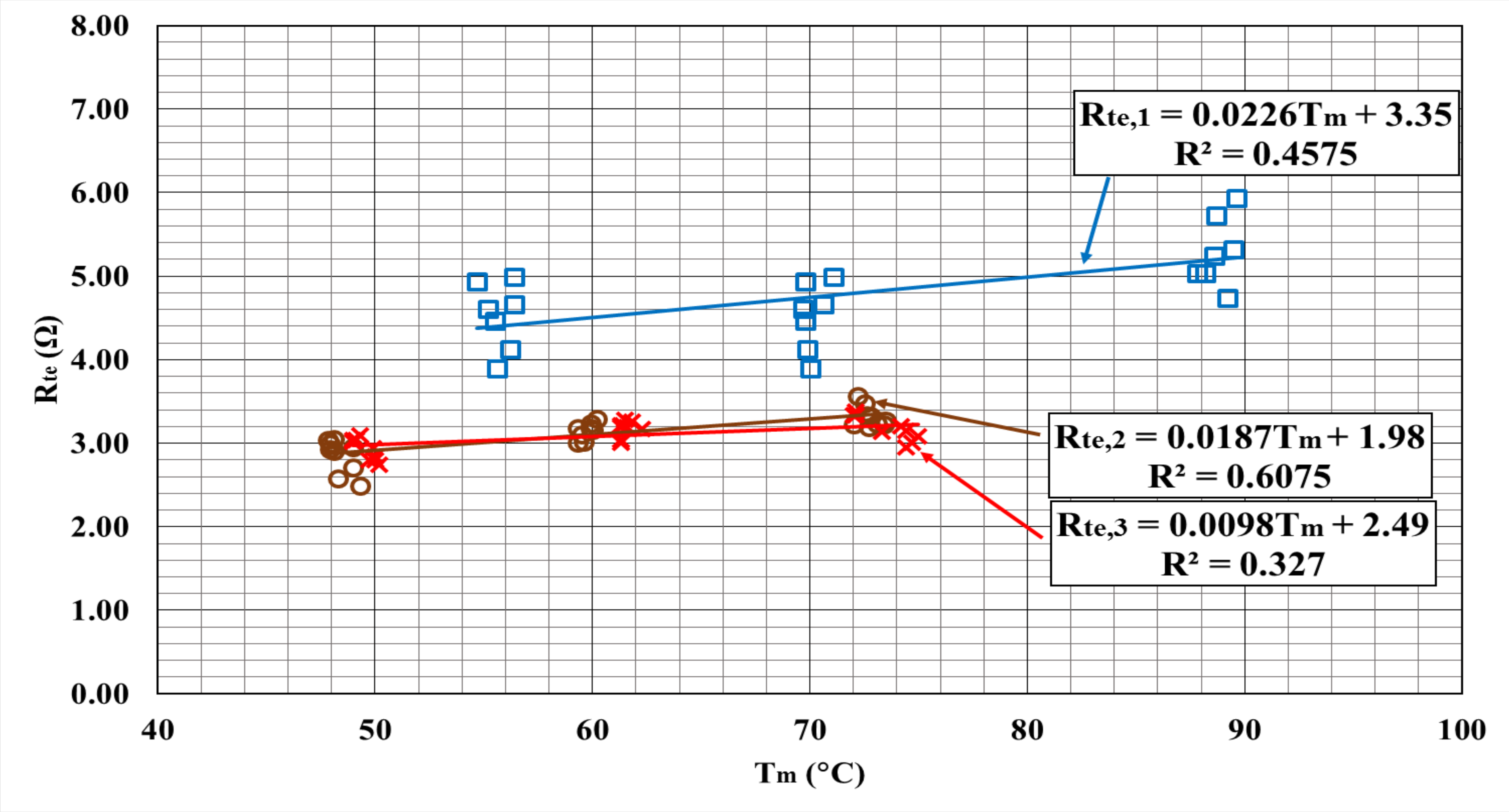


FIGURE 13 INTERNAL RESISTANCE OF HT8#1, HT8#2 AND HT8#3

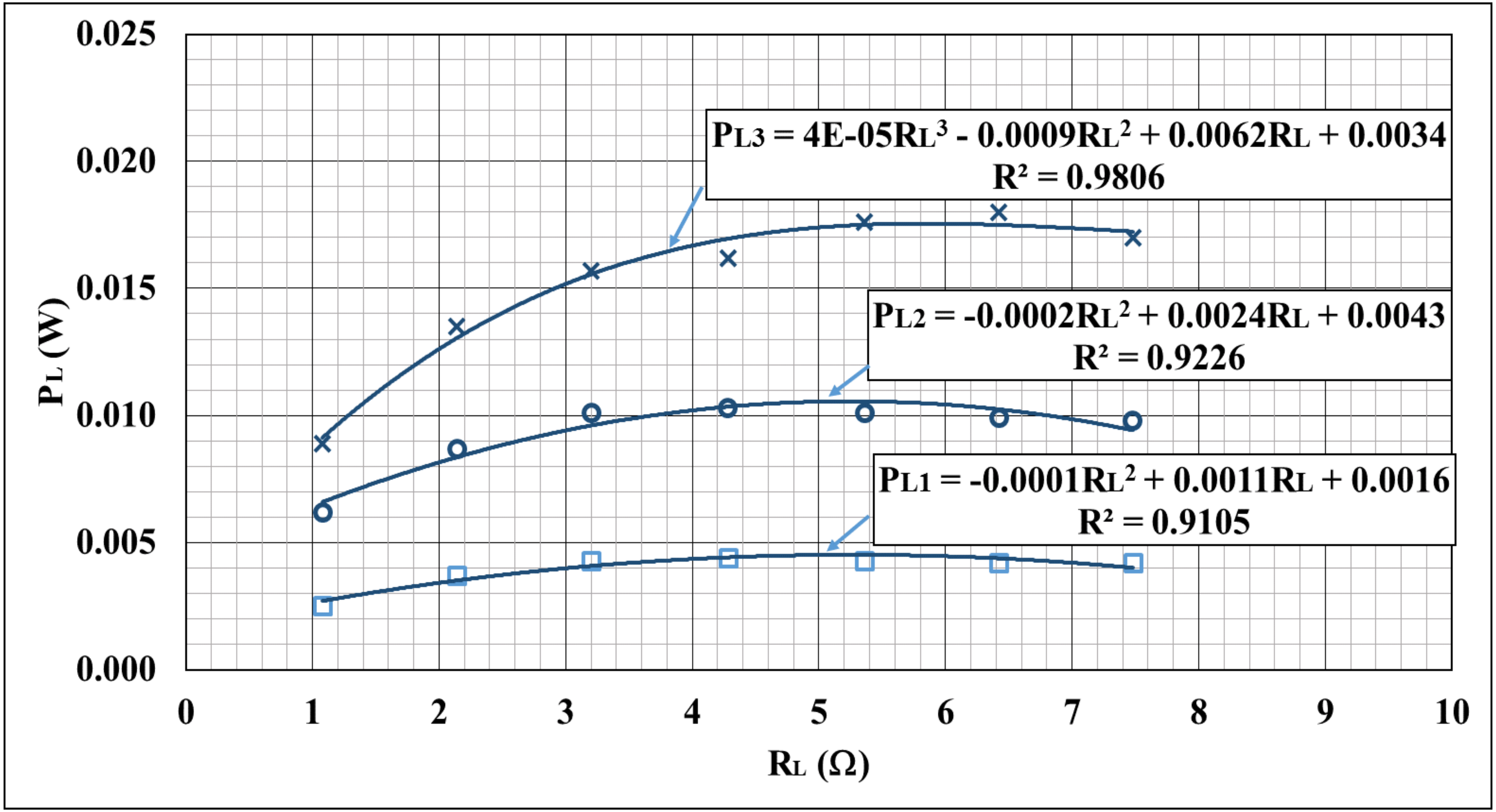


FIGURE 14 POWER GENERATED BY TE MODULE HT8#1 (RUN B1, B2 AND B3)

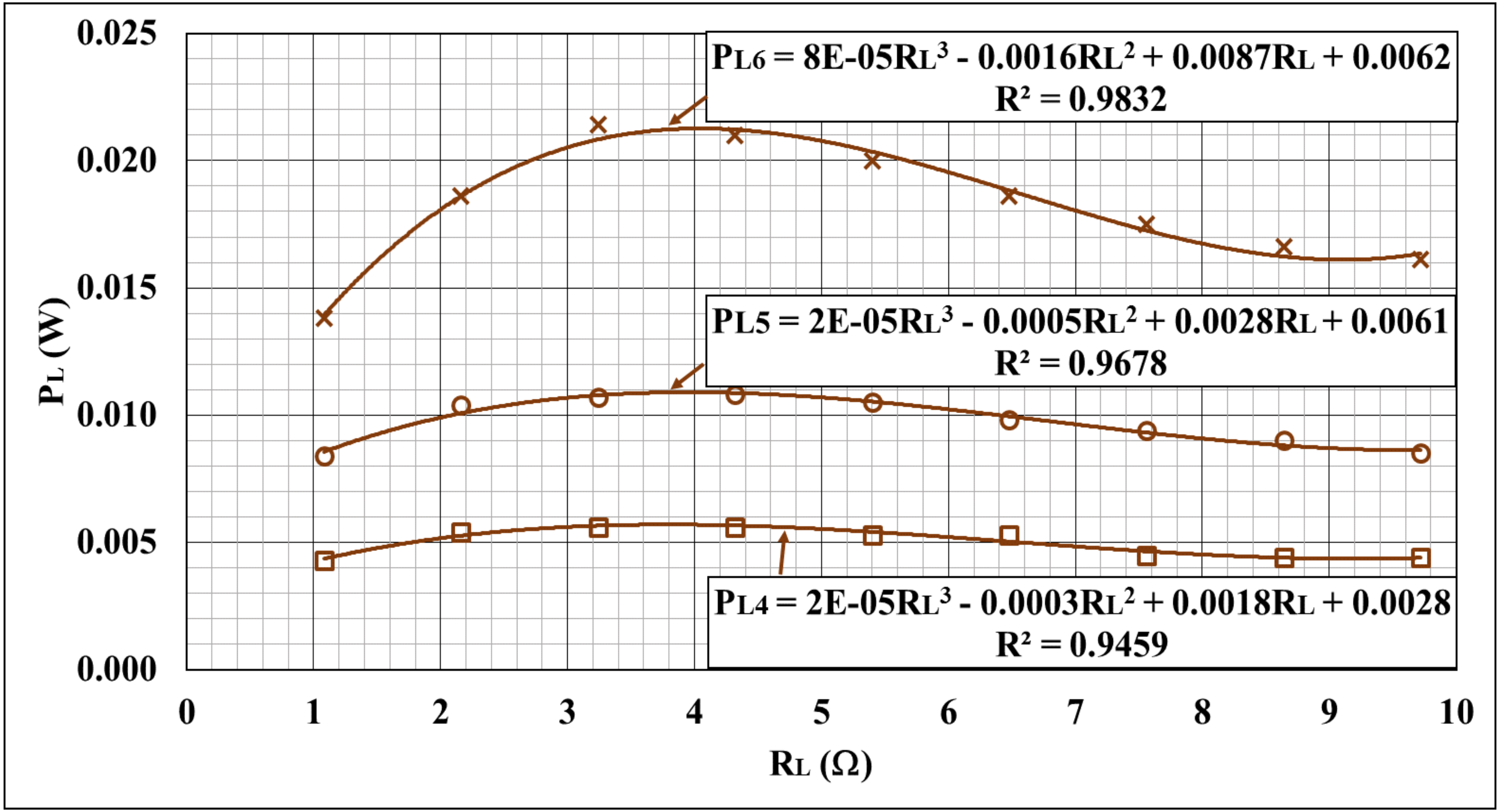


FIGURE 15 POWER GENERATED BY TE MODULE HT8#2 (RUN B4, B5 AND B6)

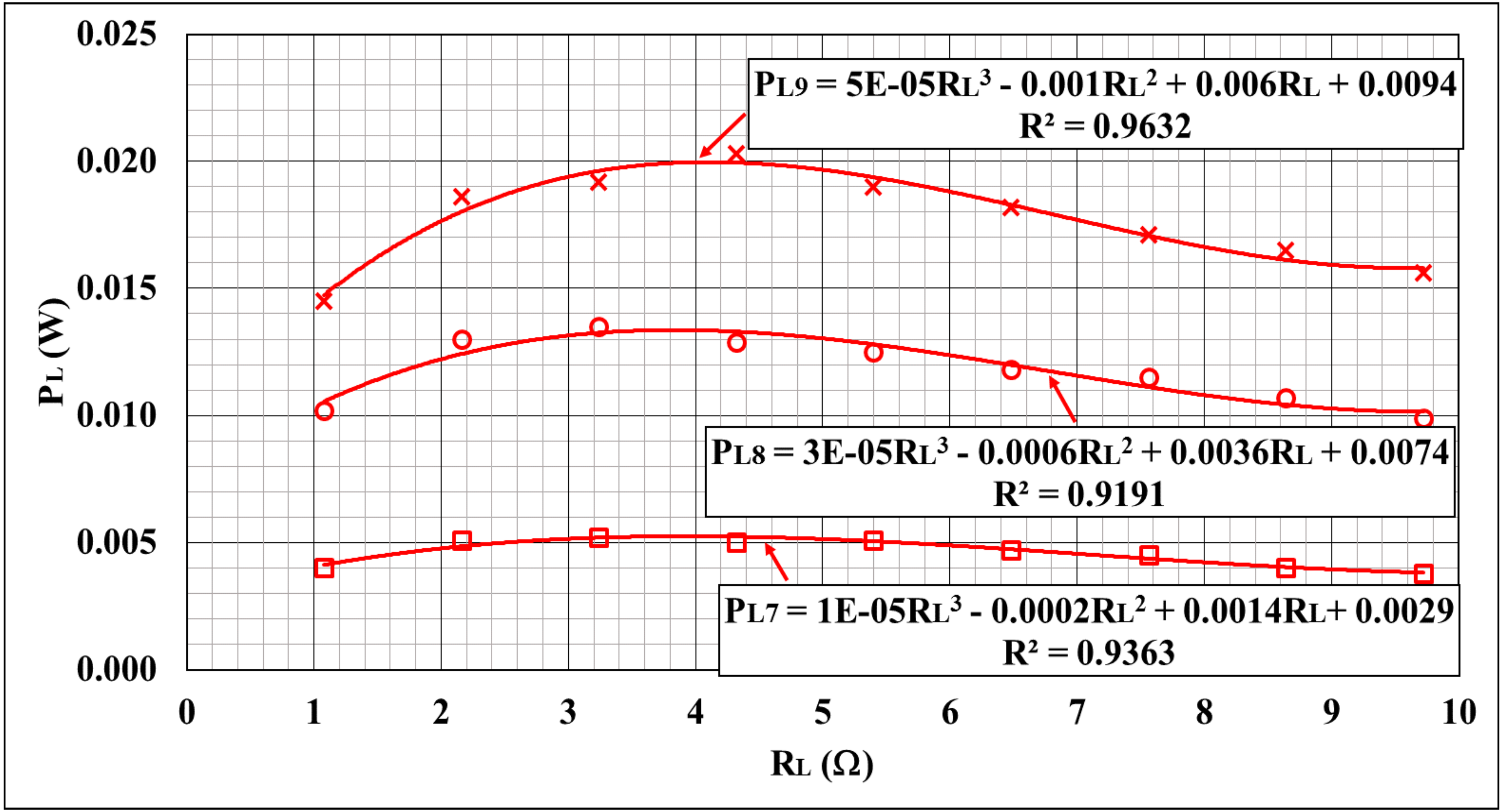


FIGURE 16 POWER GENERATED BY TE MODULE HT8#3 (RUN B7, B8 AND B9)

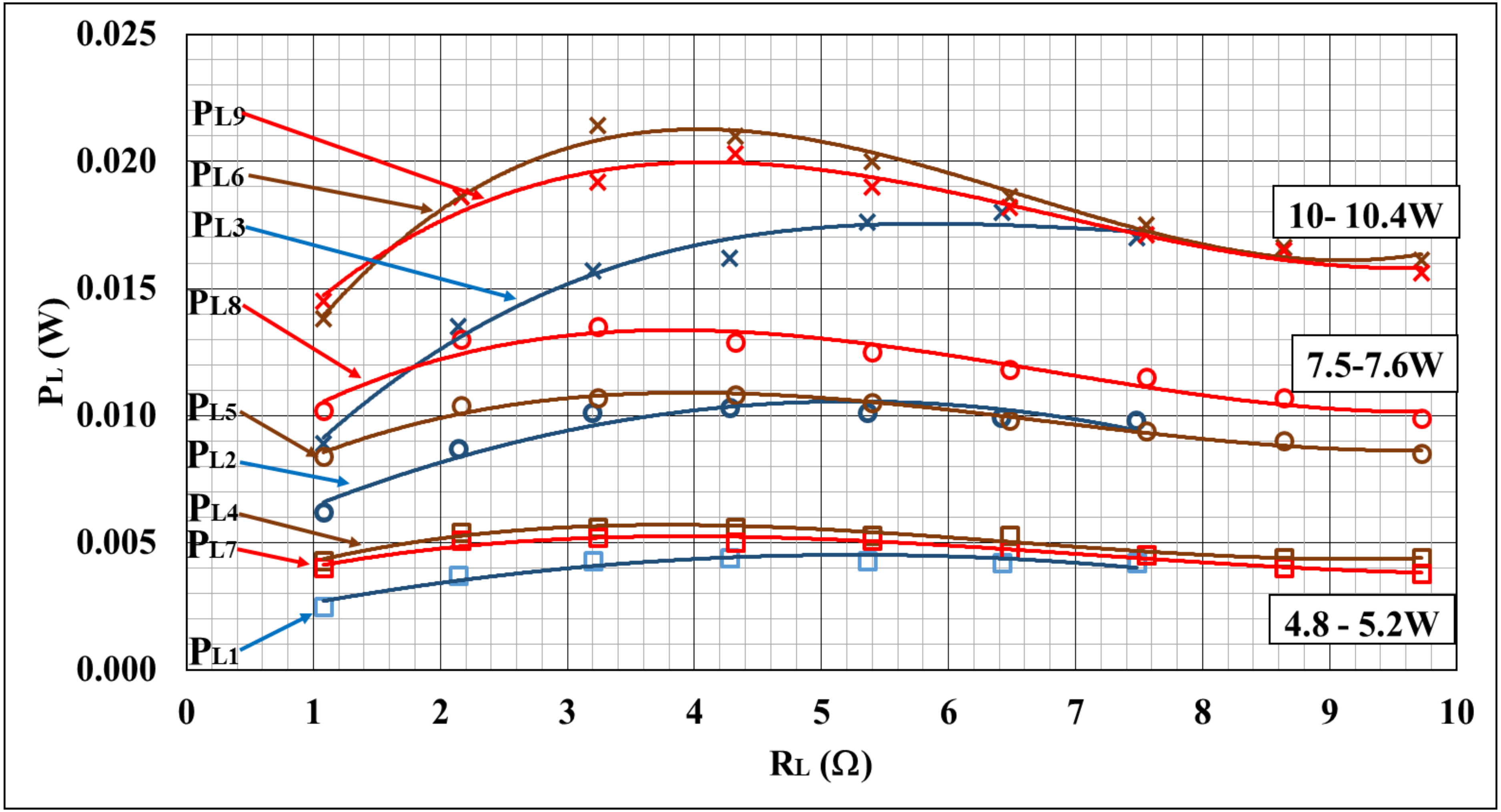


FIGURE 17 COMPARISON OF POWER GENERATED BY TE MODULE HT8#1, 2, 3

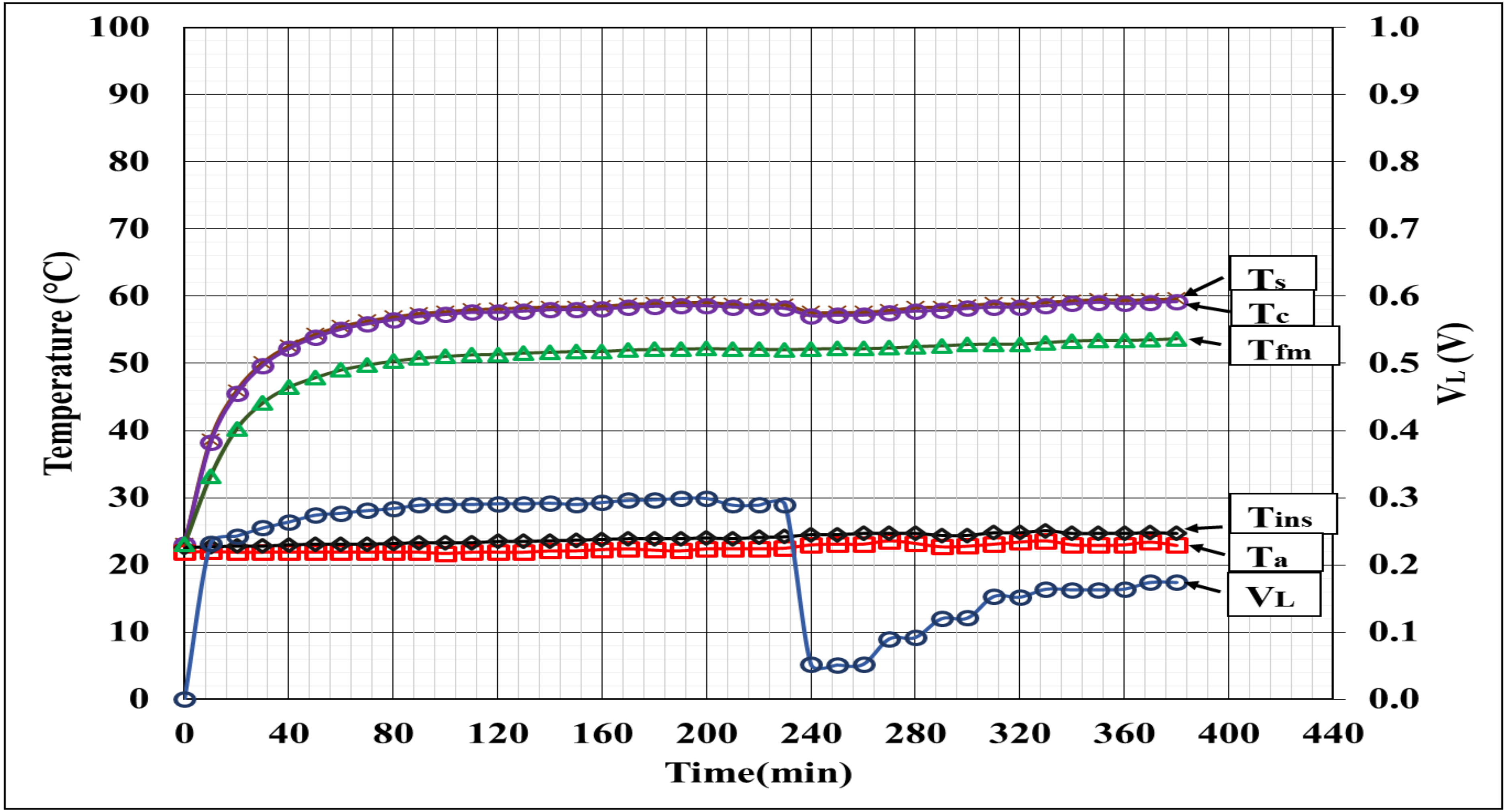


FIGURE 18 EXPERIMENTAL RESULTS OF HT8 MODULE#1 UNDER TEG MODE (4.8 W, RUN B1)

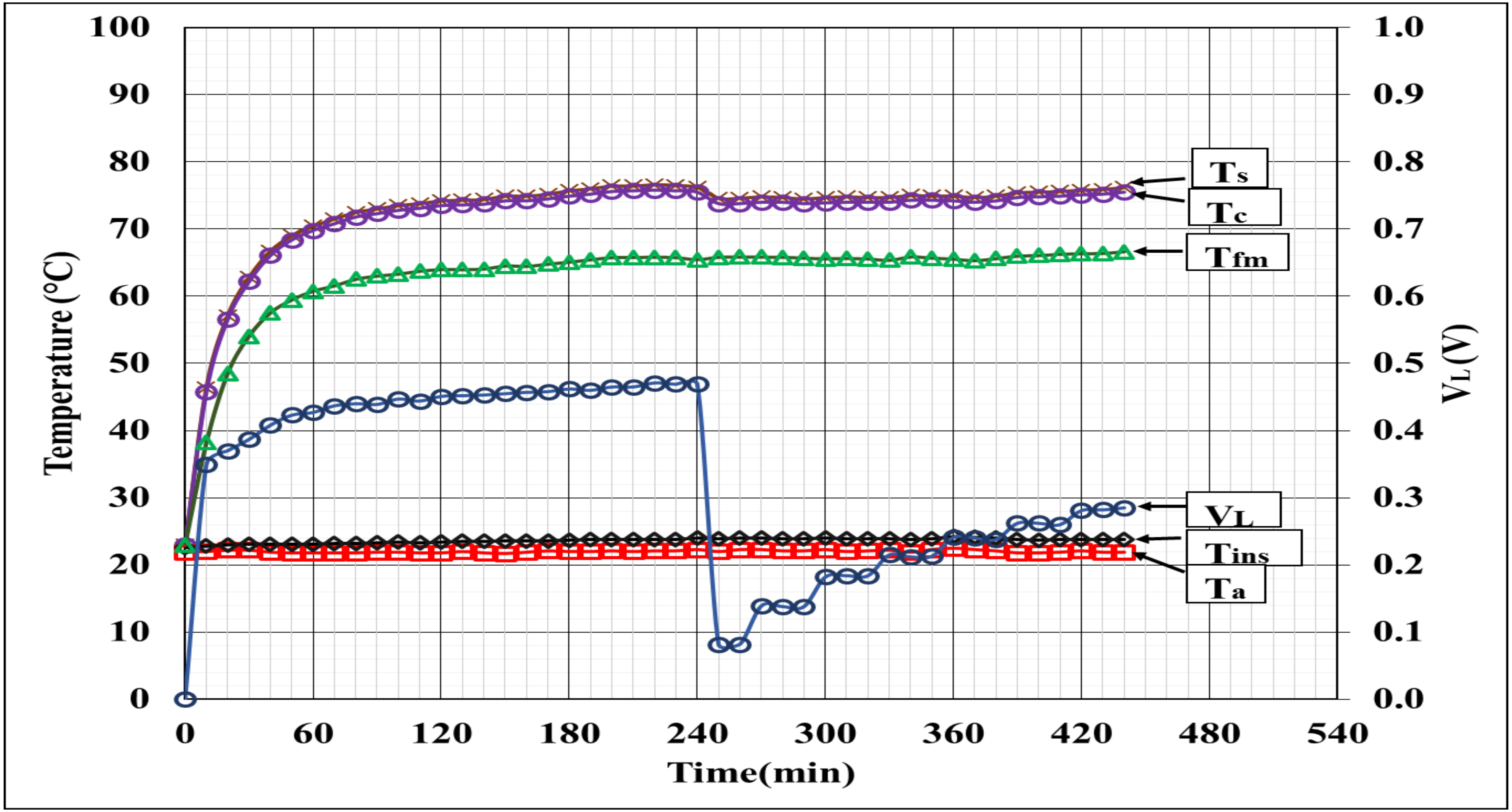


FIGURE 19 EXPERIMENTAL RESULTS OF HT8 MODULE#1 UNDER TEG MODE (7.6 W, RUN B2)

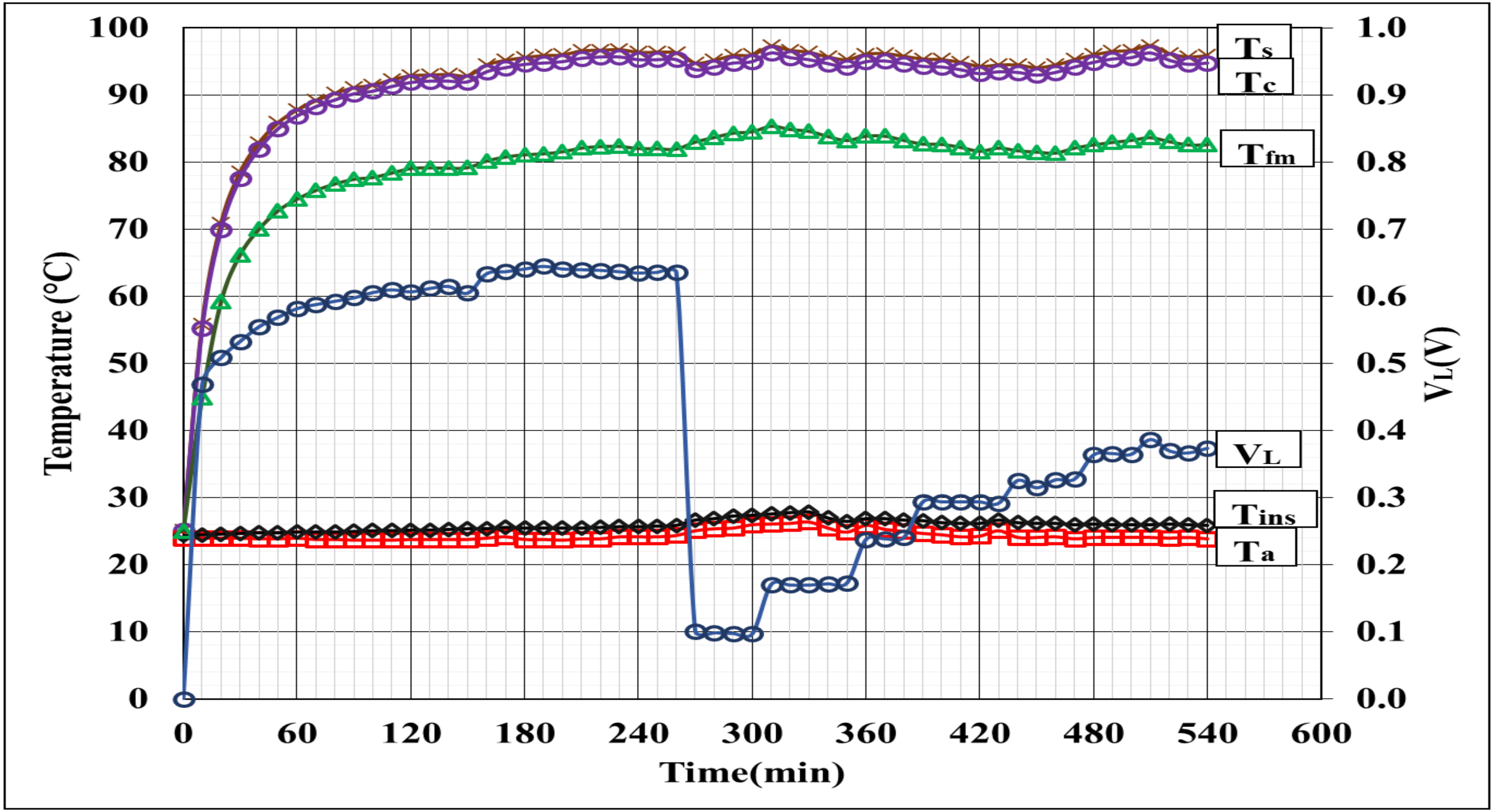


FIGURE 20 EXPERIMENTAL RESULTS OF HT8 MODULE#1 UNDER TEG MODE (10.4 W, RUN B3)

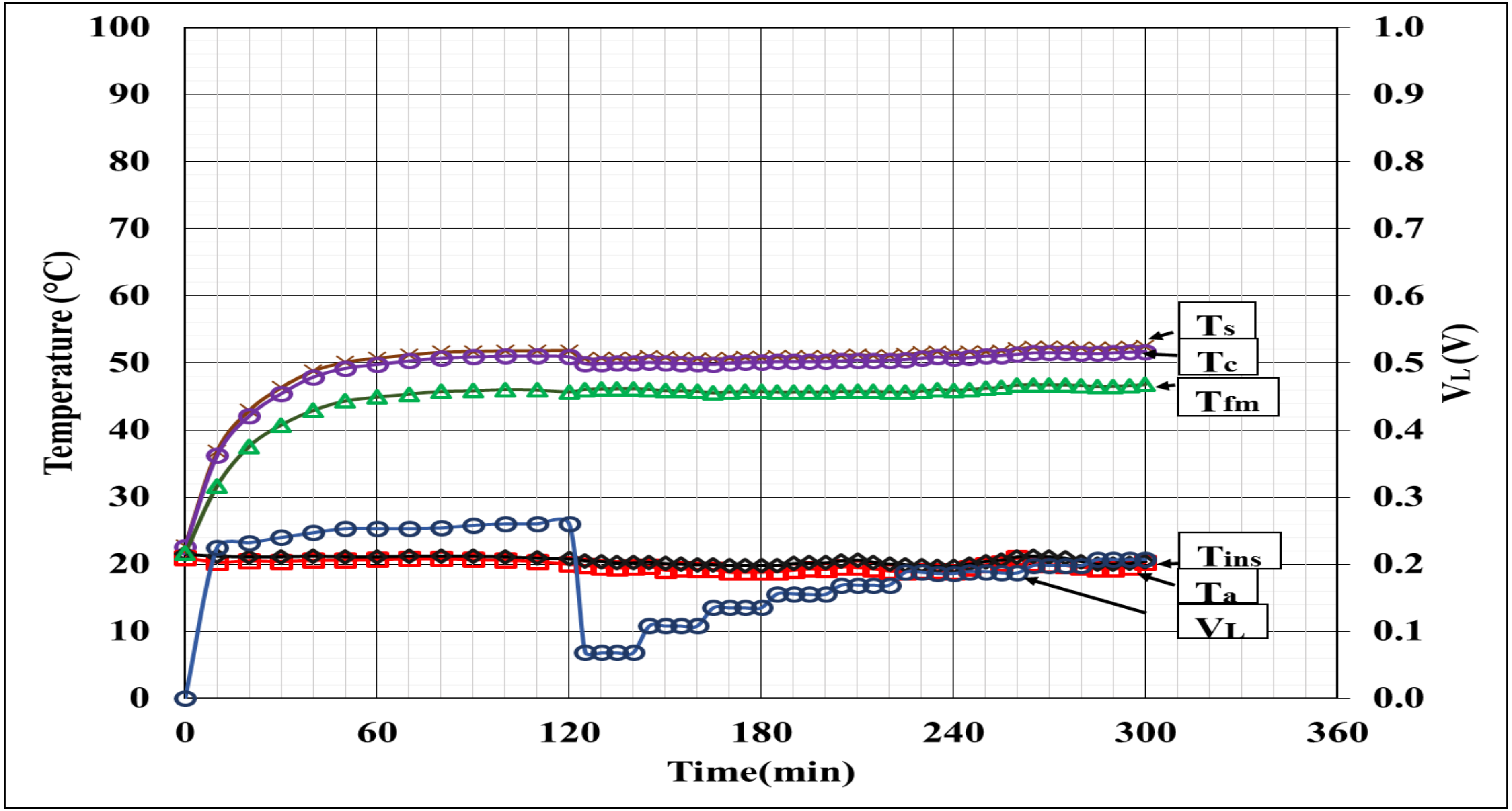


FIGURE 21 EXPERIMENTAL RESULTS OF HT8 MODULE#2 UNDER TEG MODE (5.2 W, RUN B4)

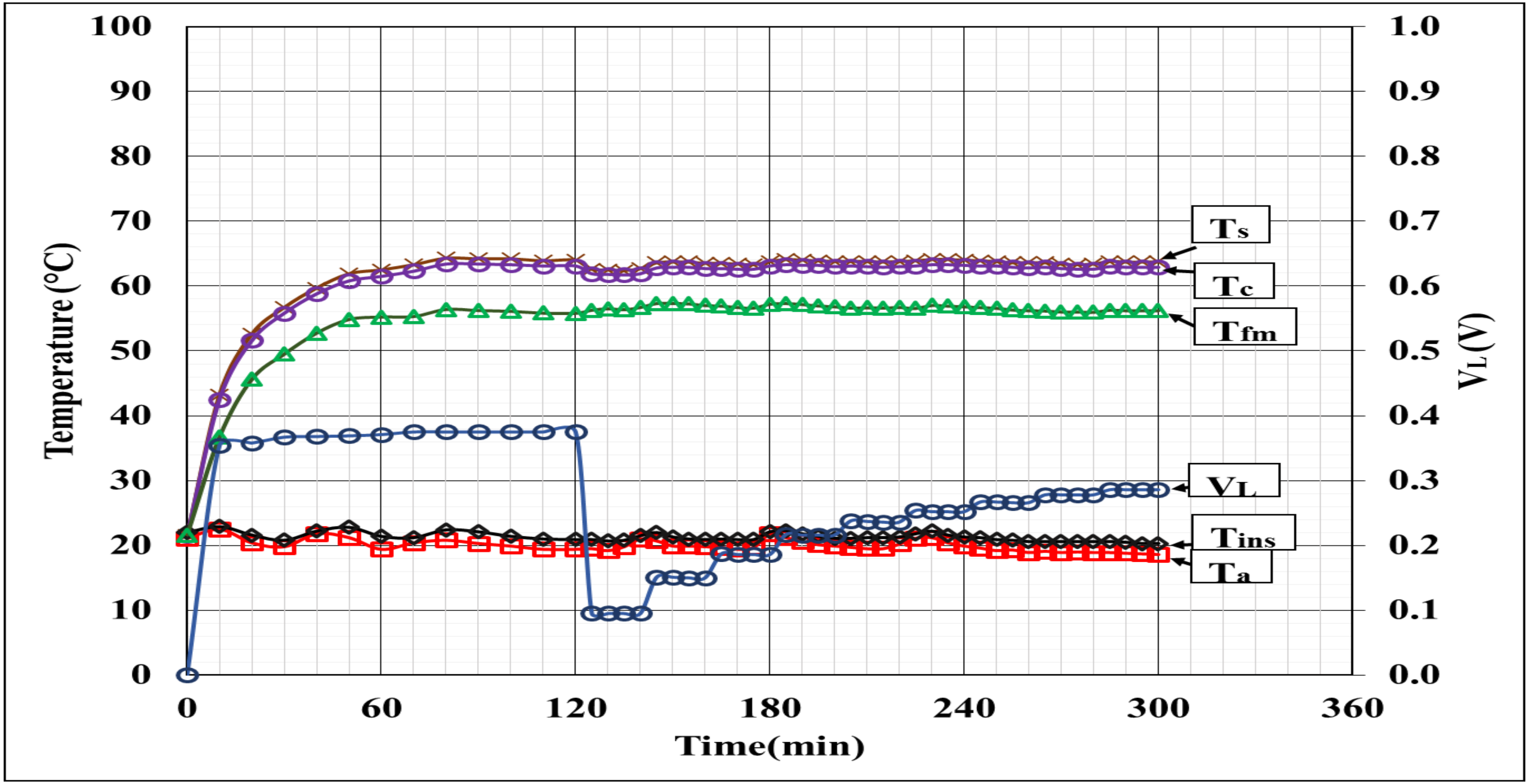


FIGURE 22 EXPERIMENTAL RESULTS OF HT8 MODULE#2 UNDER TEG MODE (7.6 W, RUN B5)

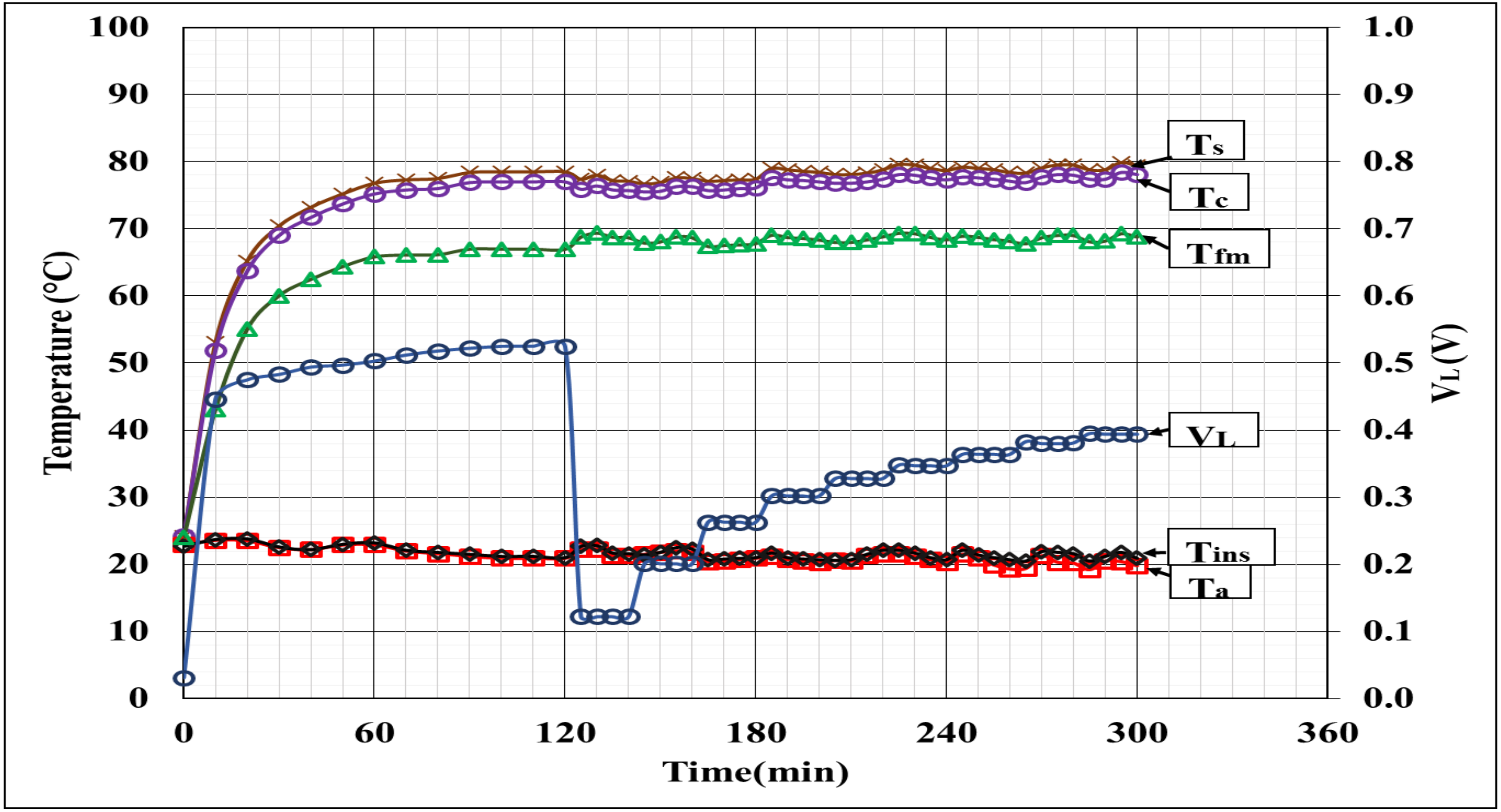


FIGURE 23 EXPERIMENTAL RESULTS OF HT8 MODULE#2 UNDER TEG MODE (10 W, RUN B6)

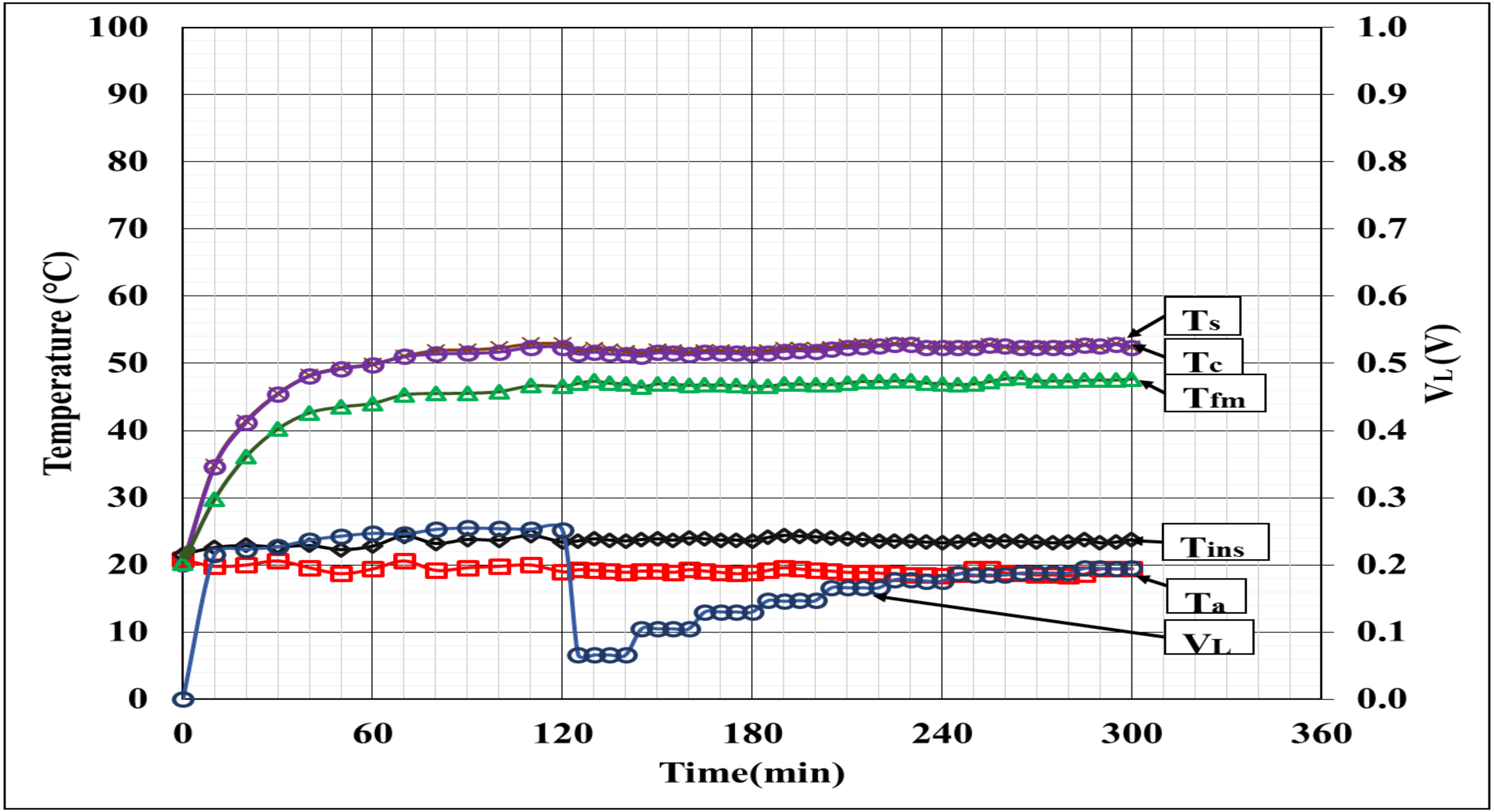


FIGURE 24 EXPERIMENTAL RESULTS OF HT8 MODULE#3 UNDER TEG MODE (5.1 W, RUN B7)

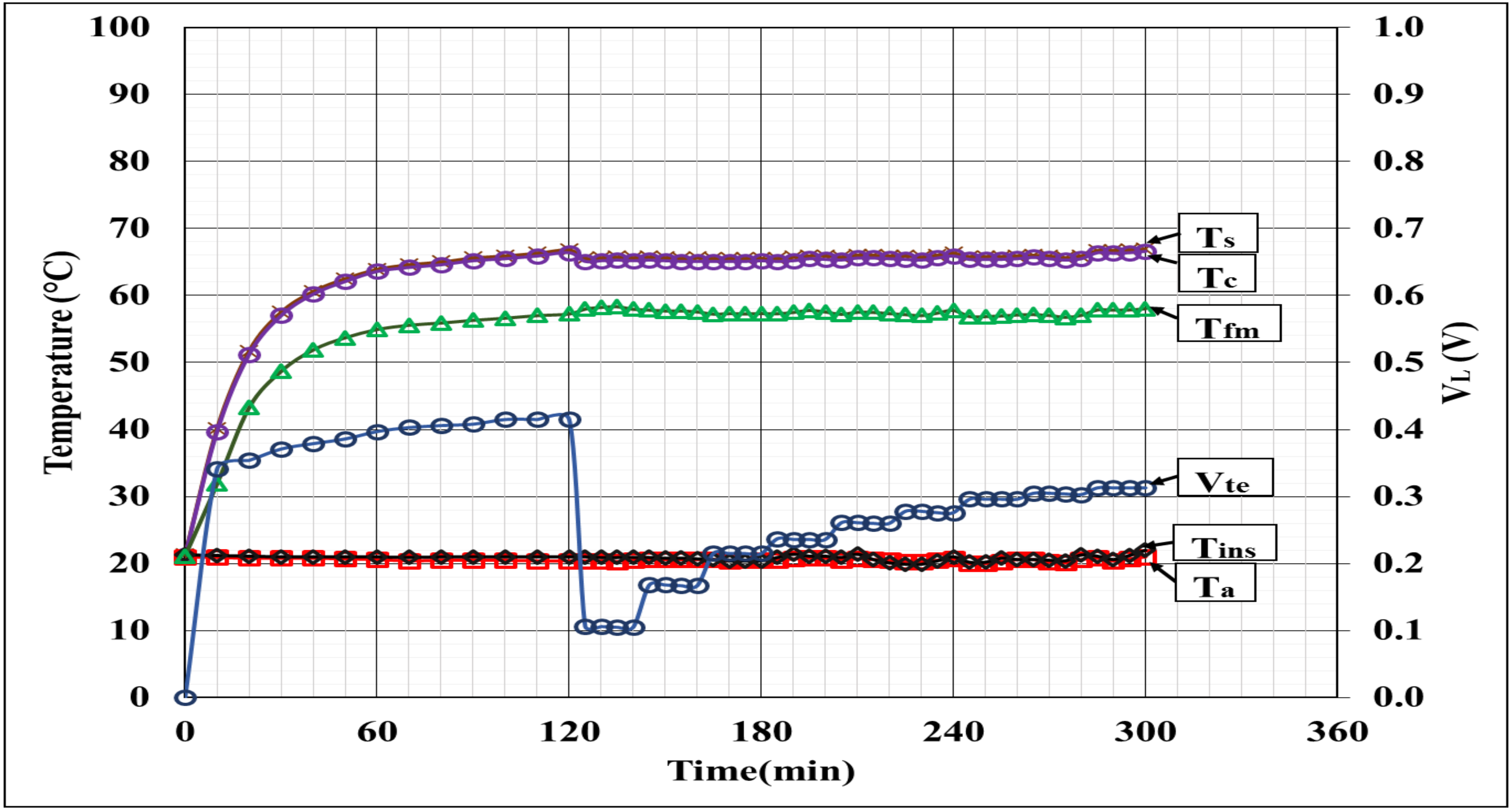


FIGURE 25 EXPERIMENTAL RESULTS OF HT8 MODULE#3 UNDER TEG MODE (7.5 W, RUN B8)

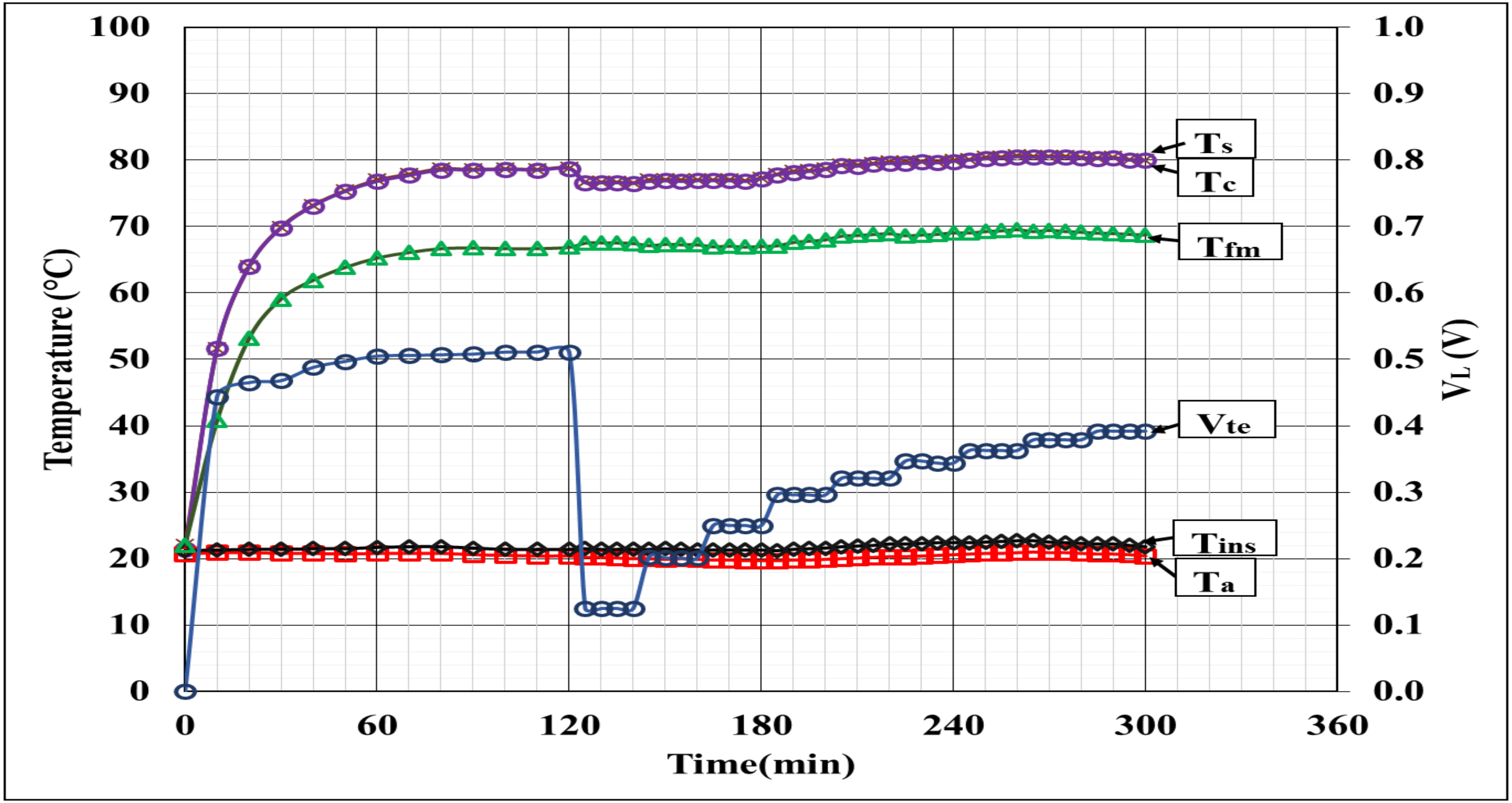


FIGURE 26 EXPERIMENTAL RESULTS OF HT8 MODULE#3 UNDER TEG MODE (10.3 W, RUN B9)

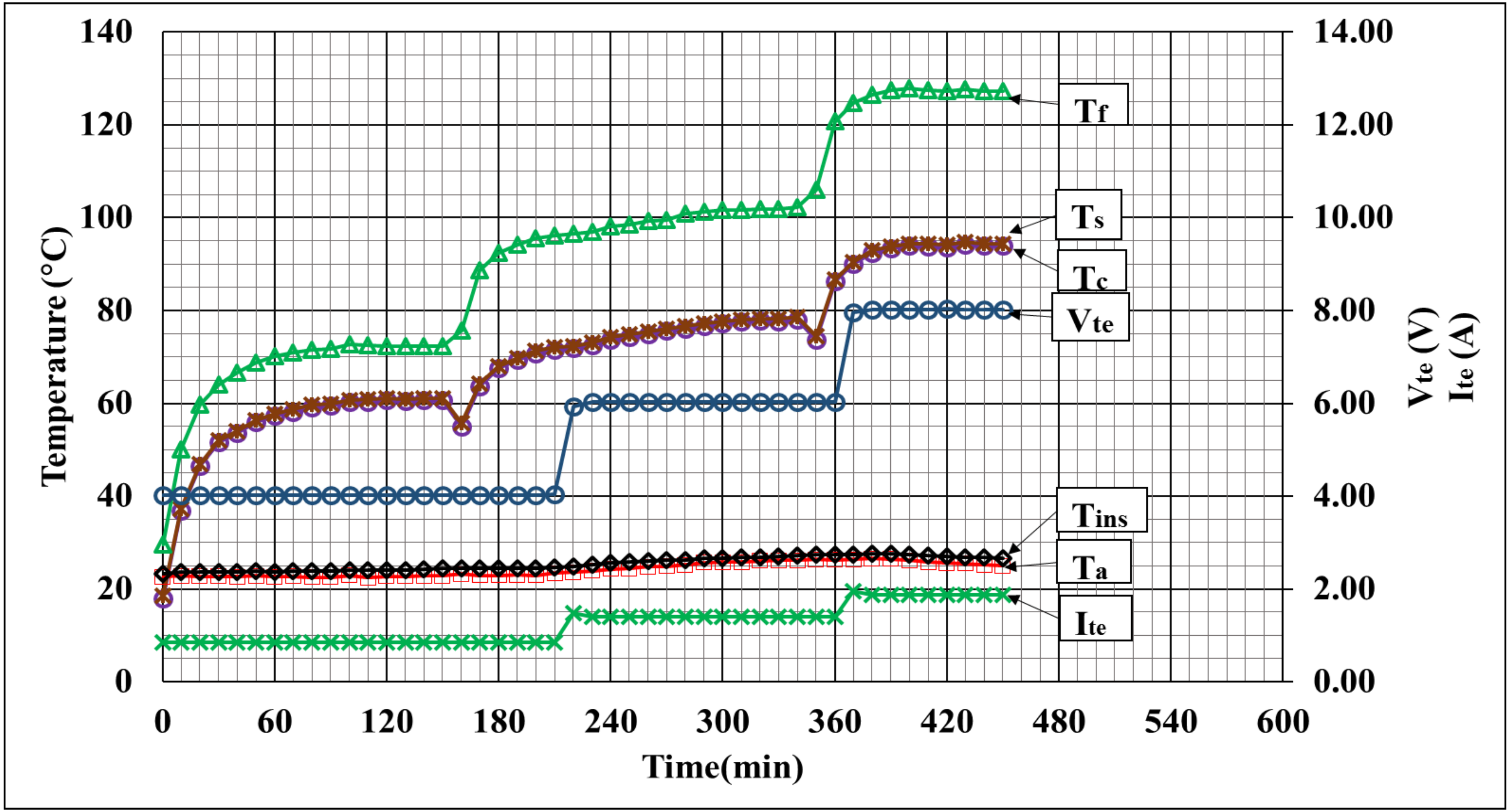


FIGURE 27 EXPERIMENTAL RESULTS OF HT8 MODULE#1 UNDER TEC MODE (5.1 W, RUN C1)

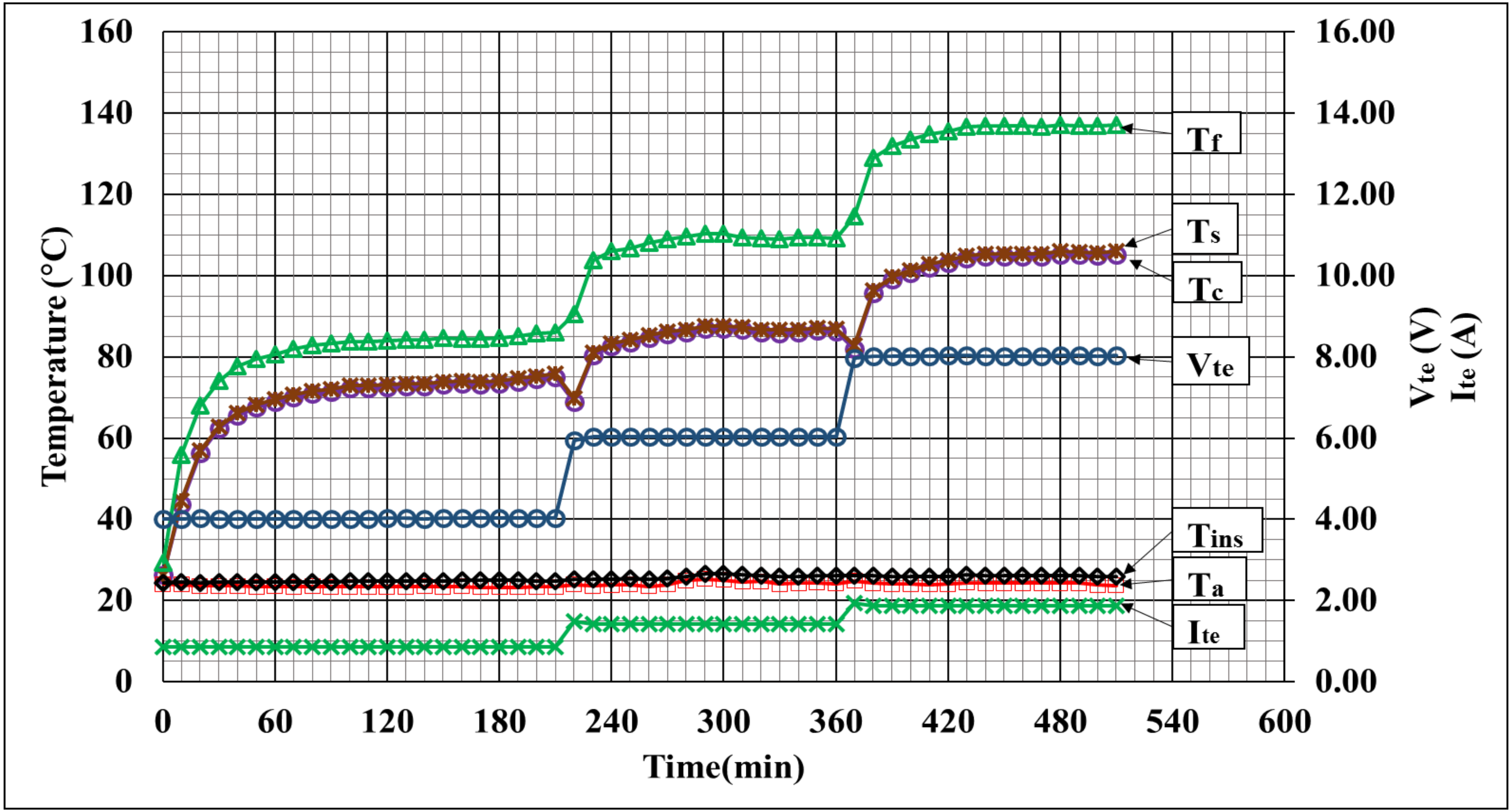


FIGURE 28 EXPERIMENTAL RESULTS OF HT8 MODULE#1 UNDER TEC MODE (7.3 W, RUN C2)

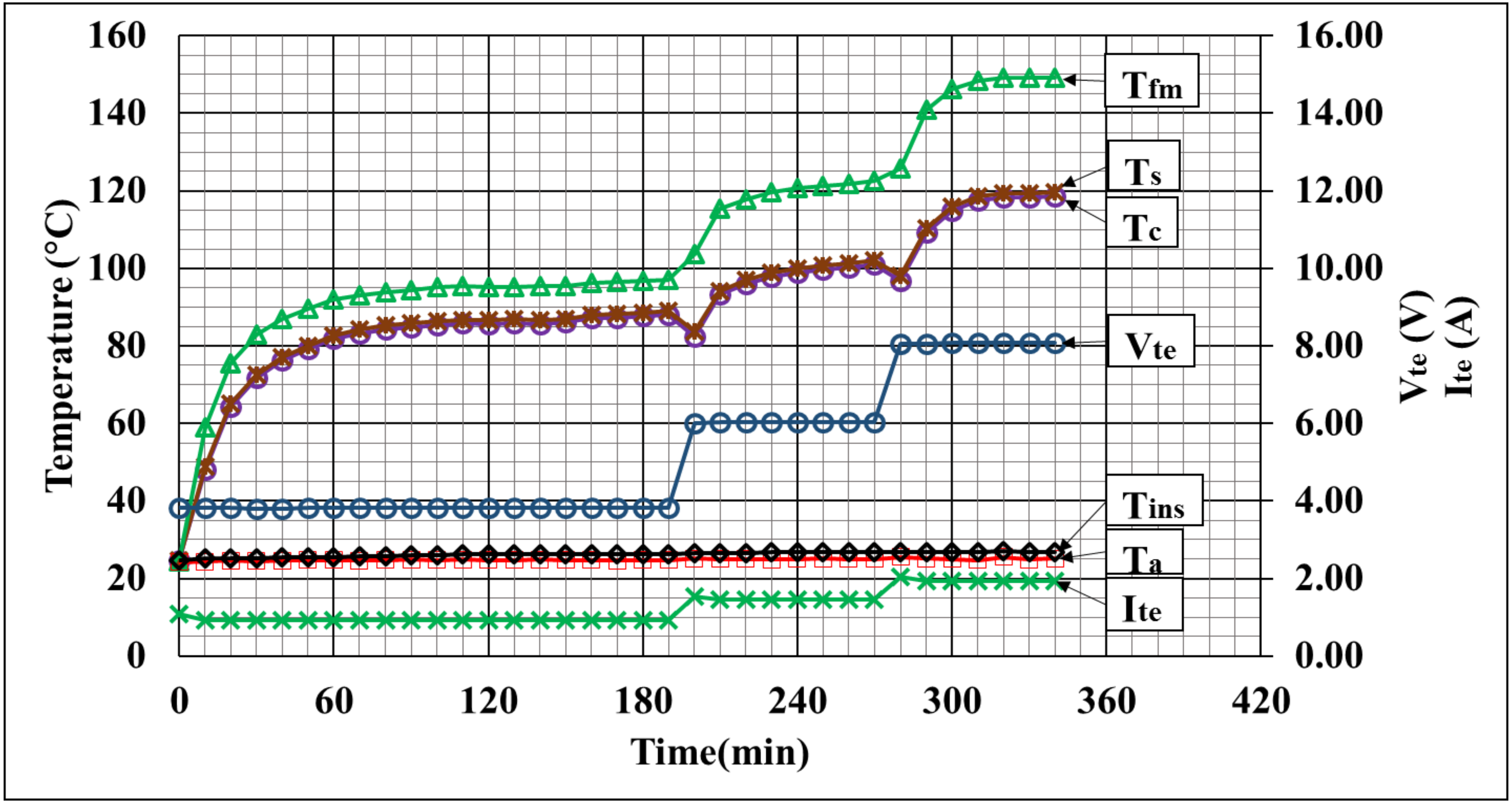


FIGURE 29 EXPERIMENTAL RESULTS OF HT8 MODULE#1 UNDER TEC MODE (10 W, RUN C3)

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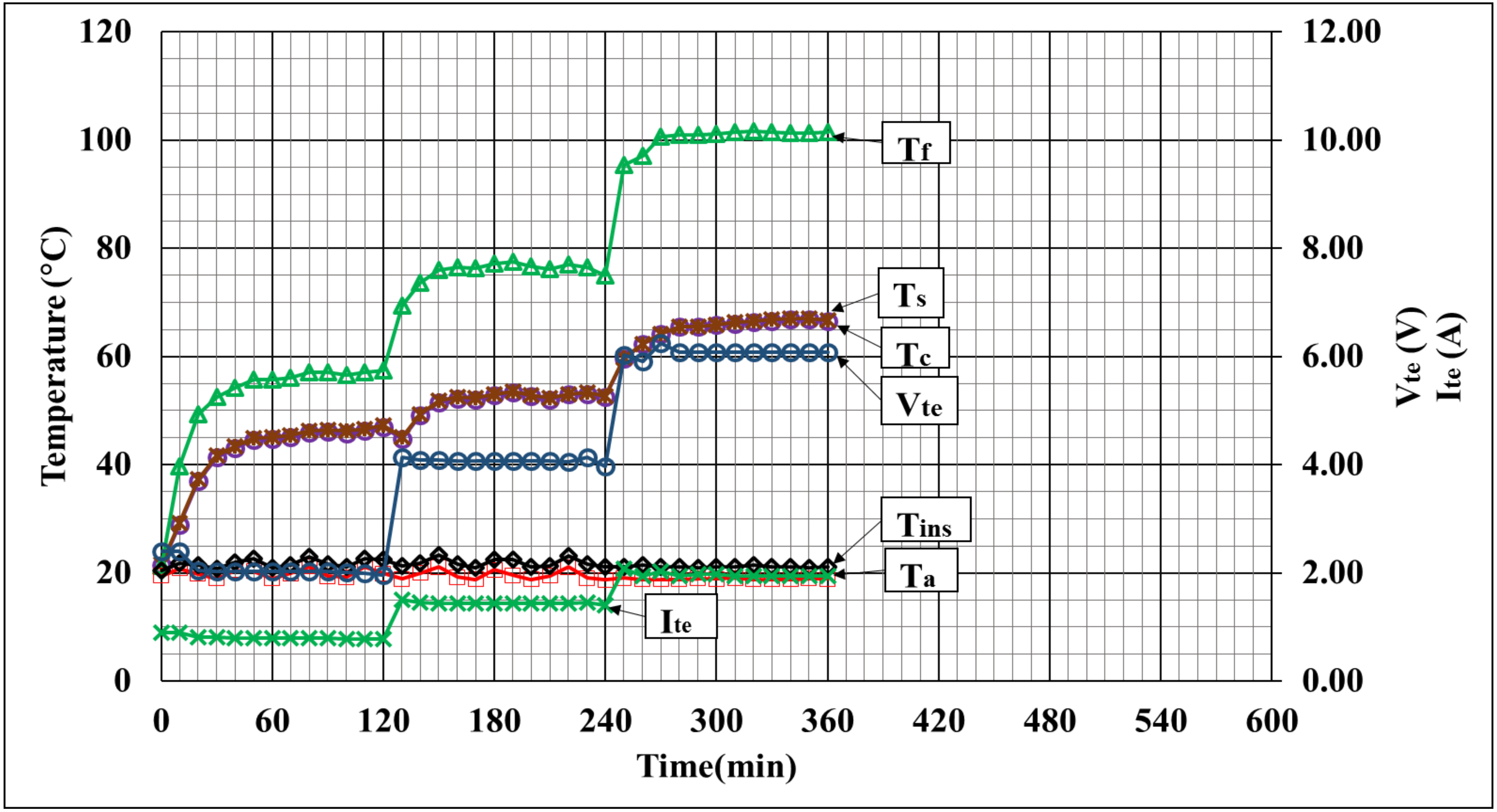

FIGURE 30 EXPERIMENTAL RESULTS OF HT8 MODULE#2 UNDER TEC MODE (5 W, RUN C4)

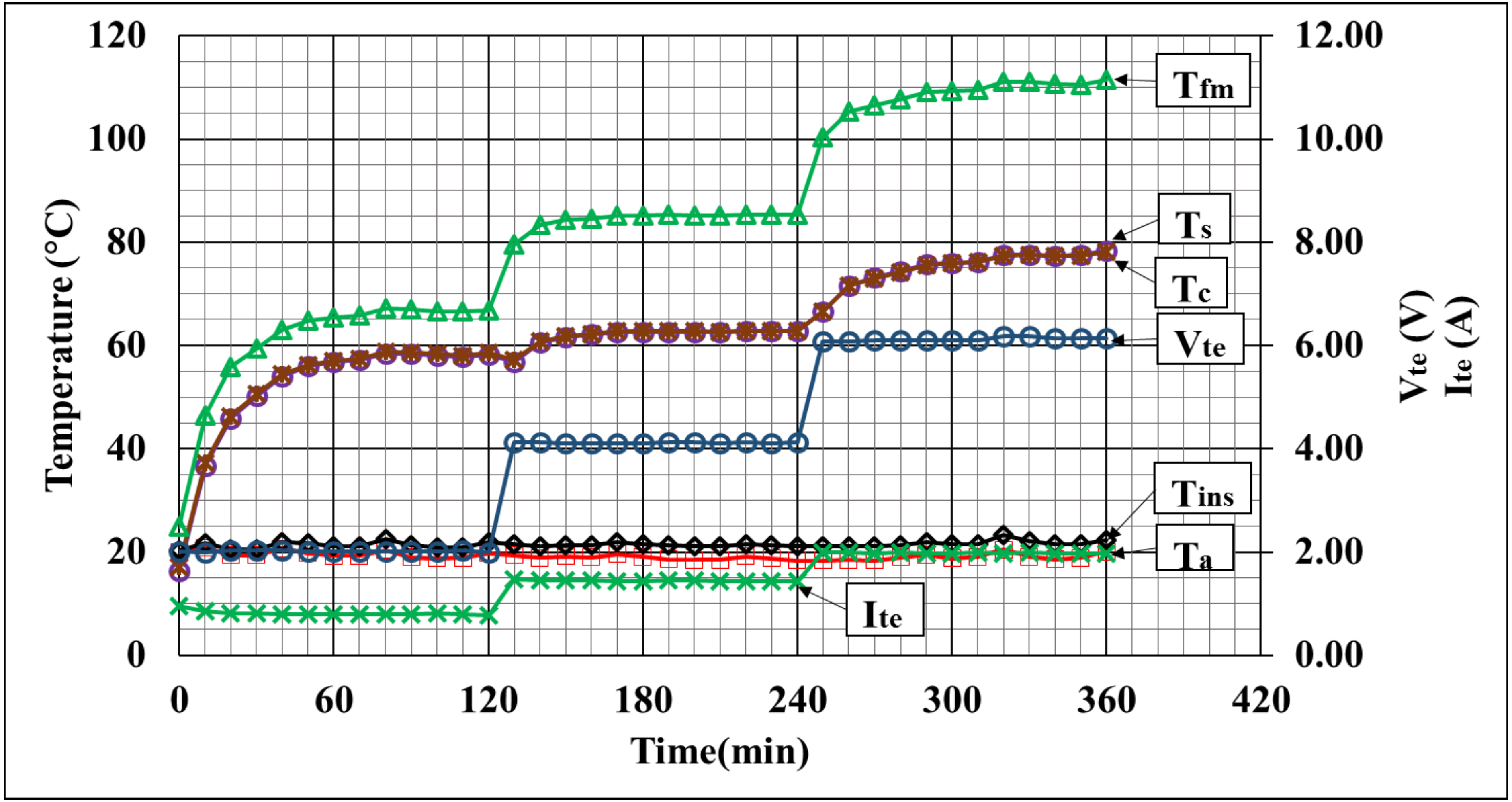

FIGURE 31 EXPERIMENTAL RESULTS OF HT8 MODULE#2 UNDER TEC MODE (7.5 W, RUN C5)

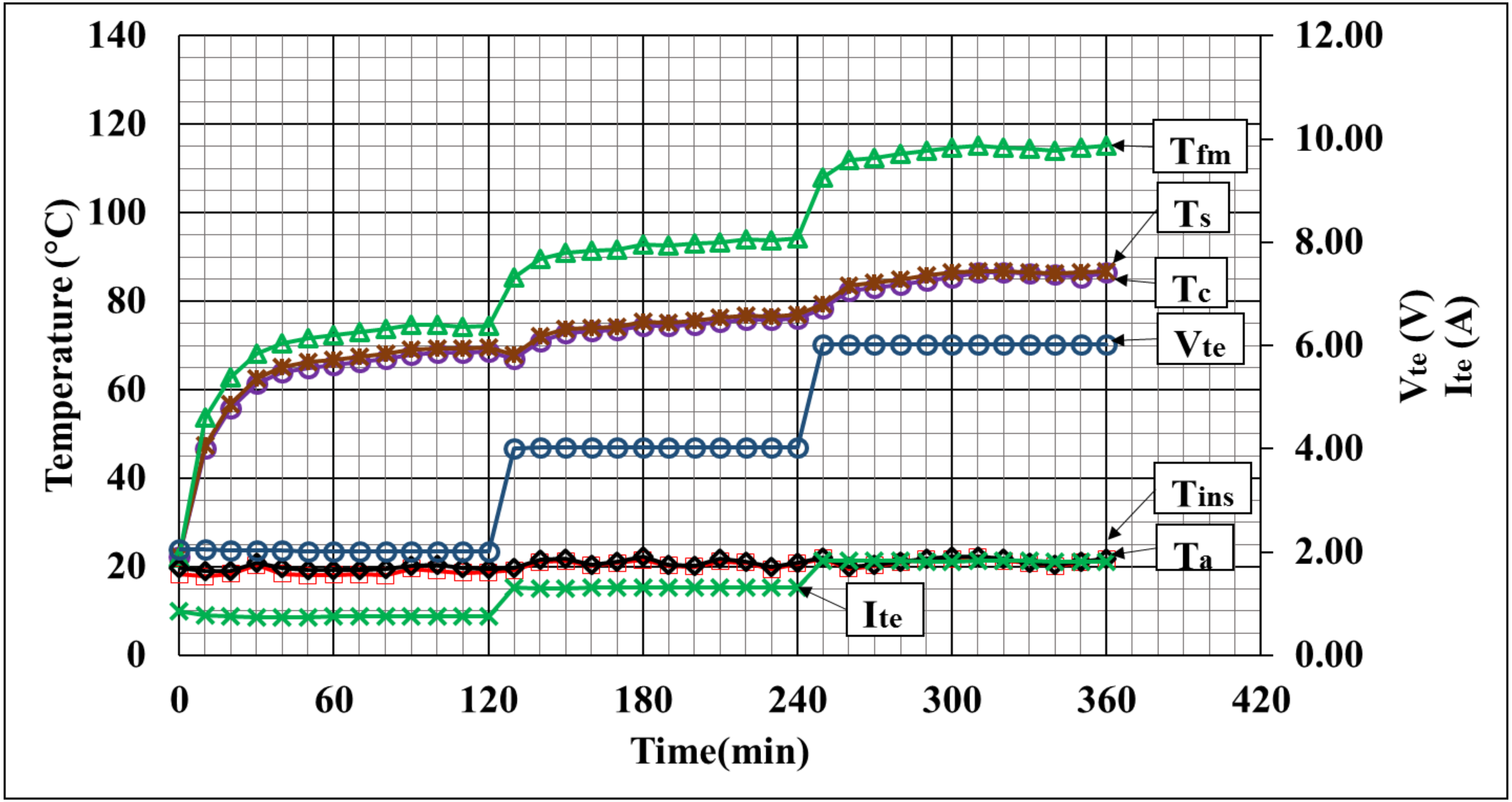

FIGURE 32 EXPERIMENTAL RESULTS OF HT8 MODULE#2 UNDER TEC MODE (10.4 W, RUN C6)

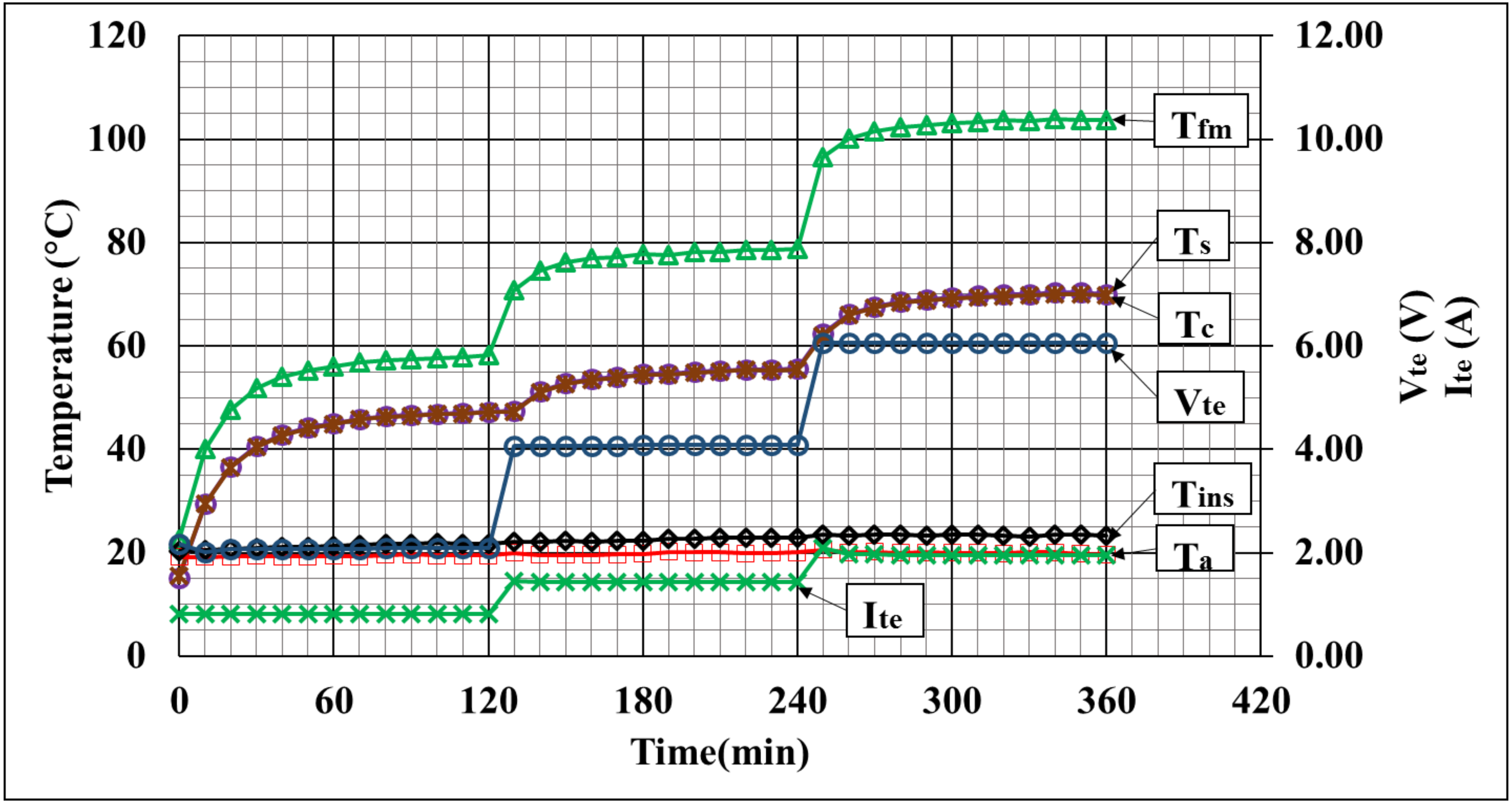

FIGURE 33 EXPERIMENTAL RESULTS OF HT8 MODULE#3 UNDER TEC MODE (5.1 W, RUN C7)

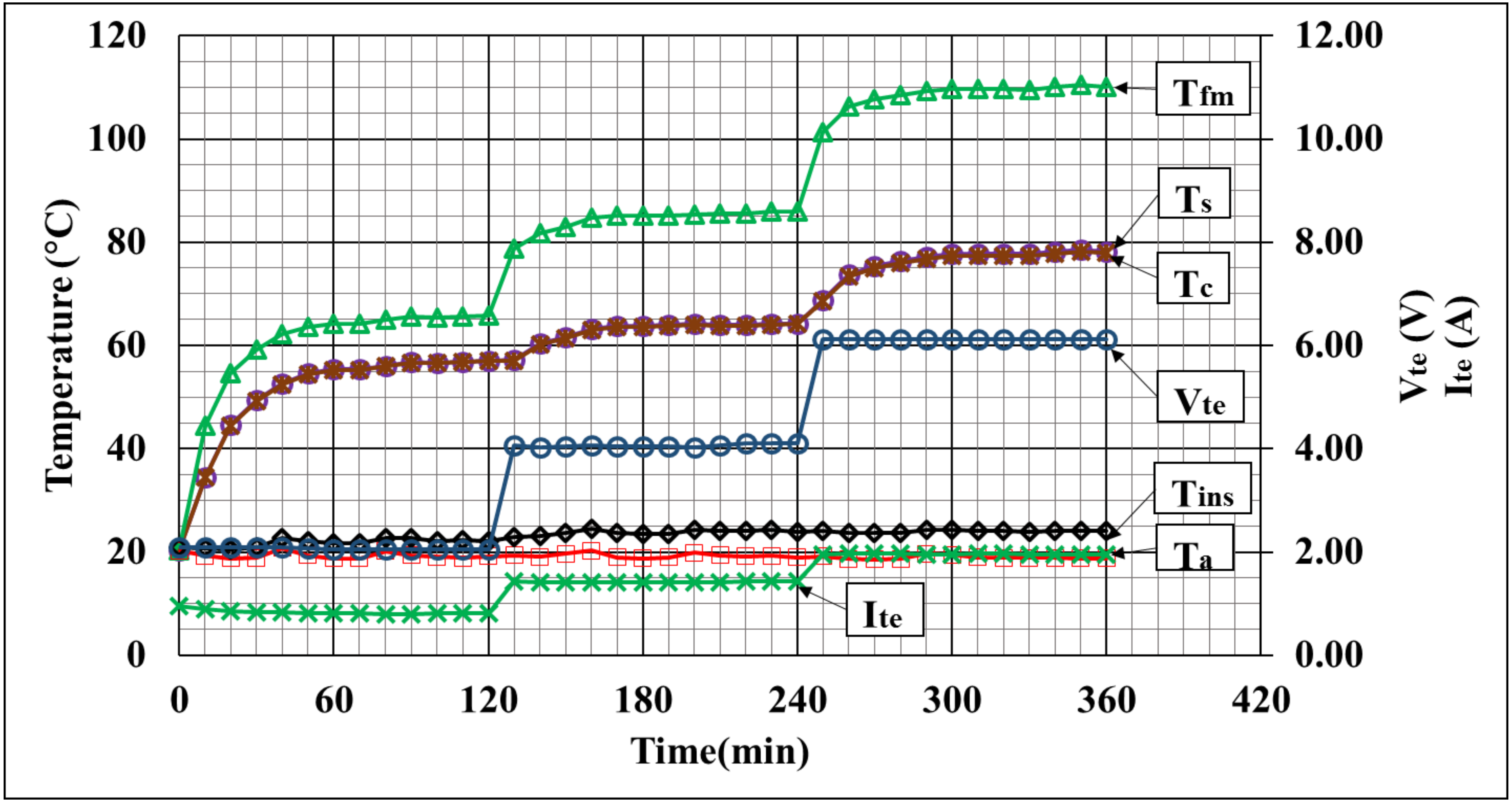

FIGURE 34 EXPERIMENTAL RESULTS OF HT8 MODULE#3 UNDER TEC MODE (7.6 W, RUN C8)

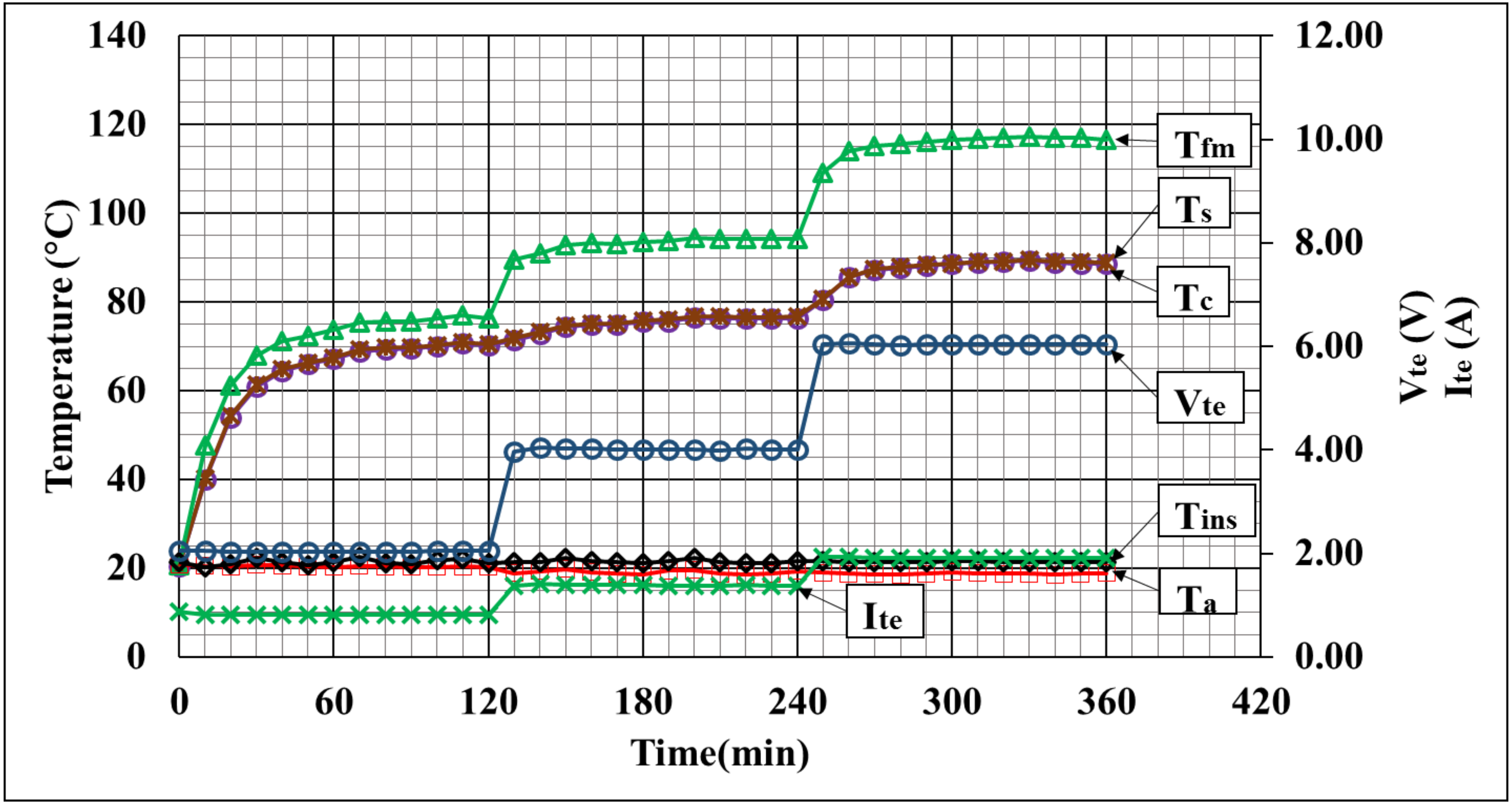

FIGURE 35 EXPERIMENTAL RESULTS OF HT8 MODULE#3 UNDER TEC MODE (10 W, RUN C9)

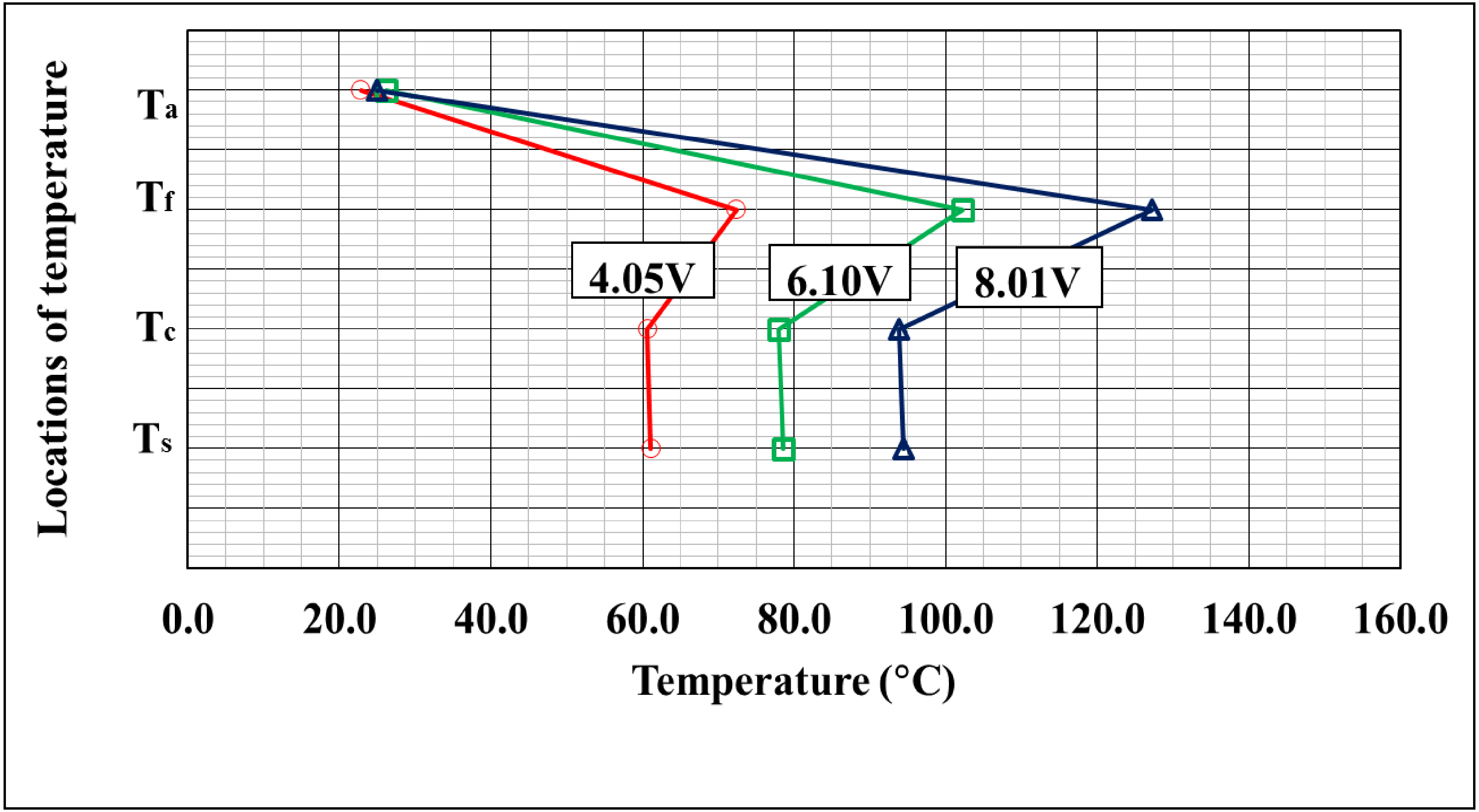

FIGURE 36 TEMPERATURE DISTRIBUTION OF HT8 MODULE#1 AT TE VOLTAGE INPUT (5.1 W, RUN C1)

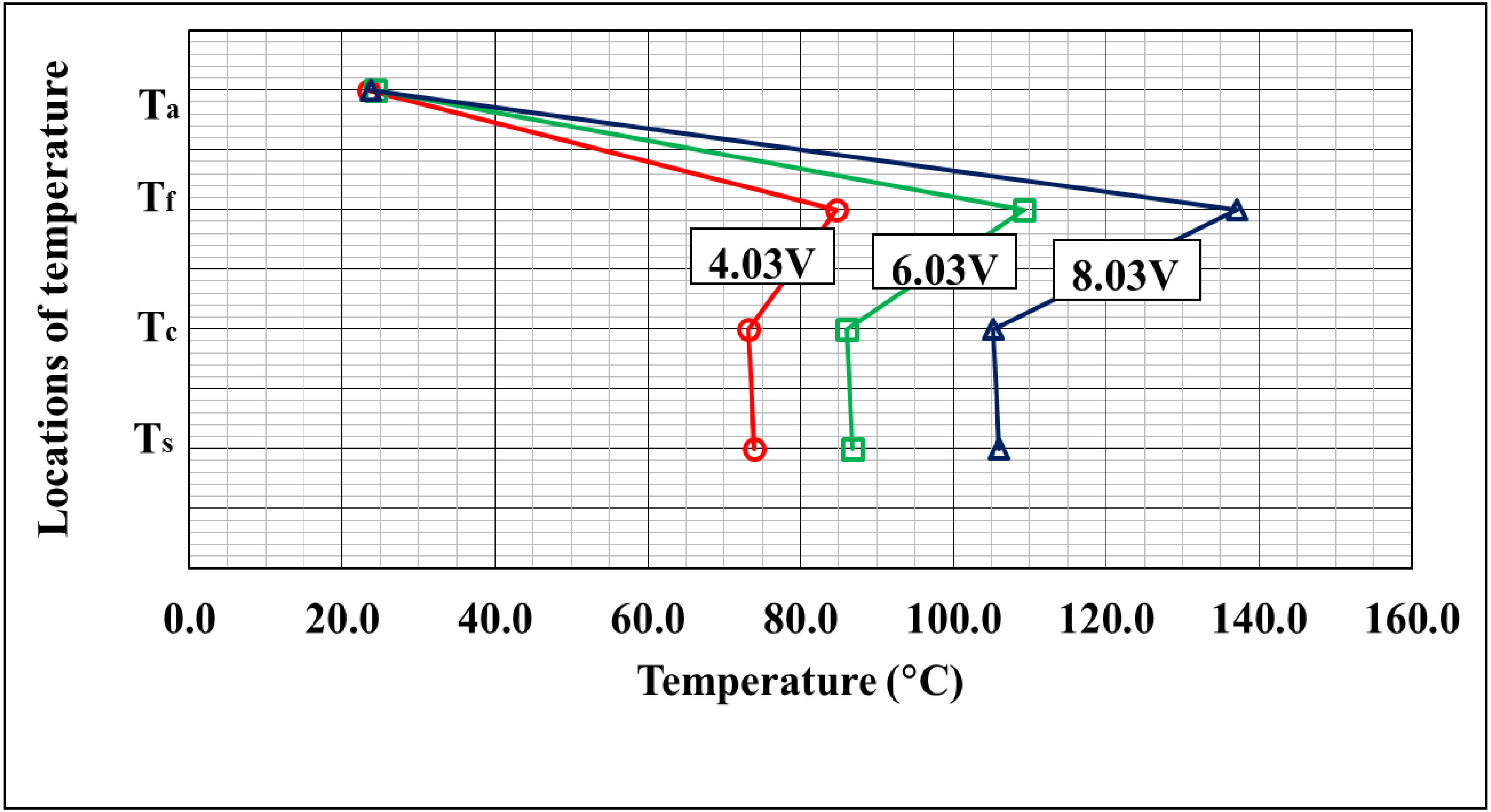

FIGURE 37 TEMPERATURE DISTRIBUTION OF HT8 MODULE#1 AT TE VOLTAGE INPUT (7.3 W, RUN C2)

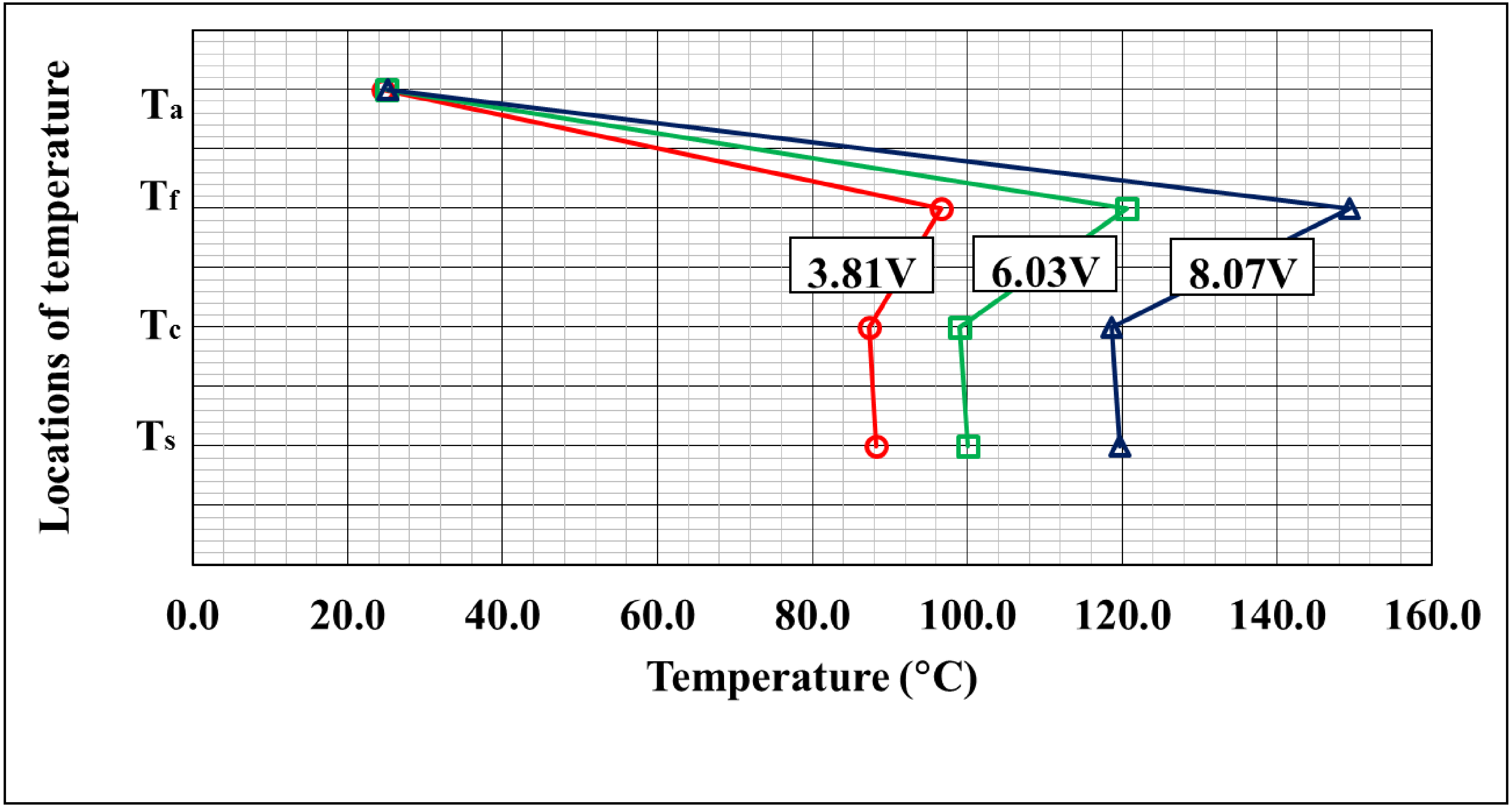

FIGURE 38 TEMPERATURE DISTRIBUTION OF HT8 MODULE#1 AT TE VOLTAGE INPUT (10 W, RUN C3)

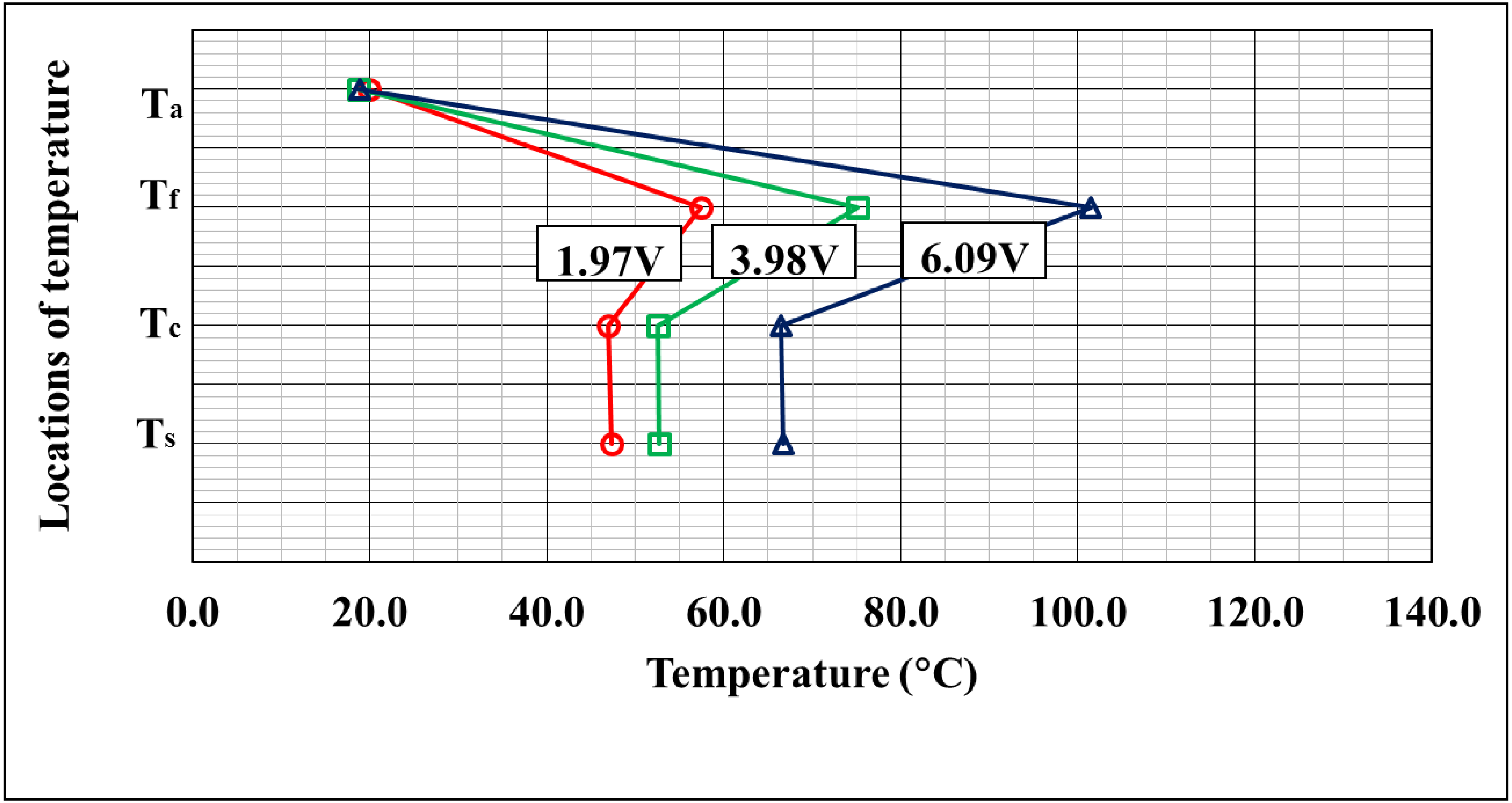

FIGURE 39 TEMPERATURE DISTRIBUTION OF HT8 MODULE#2 AT TE VOLTAGE INPUT (5 W, RUN C4)

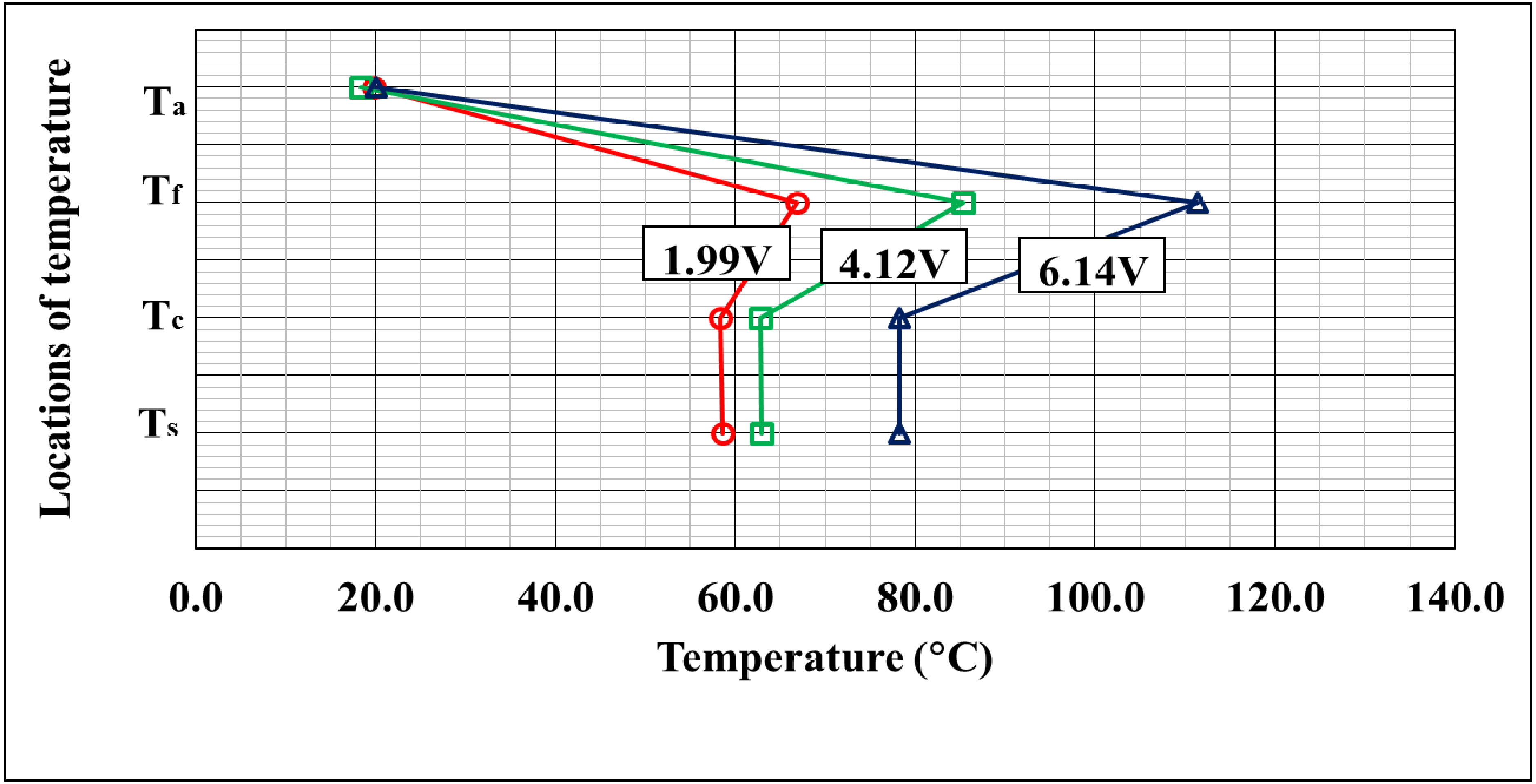

FIGURE 40 TEMPERATURE DISTRIBUTION OF HT8 MODULE#2 AT TE VOLTAGE INPUT (7.5 W, RUN C5)

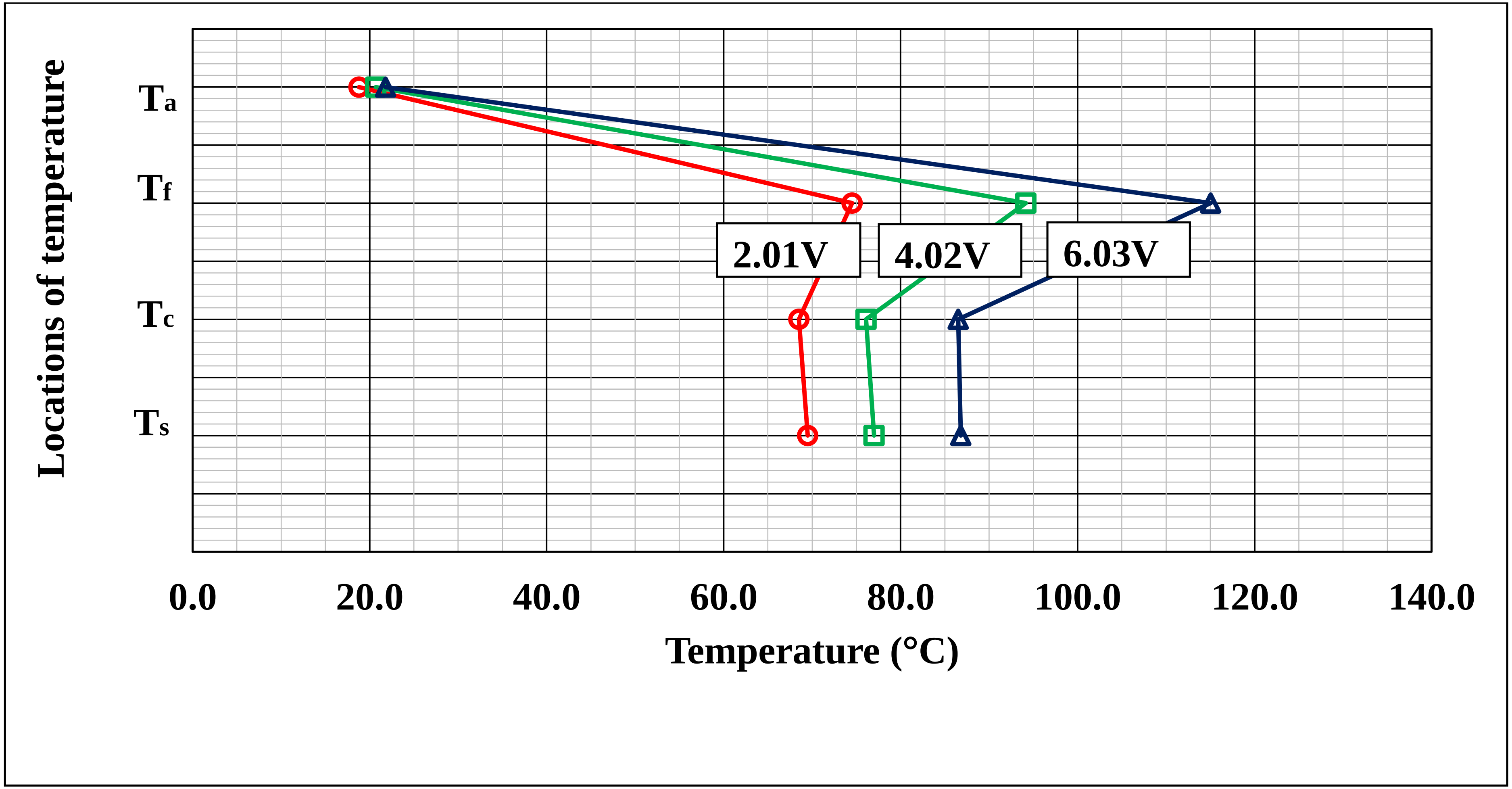

FIGURE 41 TEMPERATURE DISTRIBUTION OF HT8 MODULE#2 AT TE VOLTAGE INPUT (10.4 W, RUN C6)

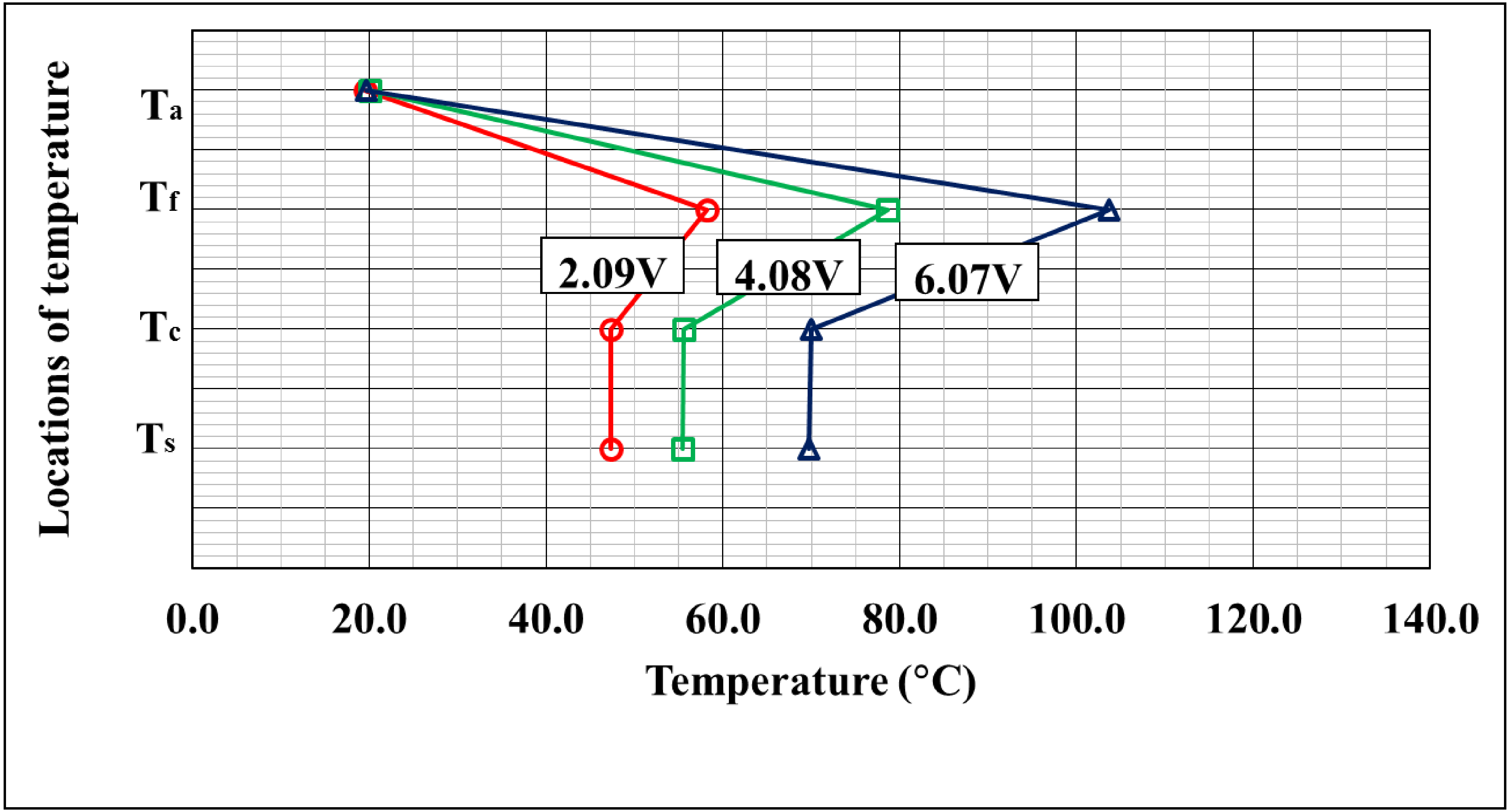

FIGURE 42 TEMPERATURE DISTRIBUTION OF HT8 MODULE#3 AT TE VOLTAGE INPUT (5.1 W, RUN C7)

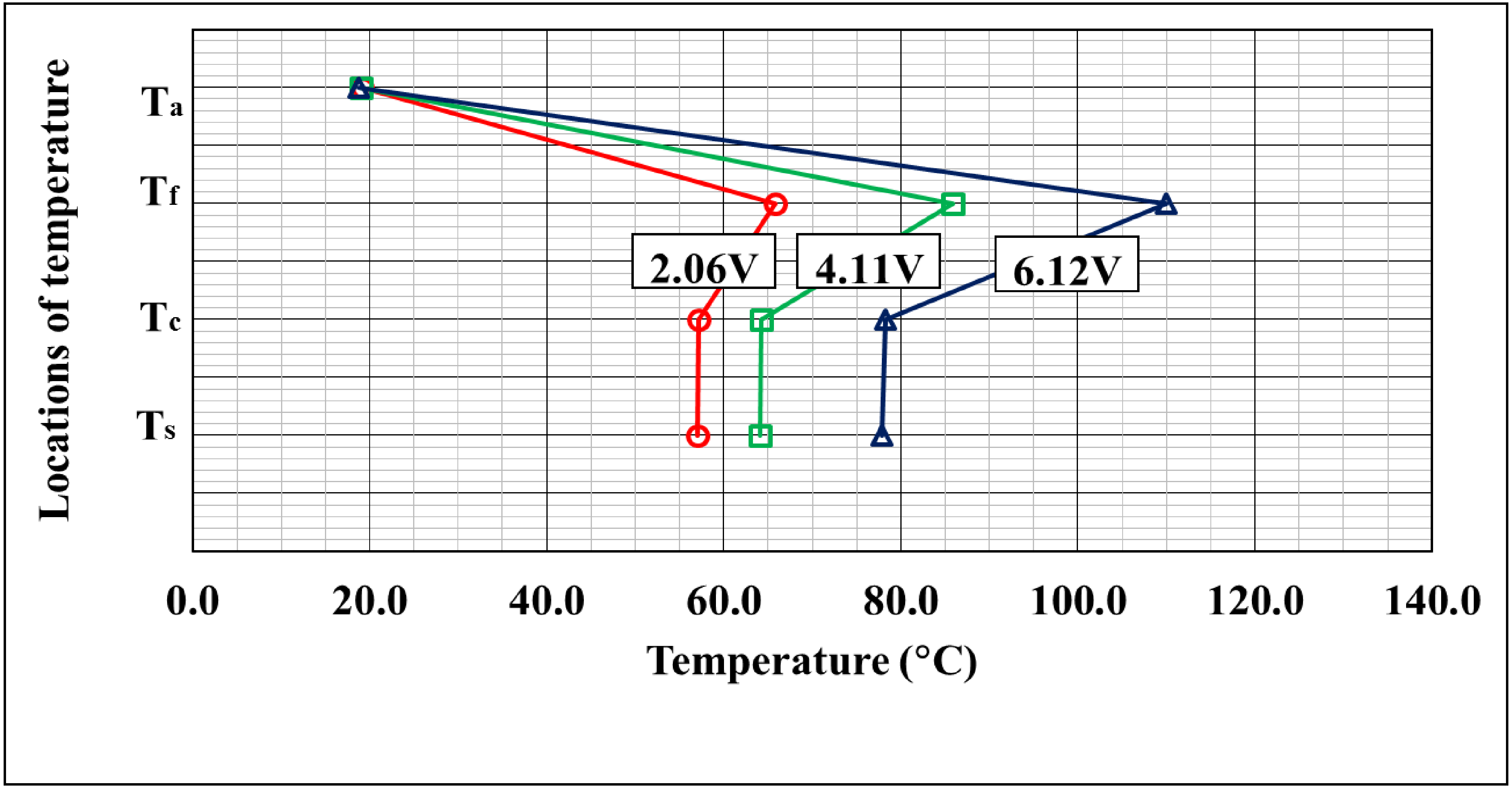

FIGURE 43 TEMPERATURE DISTRIBUTION OF HT8 MODULE#3 AT TE VOLTAGE INPUT (7.6 W, RUN C8)

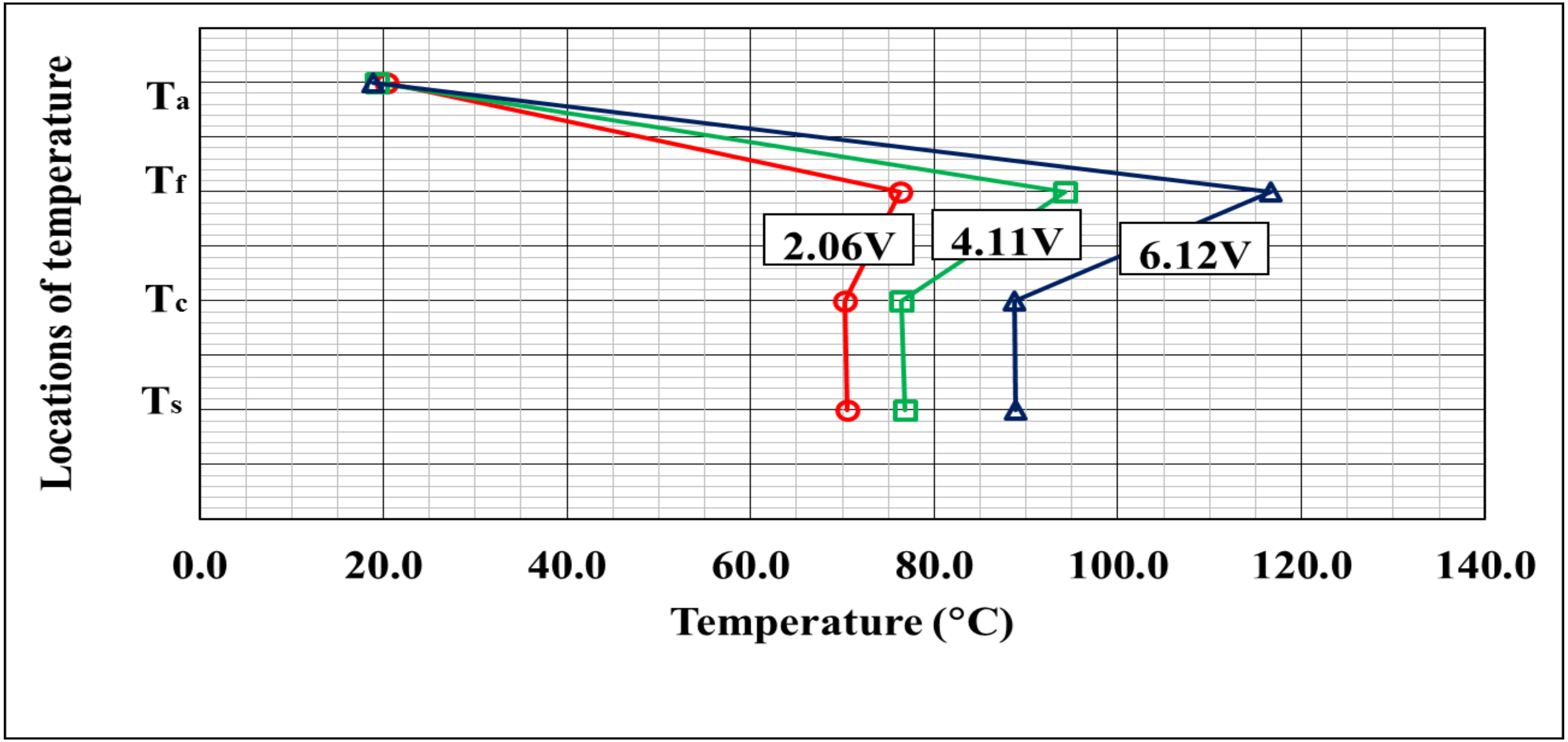

FIGURE 44 TEMPERATURE DISTRIBUTION OF HT8 MODULE#3 AT TE VOLTAGE INPUT (10 W, RUN C9)

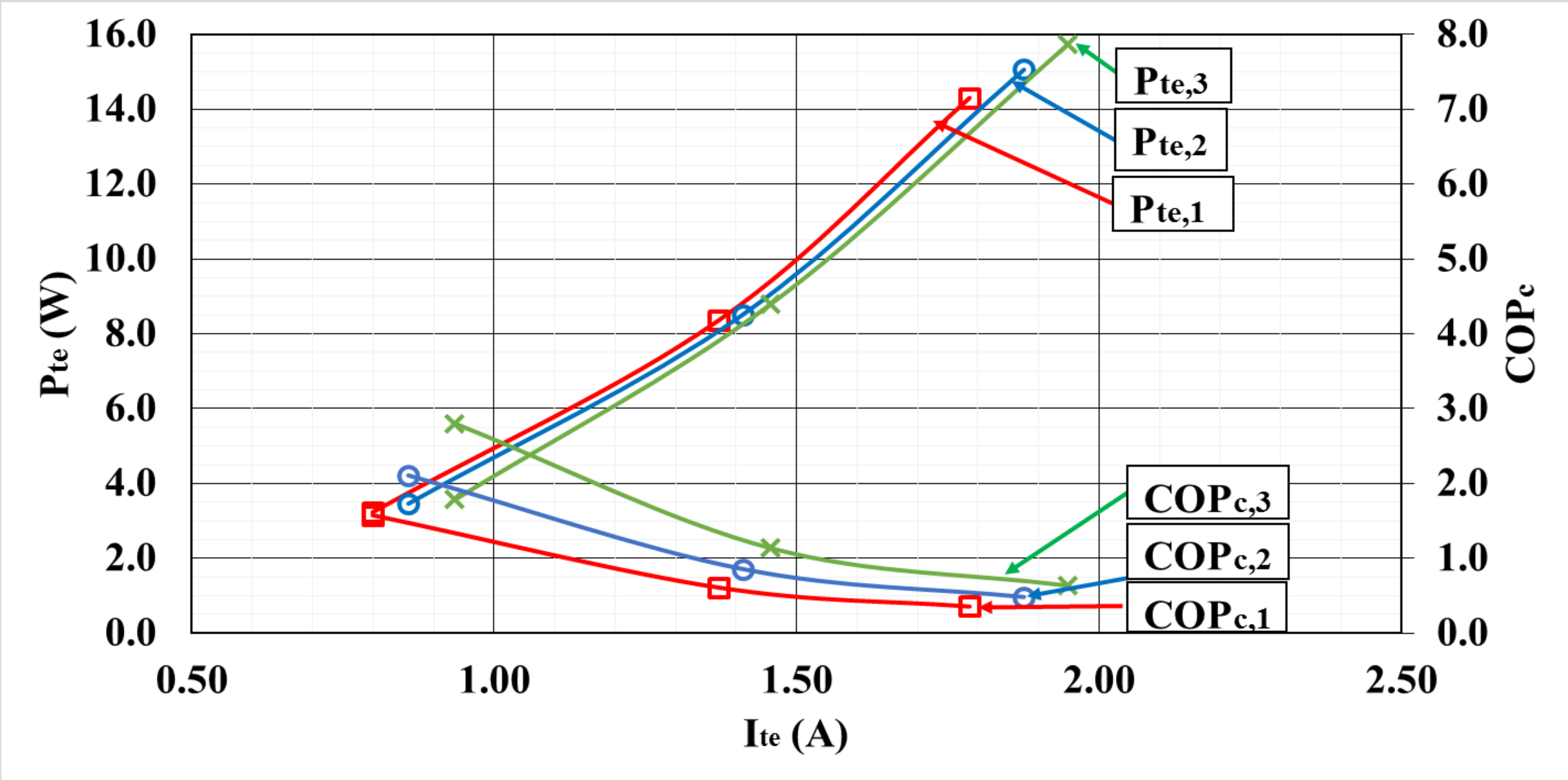

FIGURE 45 PERFORMANCE OF HT8#1

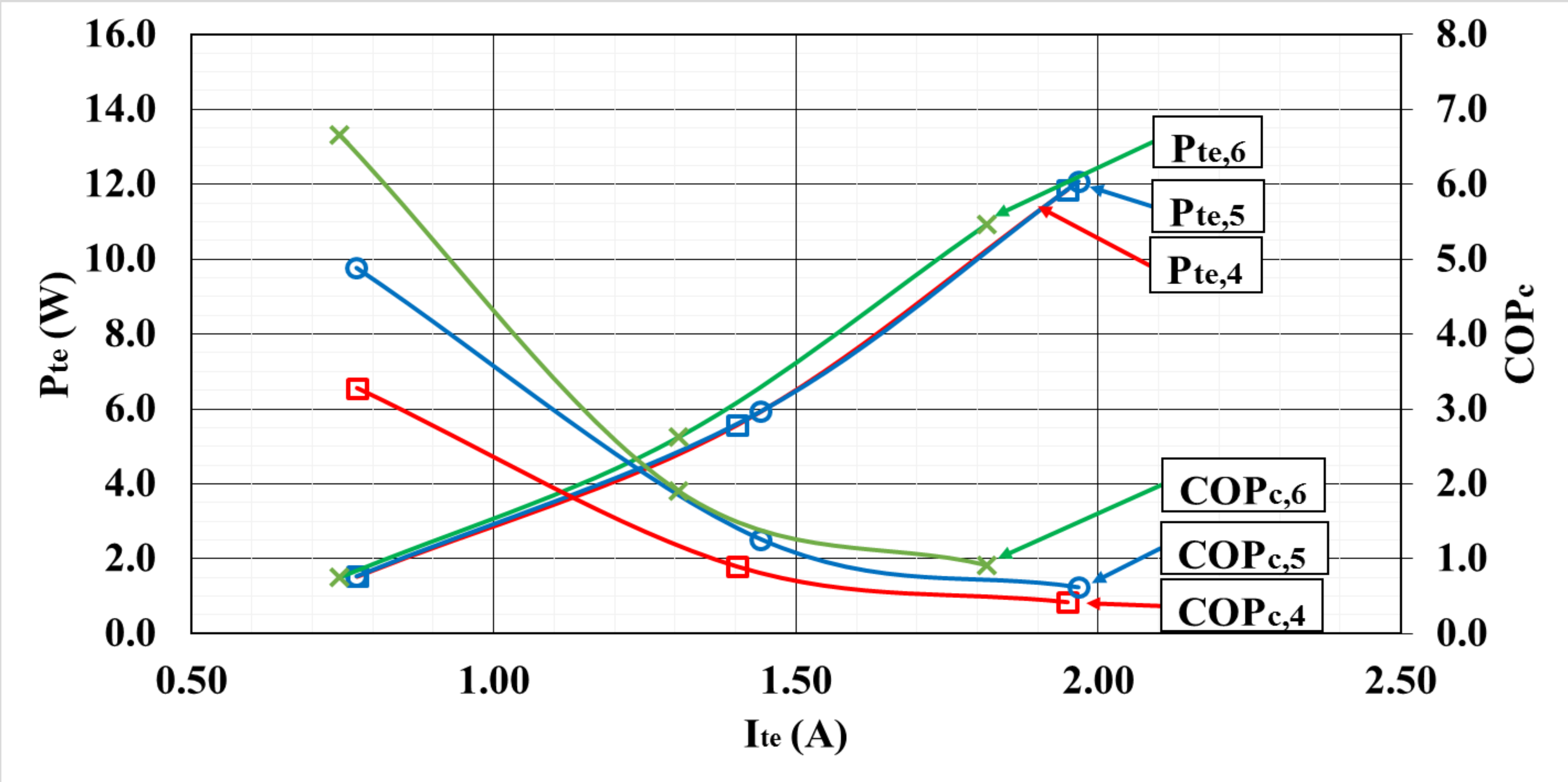

FIGURE 46 PERFORMANCE OF HT8#2

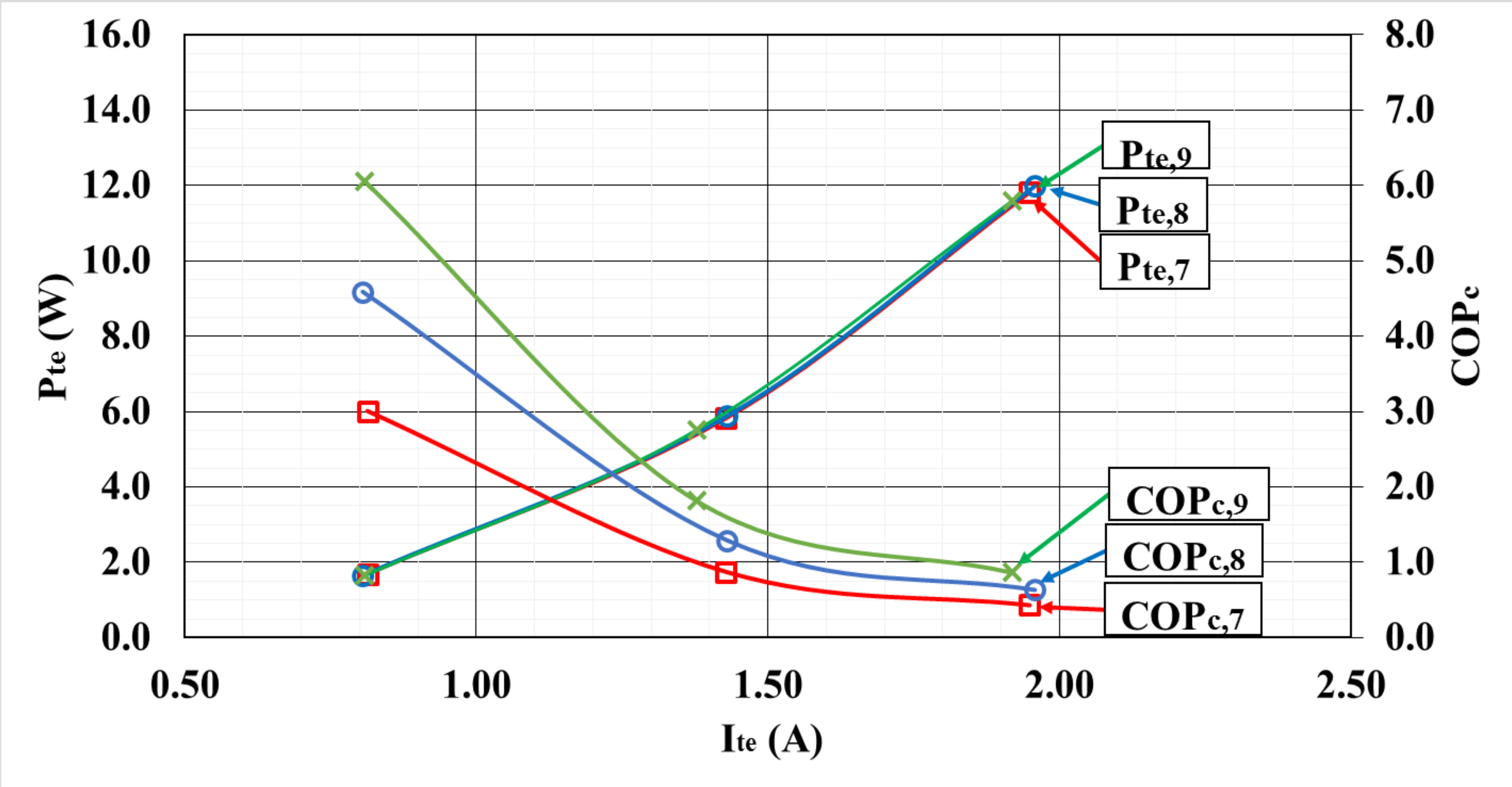

FIGURE 47 PERFORMANCE OF HT8#3

CHAPTER 5

DISCUSSION OF RESULTS

5.1 The effects of the heat sink

The thermal conductivity of the aluminum was found to be equal to 51 W/m K using the Transient Plane Source method of determination by Zhang *et al.* (2014). The results were arranged in Table 1 and the transient temperature results were plotted in Figure 11. A total 4 experimental runs were conducted over 6 hours each with increasing power inputs of 5W in intervals of 2hours. The results were indicating that not much difference between the experimental runs in 10W, 15W and 20W power input. The mean surface temperature (T_{fm}) could be obtained from the average of thermocouples T_{f1}, T_{f2}, T_{f3}, and T_{f4}. The mean surface temperature (T_{fm}) for Run A1 increases from 78℃ to 125.3℃ noting a difference of 47.3℃. For runs A2 till A4 a temperature difference of 49.4℃, 42.3℃ and 46.8℃ respectively for mean surface temperature was obtained. Table 1 shows the ambient temperature was around 20**℃** and the average thermal resistance of the fin heat sink is 5.6 $\pm$ 0.6K/W, which was calculated from Equation (14). The result shows that the surface temperature of the heating element increases as the power input increases. The temperature of the heat sink base reached a steady state at the temperature of 78℃ with 10W power input, 104.7℃ with 15W power input and 125.3℃ with 20W power input for Run A1. Whereas for run A2, steady state temperature of the heat sink base was at 78.5 ℃ for 10W power input, 106.7 ℃ with 15W power input and 127.9℃ with 20W power input.

Run A3 reached steady state at the temperature of 77.6℃ with 10W power input, 104.8℃ with 15W power input and 119.9℃ with 20 W power input. Finally Run A4 has a heat sink base steady state temperature of 81.8℃ with 10W power input, 104.4℃ with 15W power input and 128.6℃ with 20W power input. Temperature of the heat sink base at the interface reached a steady state after 1 hour and took a longer time to reach steady state when the power was increased to 20W. The results show that the heat loss (P_{loss}) was in a range of 0.6 – 0.7% of the power input. The power loss for Run A1, A2 and A3 increased from 0.07 W to 0.12 W which differed by 0.05W. The power loss for Run A4 increased from 0.07W to 0.13W which has a difference of 0.06W.

5.2 Seebeck coefficient (α_{te})

The Seebeck coefficient of TE module (α_{te}) at temperature differences across TE (T_m) were calculated based on all of nine runs. Based on Equation (27), the results were plotted as shown in Figure 12. The average Seebeck coefficient of thermoelectric (α_{te}) calculated were 0.047V/°C, 0.051V/°C and 0.044V/°C when TE modules were HT8#1, #2 and #3 respectively.

Based on Figure 12, Seebeck coefficient of thermoelectric ($\alpha_{te,1}$) has a minimal positive trend with increase of mean temperature of the TE (T_m). HT8 module#2 too demonstrated a similar trend as the previous. However HT8 module#3 TE ($\alpha_{te,3}$) has a deviation in trend, and demonstrated an irregular change as temperature increases. The differences between runs at same input power (P_{EH}) could also be caused by external factors such as measurement error, difference in ambient temperature, fluctuating power supply and irregularities in the TE modules itself.

5.3 Thermal conductance, K_{te}

The thermal conductivity of TE (K_{te}) against mean temperature of TE (T_m) were plotted in Figure 12 and calculated based on Equation (30). The average thermal conductivity of thermoelectric (K_{te}) measured were 0.77W/°C, 1.02W/°C and 0.8W/°C when at TE module of HT8 module #1, #2 and #3 respectively.

For all three measurement obtained for the thermal conductivity (K_{te}) of the three different TE modules, no obvious trends could be seen as the temperature increases. For TE module HT8#1, an average thermo conductivity of 0.77W/°C ranging from 0.75W/°C to 0.78W/°C. Whereas HT8#2 has an average of 1.01W/°C ranging from 1.00W/°C to 1.04W/°C. Finally, HT8#3 offered an average reading of 0.85W/°C with a range of 0.82W/°C till 0.87W/°C. This deviation of reading is related to other factors such as measurement error, different ambient temperature, fluctuated power supply and TE modules itself caused different.

5.4 Internal resistance (R_{te})

The internal resistance of TE (R_{te}) were obtained using the equation as shown in Equation (35). The average internal resistance of TE HT8#2(R_{te}) obtained were 2.85 $\pm$ 0.17Ω, 3.15 $\pm$ 0.14Ω and 3.32 $\pm$ 0.19Ω when electrical heating element powers were 5W, 7.5W and 10W respectively.

Figure 13 shows the resistance of TE against the mean temperature. Those three TE modules showed similar trend whereby the internal resistance of TE (R_{te}) increases with increasing temperature difference (ΔT_{te}) and mean temperature (T_m) at various electrical powers of 5W, 7.5W and 10W respectively. The load resistance (R_L) used in the experiment were 1.08Ω, 2.14Ω, 3.20Ω, 4.28Ω, 5.36Ω, 6.42Ω and 7.48Ω in Run B1, B2 and B3. A total nine resistors as load resistance (R_L) used in Run B4 to Run B9 were 1.08Ω, 2.14Ω, 3.24Ω, 4.28Ω, 5.36Ω, 6.42Ω, 7.48Ω, 8.64Ω and 9.72Ω. HT8#1 had the highest value of the internal resistance of TE (R_{te}), as compared with HT8#2 and HT8#3. The values were found to be around 4.53Ω, 4.53Ω and 5.29 Ω at different power input of 5W, 7.5W and 10W. By comparing HT8#2 and HT8#3, the internal resistance of TE (R_{te}) were about difference of 0.07Ω, 0.02Ω and 0.14Ω electrical heating element powers were 5W, 7.5W and 10W respectively.

5.5 Power generated, P_L

. The power load of TE, P_L was calculated based on Equation (21). Figure 14 to Figure 17 show the experimental power output against resistance. The power generated by TE (P_L) increased as the amount of resistor increased.

Figure 14 is a representation of the power generated by the TE module HT8#1 against its load resistance for 3 different power input values of 4.8W, 7.6W and 10.4W. For all three power settings, a general trend could be seen as a general polynomial where it peaks then gradually decreases. Run B1 of 4.8W starts off with a power generated of 0.0025W peaking at 0.0044W with 4.28Ω which then drops off to a low of 0.0042W. Run B2 of 7.6W starts off with a power generated of 0.0062W peaking at 0.0103W with 4.28Ω which then drops off to a low of 0.0098W. Finally, Run B3 of 10.4W starts off with a power generated of 0.0089W peaking at 0.018W with 6.42Ω which then drops off to a low of 0.017W. Both Run B1 and B2 peaked at a same resistance of 4.28Ω, but B3 differed from the trend and peaked at 6.42Ω. By comparing all the three modules at same 5W power input, HT8#2 has the highest power load of 0.0062W, 0.0087W, 0.0101W, 0.0103W, 0.0101W, 0.0099W and 0.0098W when load resistor of TE (R_L) were 1.08Ω, 2.14Ω, 3.24Ω, 4.28Ω, 5.36Ω, 6.42Ω, 7.48Ω, 8.64Ω and 9.72Ω. Based on the graphs plotted, the peak point of the power load mostly located between third and fourth resistor except Run B3 which located at seventh resistor. Polynomial lines of three degree were used as the regression closed to one. Theory stated that the maximum power load is produced when load resistor (R_L) is equal to the internal resistance of TE (R_{te}). The values from the experimental results were higher than the values that provided by manufacturer. This might be due to the assumption of ideal condition being used.

5.6 TEC cooling

The experimental result was described in section 4.3. The objective of the experiment was to characterize the TE module in heat pump mode. Table 3 shows a summary of the experimental result and coefficients of performance (COP_C) were calculated based on the experimental data by using Equation (43).

Figure 27 to Figure 35 shown the change in temperature, current and voltage against time for 5W, 7.5W and 10W power input respectively. Three TE voltage settings were used for all three power input, which were 4V, 6V and 8V in Run C1, C2 and C3 while 2V, 4V and 6V in Run C4 to C9. The current were recorded at the end of each voltage interval. A comparison of the three graphs shows that under air cooled heat sink, the TE could only perform as an effective heat pump at a maximum of 10.4W power input to the electrical heater with 2V voltage input.

Figure 36 to Figure 44 were the changes in temperature of each part of the TE set up for 5W, 7.5W and 10W powers setting respectively. The different lines show the different voltage input to the TE and the changes of temperature were found. The effectiveness of the TE at different power input was explained from these graphs. Figure 36, Figure 37, Figure 38, Figure 41 and Figure 44 shows the desired results as T_s was larger than T_c, but Figure 39, Figure 40, Figure 42 and Figure 43 did not produce the desired shape as Ts was larger than Tc. The TE might be able to operate at higher power input to the electric heating element if used a powerful heat sink.

Figure 45, Figure 46, and Figure 47 shows the power of TE (P_{te}) and the coefficient of performance (COP_C) against current in the TE. The power to the TE against the current and the effect of current to the coefficient of performance was also shown in the graph. The coefficient of performance shows the capability of TE cooling. Table 3 shows the experimental values used to obtain the coefficient of performance. The coefficient of performance (COP_C) for Run C3 decreased from 2.8 to 0.6 with an approximate difference of 2.2 where the voltage input to TE increased from 3.81V to 8.07V. For Run C6, the coefficient of performance (COP_C) similar to Run C3 which decreases from 6.9 to 1.0 while the voltage input to TE increased from 2.01V to 6.03V. The voltage input to TE increased from 2.04 V to 6.04 V causes the coefficient of performance (COP_C) to decrease from 6.0 to 0.9 in Run C9. By comparing the three runs with same power input, Run C6 which was used the HT8#2 obtained the highest coefficient of performance value among the others. As seen from the graphs, as more power is supplied into the TE, the COP will reduce.

CHAPTER 6

SUGGESTIONS FOR FURTHER STUDIES

The following are some recommendations for further studies:

- Use a more stable power supply to the heating element.
- Conduct the experiment runs where the ambient temperature must be control.
- A more efficient heat sink is needed to maintain the temperature at a desired level.
- Future research in application for simultaneous heating and cooling.
- Replace heating element with an actual LED for LED cooling application in future research.

CHAPTER 7

CONCLUSIONS

In order to fix the thermal fin heat sink resistance to the experimental results, the natural heat transfer coefficient for natural convection air cooling of the fin heat sink was about 12 W/m^2K. This given a thermal resistance for the fin heat sink to be equal to 5.6 $\pm$ 0.6 K/W. The following Seebeck coefficient (α_{te}), thermal conductivity (K_{te}) and internal resistance (R_{te}) for the three TE modules were determined:

Module	α_{te} (V/°C)	K_{te} (W/ °C)	R_{te} (Ω)
1	0.048	0.78	5.29 $\pm$ 0.42
2	0.052	1.00	3.32 $\pm$ 0.19
3	0.043	0.87	3.17 $\pm$ 0.12

Maximum power generated varied from 0.0180W to 0.0214W at 10W power input at about 3.5Ω load resistance. Maximum COPc obtained by TE module HT8#2 was 6.9, 2.0 and 1.0 at 10 W power input with 2 V, 4 V and 6 V voltage input respectively.

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NOMENCLATURE

COPc Coefficient of performance

I_{te} Current under TE module [A]

I_L Current under load [A]

K_{te} Thermal conductance of TE [W/˚C]

P_{EH} Input power to electric heating element [W]

P_L Power generated by TE [W]

P_{te} Power supplied to TE module [W]

q_c Heat transfer rate on cold side of TEG [W]

q_h Heat transfer rate on hot side of TEG [W]

R_L Load resistance [Ω]

R_{ref} reference resistor [Ω]

R_{te} resistance of TE module [Ω]

T_a Ambient temperature [˚C]

T_c temperature of cold side TE module [˚C]

T_m mean temperature of base of heat sink or hot side TE module [˚C]

T_s temperature of heating element [˚C]

ΔT_{te} temperature difference between hot and cold sides of TE module [˚C]

V_{te} Voltage across TE module [V]

V_L induced voltage under load condition [V]

V_{NL} induced voltage under no load condition [V]

α_{te} Seebeck coefficient [V/˚C]

APPENDICES

TABLE 1 EXPERIMENTAL RESULTS TO DETERMINE THE THERMAL RESISTANCE OF FIN HEAT SINK.

ε	Run#	P_{EH} (W)	T_a (°C)	T_{insm} (°C)	T_{f1} (°C)	T_{f2} (°C)	T_{f3} (°C)	T_{f4} (°C)	T_s (°C)	R_{f1D} (K/W) Eq. (14)	P_{loss} (W)	$\frac{P_{loss}}{P_{EH}} \times 100\%$
0.79	A1	10.0	19.5	21.2	77.9	78.1	77.5	78.6	78.0±0.5	5.9	0.07	0.70
		14.6	20.9	22.5	104.6	104.9	104.4	104.9	104.7±0.3	5.6	0.10	0.67
		19.7	20.1	23.1	124.9	125.7	124.4	126.3	125.3±0.9	5.3	0.12	0.60
	A2	10.0	19.6	21.1	78.5	78.7	78.0	78.7	78.5±0.4	5.9	0.07	0.70
		14.9	20.5	22.0	106.7	107.1	106.1	107.0	106.7±0.5	5.7	0.10	0.67
		19.9	19.9	22.7	128.0	128.5	127.0	128.2	127.9±0.8	5.4	0.12	0.60
	A3	10.0	18.5	20.8	77.7	77.3	77.1	78.1	77.6±0.5	5.9	0.07	0.70
		14.9	19.7	21.6	105.2	104.5	104.2	105.4	104.8±0.6	5.7	0.10	0.67
		20.0	19.7	22.5	120.6	119.4	119.1	120.5	119.9±0.8	5.0	0.12	0.60
	A4	10.1	19.2	21.0	81.4	81.7	81.5	82.5	81.8±0.5	6.3	0.07	0.70
		14.8	19.9	22.1	103.8	104.4	104.2	105.2	104.4±0.7	5.6	0.10	0.67
		20.0	20.5	22.7	129.1	128.5	127.8	128.9	128.6±0.6	5.4	0.13	0.65

TABLE 2 SUMMARY RESULT OF TEG.

Run #	HT8 module	P (W)	R_L (Ω)	V_{ref} (V)	I_L (A)	V_L (V)	T_a (°C)	T_{ins} (°C)	T_s (°C)	T_c (°C)	T_{fm} (°C)	T_m (°C)	ΔT_{te} (°C)	R_{te} (Ω)	$R_{te,ave}$ (Ω)	α_{te} (V/°C)	K_{te} (W/°C)	P_L (W)
B1	1	4.8	0	-	-	0.290	22.5	24.2	58.7	58.2	52.1±0.2	55.1	6.2	-	4.52±0.41	0.047	0.78	-
			1.08	0.052	0.048	0.052	23.1	24.7	57.6	57.2	52.2±0.2	54.7	5.0	4.94		-	-	0.0025
			2.14	0.044	0.041	0.092	23.2	24.7	58.3	57.8	52.5±0.2	55.2	5.3	4.61		-	-	0.0037
			3.20	0.038	0.035	0.121	22.8	24.4	58.6	58.2	52.8±0.2	55.5	5.4	4.47		-	-	0.0043
			4.28	0.031	0.029	0.152	23.4	24.8	58.8	58.4	52.9±0.2	55.6	5.5	3.89		-	-	0.0044
			5.36	0.028	0.026	0.163	23.0	24.7	59.4	58.9	53.4±0.2	56.2	5.5	4.12		-	-	0.0043
			6.42	0.028	0.025	0.164	23.0	24.7	59.4	58.9	53.4±0.2	56.2	5.5	4.66		-	-	0.0042
			7.48	0.027	0.024	0.174	22.9	24.7	59.6	59.2	53.5±0.2	56.4	5.7	4.99		-	-	0.0042
B2	1	7.6	0	-	-	0.469	22.3	24.0	76.2	75.5	65.5±0.2	70.5	10.1	-	5.07±0.13	0.047	0.75	-
			1.08	0.081	0.075	0.082	22.3	24.0	74.6	73.8	65.8±0.2	69.8	8.0	5.10		-	-	0.0062
			2.14	0.068	0.063	0.138	22.1	23.9	74.5	73.8	65.7±0.3	69.7	8.1	5.13		-	-	0.0087
			3.20	0.059	0.055	0.184	22.1	23.9	74.7	74.0	65.6±0.2	69.8	8.5	4.96		-	-	0.0101
			4.28	0.052	0.048	0.213	22.3	23.9	74.9	74.3	65.7±0.3	70.0	8.6	5.14		-	-	0.0103
			5.36	0.046	0.043	0.238	22.1	24.0	74.9	74.2	65.6±0.2	69.9	8.6	5.20		-	-	0.0101
			6.42	0.041	0.038	0.260	21.9	23.8	75.6	74.9	66.3±0.2	70.6	8.7	5.16		-	-	0.0099
			7.48	0.037	0.034	0.285	21.9	23.8	76.2	75.5	66.6±0.2	71.1	8.9	4.83		-	-	0.0098
B3	1	10.4	0	-	-	0.636	24.4	25.9	96.3	95.3	82.0±0.3	88.6	13.3	-	5.29±0.42	0.048	0.78	-
			1.08	0.098	0.091	0.098	25.5	27.3	95.9	94.8	84.4±0.2	89.6	10.5	5.93		-	-	0.0089
			2.14	0.084	0.078	0.173	24.9	26.5	95.3	94.2	83.3±0.2	88.7	11.0	5.73		-	-	0.0135
			3.20	0.071	0.066	0.239	25.3	26.9	96.2	95.1	83.9±0.3	89.5	11.2	5.32		-	-	0.0157
			4.28	0.060	0.056	0.292	25.1	26.7	94.5	93.5	82.1±0.2	87.8	11.4	5.04		-	-	0.0162
			5.36	0.058	0.054	0.328	23.9	26.0	95.3	94.2	82.1±0.2	88.2	12.1	5.03		-	-	0.0176
			6.42	0.053	0.049	0.366	24.1	26.0	96.5	95.4	83.0±0.3	89.2	12.4	4.74		-	-	0.0180
			7.48	0.048	0.045	0.374	23.9	25.9	95.9	94.8	82.6±0.3	88.6	12.3	5.24		-	-	0.0170

Run #	HT8 module	P (W)	R_L (Ω)	V_{ref} (V)	I_L (A)	V_L (V)	T_a (°C)	T_{ins} (°C)	T_s (°C)	T_c (°C)	T_{fm} (°C)	T_m (°C)	ΔT_{te} (°C)	R_{te} (Ω)	$R_{te,ave}$ (Ω)	α_{te} (V/°C)	K_{te} (W/°C)	P_L (W)
B4	2	5.2	0.00	-	-	0.260	20.0	20.8	51.8	50.9	45.7±0.0	48.3	5.2	-		0.050	1.00	-
			1.08	0.068	0.063	0.068	19.5	20.2	50.7	50.0	46.2±0.1	48.1	3.8	3.05		-	-	0.0043
			2.16	0.054	0.050	0.108	19.2	19.9	50.6	49.9	45.8±0.0	47.8	4.1	3.04		-	-	0.0054
			3.24	0.045	0.042	0.135	18.8	19.8	50.8	50.1	45.8±0.0	47.9	4.4	3.00		-	-	0.0056
			4.32	0.039	0.036	0.155	19.2	20.2	50.9	50.2	45.7±0.1	47.9	4.5	2.93	2.85±0.17	-	-	0.0056
			5.40	0.034	0.031	0.169	19.0	20.0	51.1	50.4	45.7±0.0	48.1	4.7	2.91		-	-	0.0053
			6.48	0.031	0.029	0.186	18.9	19.7	51.4	50.7	45.9±0.1	48.3	4.8	2.58		-	-	0.0053
			7.56	0.026	0.024	0.187	20.9	21.1	52.1	51.3	46.7±0.1	49.0	4.6	2.95		-	-	0.0045
			8.64	0.024	0.022	0.198	19.6	20.4	52.2	51.4	46.6±0.1	49.0	4.8	2.71		-	-	0.0044
			9.72	0.023	0.021	0.207	20.3	20.4	52.5	51.7	46.8±0.1	49.3	4.9	2.49		-	-	0.0044
B5	2	7.6	0.00	-	-	0.375	19.4	20.9	64.0	63.1	55.8±0.1	59.5	7.3	-		0.051	1.04	-
			1.08	0.095	0.088	0.095	21.0	21.5	62.7	61.9	56.7±0.1	59.3	5.2	3.18		-	-	0.0084
			2.16	0.075	0.069	0.150	19.8	20.9	63.5	62.7	57.0±0.1	59.9	5.7	3.24		-	-	0.0104
			3.24	0.062	0.057	0.186	21.8	22.1	63.8	63.1	57.2±0.1	60.2	5.9	3.29		-	-	0.0107
			4.32	0.054	0.050	0.216	19.9	21.1	63.8	63.0	56.8±0.1	59.9	6.2	3.18	3.15±0.14	-	-	0.0108
			5.40	0.048	0.044	0.236	20.2	21.3	63.8	63.0	56.7±0.1	59.9	6.3	3.18		-	-	0.0105
			6.48	0.042	0.039	0.252	19.9	21.3	64.0	63.2	56.8±0.1	60.0	6.4	3.16		-	-	0.0098
			7.56	0.038	0.035	0.266	18.9	20.6	63.6	62.8	56.2±0.1	59.5	6.6	3.10		-	-	0.0094
			8.64	0.035	0.032	0.278	18.9	20.6	63.4	62.6	56.0±0.2	59.3	6.7	3.01		-	-	0.0090
			9.72	0.032	0.030	0.286	18.6	20.3	63.7	62.9	56.2±0.1	59.6	6.7	3.02		-	-	0.0085
B6	2	10.0	0.00	-	-	0.525	20.9	21.0	78.5	77.0	67.0±0.1	72.0	10.1	-		0.052	1.00	-
			1.08	0.122	0.113	0.122	21.3	21.6	77.1	75.7	68.7±0.1	72.2	7.0	3.57		-	-	0.0138
			2.16	0.100	0.093	0.201	21.8	22.3	77.5	76.3	68.7±0.1	72.5	7.6	3.48		-	-	0.0186
			3.24	0.088	0.081	0.263	20.9	21.0	77.4	76.1	67.8±0.1	72.0	8.3	3.23		-	-	0.0214
			4.32	0.075	0.069	0.302	20.3	20.7	78.4	77.0	68.3±0.1	72.7	8.7	3.19	3.32±0.19	-	-	0.0210
			5.40	0.066	0.061	0.328	21.6	22.1	78.8	77.4	68.8±0.1	73.1	8.6	3.24		-	-	0.0200
			6.48	0.058	0.054	0.347	20.3	20.7	78.7	77.3	68.4±0.1	72.8	8.9	3.32		-	-	0.0186
			7.56	0.052	0.048	0.364	19.3	20.7	78.4	77.1	68.2±0.1	72.6	8.9	3.34		-	-	0.0175
			8.64	0.047	0.044	0.381	20.2	21.6	79.5	78.0	69.0±0.1	73.5	9.0	3.27		-	-	0.0166
			9.72	0.044	0.041	0.394	19.8	20.9	79.4	78.1	68.8±0.1	73.4	9.3	3.23		-	-	0.0161

Run #	HT8 module	P (W)	R_L (Ω)	V_{ref} (V)	I_L (A)	V_L (V)	T_a (°C)	T_{ins} (°C)	T_s (°C)	T_c (°C)	T_{fm} (°C)	T_m (°C)	ΔT_{te} (°C)	R_{te} (Ω)	$R_{te,ave}$ (Ω)	α_{te} (V/°C)	K_{te} (W/°C)	P_L (W)
B7	3	5.1	0	-	-	0.252	19.0	23.4	52.9	52.4	46.6±0.1	49.5	5.8	-	2.92±0.12	0.043	0.87	-
			1.08	0.066	0.061	0.066	18.9	23.6	51.8	51.3	47.0±0.1	49.1	4.3	3.04		-	-	0.0040
			2.16	0.052	0.048	0.105	19.3	24.0	51.7	51.3	46.8±0.0	49.0	4.6	3.02		-	-	0.0051
			3.24	0.043	0.040	0.130	18.8	23.6	51.7	51.4	46.6±0.1	49.0	4.8	3.04		-	-	0.0052
			4.32	0.037	0.034	0.147	19.2	24.2	52.2	51.8	46.9±0.1	49.3	4.9	3.09		-	-	0.0050
			5.40	0.033	0.031	0.166	18.8	23.6	52.7	52.6	47.3±0.1	50.0	5.3	2.80		-	-	0.0051
			6.48	0.029	0.027	0.176	18.4	23.3	52.5	52.4	47.0±0.1	49.7	5.4	2.80		-	-	0.0047
			7.56	0.026	0.024	0.185	18.8	23.6	52.5	52.6	47.7±0.1	50.2	4.9	2.74		-	-	0.0045
			8.64	0.023	0.021	0.188	18.4	23.4	52.5	52.4	47.4±0.4	49.9	5.0	2.94		-	-	0.0040
			9.72	0.021	0.019	0.195	19.4	23.8	52.5	52.4	47.7±0.4	50.0	4.7	2.84		-	-	0.0038
B8	3	7.5	0	-	-	0.415	20.4	21.0	66.8	66.4	57.3±0.2	61.8	9.2	-	3.17±0.07	0.045	0.82	-
			1.08	0.105	0.097	0.105	20.5	20.9	65.6	65.2	58.0±0.3	61.6	7.3	3.19		-	-	0.0102
			2.16	0.084	0.078	0.167	20.6	20.7	65.6	65.1	57.6±0.3	61.3	7.6	3.21		-	-	0.0130
			3.24	0.068	0.063	0.215	20.5	20.4	65.5	65.2	57.3±0.3	61.3	7.9	3.01		-	-	0.0135
			4.32	0.059	0.055	0.236	20.8	21.1	65.9	65.4	57.6±0.3	61.5	7.9	3.28		-	-	0.0129
			5.40	0.052	0.048	0.26	20.5	20.1	65.9	65.5	57.3±0.3	61.4	8.2	3.22		-	-	0.0125
			6.48	0.046	0.043	0.276	20.7	21.0	66.3	65.9	57.8±0.3	61.8	8.1	3.26		-	-	0.0118
			7.56	0.042	0.039	0.296	20.6	20.6	65.9	65.5	57.1±0.3	61.3	8.4	3.04		-	-	0.0115
			8.64	0.038	0.035	0.303	20.6	21.3	65.9	65.5	57.1±0.3	61.3	8.5	3.19		-	-	0.0107
			9.72	0.034	0.031	0.313	21.0	22.0	66.9	66.6	58.0±0.3	62.3	8.6	3.17		-	-	0.0099
B9	3	10.3	0	-	-	0.511	20.4	21.4	78.8	78.7	66.9±0.1	72.8	11.8	-	3.17±0.12	0.043	0.87	-
			1.08	0.125	0.116	0.125	20.0	21.4	76.6	76.5	67.5±0.0	72.0	9.1	3.34		-	-	0.0145
			2.16	0.100	0.093	0.201	19.9	21.3	77.0	76.9	67.3±0.0	72.1	9.7	3.33		-	-	0.0186
			3.24	0.083	0.077	0.250	19.7	21	77.3	77.2	67.0±0.1	72.1	10.2	3.38		-	-	0.0192
			4.32	0.074	0.069	0.296	19.9	21.6	78.7	78.6	68.0±0.1	73.3	10.6	3.14		-	-	0.0203
			5.40	0.064	0.059	0.321	20.3	22.2	79.7	79.5	68.9±0.1	74.2	10.6	3.20		-	-	0.0190
			6.48	0.057	0.053	0.344	20.6	22.4	80.0	79.8	69.1±0.0	74.4	10.8	3.15		-	-	0.0182
			7.56	0.051	0.047	0.363	20.9	22.7	80.7	80.5	69.5±0.1	75.0	11.0	3.08		-	-	0.0171
			8.64	0.047	0.044	0.379	20.8	22.3	80.4	80.3	69.2±0.1	74.7	11.2	3.01		-	-	0.0165
			9.72	0.043	0.040	0.392	20.4	21.8	80.0	80.0	68.7±0.1	74.4	11.3	2.95		-	-	0.0156

Table 3 Summary results of TEC.

Run #	HT8 module	P_{EH} (W)	V_{te} (V)	I_{te} (A)	P_{te} (W)	ΣP_{te} (W)	T_a (°C)	T_{ins} (°C)	T_s (°C)	T_c (°C)	T_{fm} (°C)	ΔT_{te} (°C)	T_m (°C)	COP_c
C1	1	5.1	4.05	0.80	3.2	8.3	22.8	24.4	61.1	60.6	72.4±0.3	11.8	66.5	1.6
			6.10	1.37	8.4	13.5	26.2	27.2	78.6	78.0	102.2±0.4	24.2	90.1	0.6
			8.01	1.79	14.3	19.4	25.0	26.7	94.4	93.9	127.2±0.5	33.3	110.6	0.4
C2	1	7.3	4.03	0.86	3.5	10.8	23.4	24.9	75.8	75.0	86.1±0.3	11.1	80.5	2.1
			6.03	1.41	8.5	15.8	24.2	26.1	86.9	86.2	109.3±0.3	23.1	97.7	0.9
			8.03	1.88	15.1	22.4	23.7	26.0	106.0	105.2	137.1±0.5	31.9	121.1	0.5
C3	1	10.0	3.81	0.94	3.6	13.6	24.8	26.4	89.1	88.1	97.2±0.3	9.1	92.6	2.8
			6.03	1.46	8.8	18.8	25.0	26.7	102.1	101.1	122.6±0.4	21.5	111.9	1.1
			8.07	1.95	15.7	25.7	25.2	26.9	119.7	118.7	149.3±0.6	30.8	134.0	0.6
C4	2	5.0	1.97	0.77	1.5	6.5	19.9	22.4	47.3	46.9	57.5±0.1	10.6	52.2	3.3
			3.98	1.40	5.6	10.6	18.7	21.1	52.7	52.5	75.1±0.2	22.6	63.8	0.9
			6.09	1.95	11.9	16.9	18.9	21.1	66.7	66.5	101.4±0.4	34.9	84.0	0.4
C5	2	7.5	1.99	0.77	1.54	9.0	19.8	21.9	59.6	58.3	66.8±0.1	8.5	62.6	4.9
			4.12	1.44	5.93	13.4	18.4	21.1	62.9	62.8	85.3±0.1	22.5	74.1	1.3
			6.14	1.97	12.08	19.5	20.1	22.4	78.2	78.3	111.4±0.1	33.1	94.9	0.7
C6	2	10.4	2.01	0.75	1.5	11.9	18.8	19.6	69.5	68.5	74.5±0.1	6.0	82.8	6.9
			4.02	1.31	5.3	15.7	20.7	21.0	77.0	76.1	94.2±0.1	18.1	99.4	2.0
			6.03	1.82	11.0	21.4	21.8	21.8	86.8	86.5	115.1±0.3	28.6	117.9	1.0
C7	3	5.1	2.09	0.81	1.7	6.8	19.5	21.8	47.3	47.3	58.2±0.2	10.9	52.7	3.0
			4.08	1.43	5.8	10.9	20.1	22.8	55.5	55.6	78.7±0.3	23.1	67.1	0.9
			6.07	1.95	11.8	16.9	19.7	23.3	69.7	70.0	103.7±0.4	33.7	86.8	0.4
C8	3	7.6	2.06	0.81	1.7	9.3	19.2	22.2	57.0	57.1	65.8±0.2	8.7	61.5	4.6
			4.11	1.43	5.9	13.5	19.0	23.8	64.1	64.2	85.9±0.1	21.7	75.0	1.3
			6.12	1.96	12.0	19.6	18.8	24.0	77.9	78.2	110.0±0.2	31.8	94.1	0.6
C9	3	10.0	2.04	0.81	1.6	11.6	20.3	21.2	70.5	70.2	76.4±0.4	6.1	73.3	6.0
			4.00	1.38	5.5	15.5	19.3	21.3	76.8	76.4	94.3±0.6	17.9	85.4	1.8
			6.04	1.92	11.6	21.6	18.9	21.3	88.9	88.7	116.7±0.8	28.0	102.7	0.9

TABLE 4 RAW DATA FOR EXPERIMENTAL RUN A1.

Time(Min)	Power(P)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	10	18.6	19.6	19.6	19.6	19.6	19.7	19.6
10	10	18.8	19.9	47.7	47.9	47.6	48.3	47.9
20	10	18.9	19.9	61.8	62.0	61.6	62.3	61.9
30	10	19.5	19.9	67.9	68.1	67.7	68.6	68.1
40	10	19.3	20.0	71.5	71.8	71.3	72.2	71.7
50	10	20.0	20.2	73.8	74.0	73.6	74.5	74.0
60	10	20.0	20.4	75.0	75.2	74.9	75.7	75.2
70	10	19.7	20.5	75.8	76.1	75.7	76.5	76.0
80	10	19.4	20.7	76.7	77.0	76.4	77.4	76.9
90	10	19.9	20.9	77.1	77.3	76.9	77.7	77.3
100	10	19.9	21.0	77.7	77.9	77.5	78.3	77.9
110	10	20.2	21.1	77.7	78.0	77.5	78.5	77.9
120	10	19.5	21.2	77.9	78.1	77.5	78.6	78.0
130	15	19.3	21.4	89.7	90.0	89.5	90.6	90.0
140	15	19.6	21.6	95.7	95.9	95.3	95.7	95.7
150	15	19.7	21.6	98.7	99.0	98.3	98.9	98.7
160	15	19.8	21.8	100.2	100.5	99.9	100.5	100.3
170	15	20.1	21.8	101.6	101.9	101.4	101.9	101.7
180	15	20.4	21.9	101.3	101.6	101.0	101.4	101.3
190	15	19.9	22.1	102.2	102.4	101.7	102.1	102.1
200	15	20.2	22.3	102.7	102.9	102.3	102.9	102.7
210	15	20.2	22.5	104.0	104.3	103.6	104.0	104.0
220	15	20.0	22.5	104.6	104.8	104.1	104.6	104.5
230	15	20.9	22.5	104.6	104.9	104.4	104.9	104.7
240	20	20.1	22.5	105.0	105.3	104.6	105.1	105.0
250	20	19.3	22.7	115.4	115.8	114.6	116.3	115.5
260	20	20.3	22.6	119.8	120.6	119.4	121.1	120.2
270	20	19.8	22.6	122.2	122.9	121.8	123.5	122.6
280	20	20.4	22.7	123.1	123.8	122.6	124.5	123.5
290	20	21.0	22.8	123.6	124.4	123.4	125.2	124.2
300	20	20.9	22.8	123.7	124.6	123.5	125.4	124.3
310	20	19.7	23.0	124.8	125.5	124.1	126.2	125.2
320	20	21.0	23.0	124.5	125.3	124.0	125.9	124.9
330	20	19.8	22.9	124.3	125.0	123.6	125.6	124.6
340	20	19.7	23.0	124.1	124.9	123.4	125.4	124.5
350	20	20.0	23.1	125.0	125.7	124.3	126.3	125.3
360	20	20.1	23.1	124.9	125.7	124.4	126.3	125.3

TABLE 5 RAW DATA FOR EXPERIMENTAL RUN A2.

Time(Min)	Power(P)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	10	19.8	20.6	20.5	20.5	20.5	20.6	20.5
10	10	19.1	20.9	46.7	46.8	46.6	47.9	47.0
20	10	19.1	20.7	60.6	60.8	60.6	62.0	61.0
30	10	19.3	20.5	67.2	67.4	67.1	68.6	67.6
40	10	19.2	20.5	70.9	71.0	70.8	72.2	71.2
50	10	18.5	20.6	72.3	72.4	72.0	73.7	72.6
60	10	19.0	20.7	73.7	73.8	73.6	75.2	74.1
70	10	19.1	20.7	74.4	74.6	74.3	75.8	74.8
80	10	19.0	20.8	74.7	74.9	74.5	76.1	75.1
90	10	19.4	20.9	75.1	75.3	75.1	76.6	75.5
100	10	19.4	21.0	75.5	75.8	75.6	77.1	76.0
110	10	19.4	21.1	77.9	77.6	76.8	78.0	77.6
120	10	19.6	21.1	78.5	78.7	78.0	78.7	78.5
130	15	19.7	21.2	86.4	86.7	85.8	86.5	86.4
140	15	20.2	21.3	95.7	96.0	95.1	96.0	95.7
150	15	19.1	21.3	100.3	100.6	99.5	100.3	100.2
160	15	19.4	21.5	103.1	103.4	102.4	103.2	103.0
170	15	20.3	21.6	104.6	104.9	103.9	104.8	104.6
180	15	19.9	21.8	105.8	106.1	104.9	105.8	105.7
190	15	20.1	22.0	106.2	106.6	105.2	106.3	106.1
200	15	20.1	22.2	106.2	106.5	105.2	106.4	106.1
210	15	20.1	22.1	106.5	107.0	105.8	106.8	106.5
220	15	21.0	21.9	106.6	106.9	106.0	106.9	106.6
230	15	20.5	22.0	106.7	107.1	106.1	107.0	106.7
240	20	20.2	22.0	106.4	106.8	105.6	106.5	106.3
250	20	19.4	22.2	110.8	111.2	109.9	110.8	110.7
260	20	20.2	22.1	118.2	118.6	117.1	118.3	118.1
270	20	21.0	22.2	120.8	121.4	120.1	121.2	120.9
280	20	20.8	22.3	122.5	123.0	121.7	122.8	122.5
290	20	20.7	22.3	123.5	123.9	122.4	123.7	123.4
300	20	20.0	22.3	124.2	124.6	123.0	124.3	124.0
310	20	21.0	22.5	124.4	124.9	123.8	124.9	124.5
320	20	21.4	22.8	124.9	125.3	123.9	125.0	124.8
330	20	20.0	22.7	124.6	124.9	123.6	124.6	124.4
340	20	19.5	22.7	126.4	126.8	125.2	126.6	126.3
350	20	19.9	22.6	127.7	128.2	126.7	127.8	127.6
360	20	19.9	22.7	128.0	128.5	127.0	128.2	127.9

TABLE 6 RAW DATA FOR EXPERIMENTAL RUN A3.

Time(Min)	Power(P)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	10	19.7	20.8	22.7	22.7	22.7	22.8	22.7
10	10	19.3	20.6	48.0	48.1	48.1	49.0	48.3
20	10	19.2	20.7	62.6	62.2	62.0	63.2	62.5
30	10	19.2	20.5	69.2	68.8	68.6	69.7	69.1
40	10	19.8	20.5	72.6	72.3	72.1	73.2	72.6
50	10	19.1	20.6	74.6	74.2	74.0	75.1	74.5
60	10	19.4	20.5	75.7	75.3	75.1	76.2	75.6
70	10	18.9	20.5	76.4	76.0	75.8	76.9	76.3
80	10	19.7	20.7	76.9	76.6	76.4	77.5	76.9
90	10	18.8	20.8	77.4	77.0	76.8	77.9	77.3
100	10	19.3	20.7	77.7	77.3	77.1	78.1	77.6
110	10	19.1	20.7	77.9	77.5	77.3	78.4	77.8
120	10	18.5	20.8	77.7	77.3	77.1	78.1	77.6
130	15	19.1	20.8	83.1	82.4	82.1	83.5	82.8
140	15	18.8	20.8	93.0	92.3	91.9	93.3	92.6
150	15	19.0	20.9	96.8	96.1	95.8	97.1	96.5
160	15	18.7	21.0	98.5	97.9	97.6	98.8	98.2
170	15	18.8	21.0	99.7	99.1	98.8	100.0	99.4
180	15	19.1	21.1	101.1	100.3	100.1	101.3	100.7
190	15	18.7	21.3	101.8	101.0	100.7	101.9	101.4
200	15	19.2	21.3	103.0	102.3	102.0	103.2	102.6
210	15	18.7	21.3	103.7	103.0	102.7	103.9	103.3
220	15	19.4	21.6	104.5	103.7	103.5	104.6	104.1
230	15	19.7	21.6	105.2	104.5	104.2	105.4	104.8
240	20	19.2	21.9	105.7	104.9	104.6	105.8	105.3
250	20	21.3	23.1	107.1	106.3	105.9	107.2	106.6
260	20	22.4	24.4	117.8	116.9	116.6	117.9	117.3
270	20	20.6	23.4	121.4	120.4	120.1	121.4	120.8
280	20	20.9	23.1	122.4	121.5	121.1	122.6	121.9
290	20	20.2	22.9	121.9	120.9	120.7	122.1	121.4
300	20	18.8	22.4	117.4	116.0	115.9	117.4	116.7
310	20	20.8	22.9	121.3	120.3	120.0	121.3	120.7
320	20	19.2	22.8	120.4	118.7	118.9	120.5	119.6
330	20	19.4	22.7	122.2	121.1	120.7	122.1	121.5
340	20	18.8	22.5	117.7	116.5	116.2	117.7	117.0
350	20	19.7	22.6	120.4	119.4	119.0	120.4	119.8
360	20	19.7	22.5	120.6	119.4	119.1	120.5	119.9

TABLE 7 RAW DATA FOR EXPERIMENTAL RUN A4.

Time(Min)	Power(P)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	10	18.9	19.4	19.0	19.0	19.0	19.1	19.0
10	10	18.5	19.7	45.3	45.5	45.3	46.5	45.7
20	10	19.1	19.7	60.1	60.4	60.2	61.3	60.5
30	10	18.6	19.6	67.7	68.1	67.8	68.9	68.1
40	10	18.4	19.8	72.2	72.5	72.3	73.3	72.6
50	10	19.3	20.0	74.9	75.2	75.0	76.0	75.3
60	10	18.9	20.1	76.8	77.1	76.9	77.9	77.2
70	10	18.7	20.4	78.1	78.4	78.1	79.0	78.4
80	10	19.6	20.5	78.9	79.3	79.0	80.0	79.3
90	10	18.8	20.7	79.8	80.1	79.9	80.8	80.2
100	10	19.7	20.8	80.4	80.7	80.6	81.5	80.8
110	10	19.4	21.0	81.0	81.3	81.1	82.1	81.4
120	10	19.2	21.0	81.4	81.7	81.5	82.5	81.8
130	15	20.5	21.2	93.3	93.8	93.6	94.7	93.9
140	15	19.9	21.4	97.1	97.5	97.2	98.3	97.5
150	15	20.2	21.4	98.8	99.3	98.9	100.1	99.3
160	15	20.6	21.6	99.7	100.2	99.9	100.9	100.2
170	15	20.9	21.8	98.2	98.7	98.5	99.6	98.8
180	15	19.8	21.9	99.5	100.0	99.7	100.8	100.0
190	15	18.8	21.7	97.3	97.7	97.8	99.0	98.0
200	15	20.6	21.9	100.3	100.8	100.7	101.8	100.9
210	15	19.9	21.9	102.4	103.0	102.7	103.8	103.0
220	15	20.1	21.9	103.4	104.0	103.9	104.9	104.1
230	15	19.9	22.1	103.8	104.4	104.2	105.2	104.4
240	20	19.7	22.2	104.0	104.0	104.7	104.4	104.3
250	20	20.9	22.3	116.1	116.8	116.6	117.9	116.9
260	20	20.7	22.2	123.1	123.8	123.5	124.8	123.8
270	20	20.4	22.3	128.0	127.6	126.7	128.0	127.6
280	20	19.9	22.5	130.7	130.3	129.3	130.7	130.3
290	20	19.8	22.5	131.1	130.8	130.0	131.4	130.8
300	20	20.6	22.6	133.4	132.9	132.1	133.4	133.0
310	20	21.9	22.7	131.3	130.6	129.8	131.1	130.7
320	20	20.9	22.7	130.5	129.9	129.0	130.3	129.9
330	20	20.9	22.6	129.3	128.8	127.9	129.1	128.8
340	20	19.9	22.8	128.7	128.1	127.2	128.4	128.1
350	20	19.7	22.7	128.4	128.0	127.0	128.3	127.9
360	20	20.5	22.7	129.1	128.5	127.8	128.9	128.6

TABLE 8 RAW DATA FOR EXPERIMENTAL RUN B1

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	5.2	23.1	23.1	21.9	22.6	23.0	23.0	23.0	23.1	23.0	0.000	0.000
10	5.2	38.6	38.2	22.0	22.7	33.2	33.2	33.2	33.3	33.2	0.232	0.232
20	5.2	45.9	45.5	21.9	22.8	40.2	40.2	40.2	40.4	40.3	0.243	0.243
30	5.2	50.1	49.7	21.9	22.8	44.1	44.0	44.1	44.3	44.1	0.255	0.255
40	5.2	52.6	52.2	21.9	23.0	46.4	46.3	46.5	46.6	46.5	0.264	0.264
50	5.2	54.3	53.9	21.9	23.1	47.8	47.8	47.9	48.0	47.9	0.274	0.274
60	5.2	55.5	55.1	21.9	23.1	49.0	48.9	49.0	49.2	49.0	0.277	0.277
70	5.2	56.3	55.9	21.9	23.1	49.7	49.7	49.8	49.9	49.8	0.281	0.281
80	5.2	56.9	56.5	21.9	23.2	50.3	50.2	50.3	50.5	50.3	0.284	0.284
90	5.2	57.4	57.0	21.9	23.3	50.7	50.7	50.8	50.9	50.8	0.289	0.289
100	5.2	57.7	57.3	21.7	23.3	51.0	50.9	51.1	51.2	51.1	0.290	0.290
110	5.2	58.0	57.6	21.9	23.3	51.2	51.2	51.3	51.4	51.3	0.290	0.290
120	5.2	58.1	57.6	21.9	23.5	51.3	51.2	51.4	51.5	51.4	0.291	0.291
130	5.2	58.3	57.8	21.9	23.5	51.5	51.4	51.6	51.7	51.6	0.291	0.291
140	5.2	58.4	58.0	22.1	23.6	51.6	51.6	51.7	51.8	51.7	0.292	0.292
150	5.2	58.4	58.0	22.1	23.7	51.7	51.7	51.8	51.9	51.8	0.290	0.290
160	5.2	58.5	58.1	22.3	23.8	51.7	51.7	51.8	51.9	51.8	0.293	0.293
170	5.2	58.8	58.4	22.4	23.9	51.9	51.9	52.0	52.2	52.0	0.296	0.296
180	5.2	58.9	58.5	22.2	23.9	52.0	52.0	52.1	52.2	52.1	0.297	0.297
190	5.2	59.0	58.6	22.1	23.9	52.1	52.0	52.2	52.3	52.2	0.299	0.299
200	5.2	59.1	58.6	22.4	24.0	52.1	52.1	52.2	52.4	52.2	0.299	0.299
210	5.2	58.8	58.4	22.4	23.9	52.1	52.0	52.2	52.3	52.2	0.289	0.289
220	5.2	58.7	58.3	22.4	24.1	52.1	52.0	52.1	52.3	52.1	0.289	0.289
230	5.2	58.7	58.2	22.5	24.2	52.0	51.9	52.1	52.2	52.1	0.290	0.290
240	5.2	57.6	57.1	23.0	24.5	52.1	52.0	52.2	52.3	52.2	0.052	0.052
250	5.2	57.6	57.2	23.1	24.5	52.2	52.1	52.2	52.4	52.2	0.051	0.051
260	5.2	57.6	57.2	23.1	24.7	52.1	52.1	52.2	52.4	52.2	0.052	0.052
270	5.2	57.9	57.5	23.6	24.7	52.2	52.2	52.3	52.5	52.3	0.043	0.090
280	5.2	58.3	57.8	23.2	24.7	52.4	52.4	52.5	52.7	52.5	0.044	0.092
290	5.2	58.4	57.9	22.7	24.4	52.6	52.5	52.6	52.8	52.6	0.038	0.120
300	5.2	58.6	58.2	22.8	24.4	52.8	52.7	52.8	53.0	52.8	0.038	0.121
310	5.2	58.9	58.4	23.1	24.8	52.8	52.8	52.9	53.0	52.9	0.031	0.153
320	5.2	58.8	58.4	23.4	24.8	52.8	52.8	52.9	53.0	52.9	0.031	0.152
330	5.2	59.1	58.6	23.6	25.1	53.1	53.0	53.1	53.2	53.1	0.028	0.164
340	5.2	59.3	58.9	23.0	24.7	53.3	53.2	53.4	53.5	53.4	0.028	0.163
350	5.2	59.5	59.1	22.9	24.7	53.4	53.3	53.5	53.6	53.5	0.026	0.163
360	5.2	59.4	58.9	23.0	24.7	53.4	53.3	53.4	53.6	53.4	0.028	0.164
370	5.2	59.5	59.1	23.4	24.8	53.5	53.4	53.6	53.6	53.5	0.027	0.174
380	5.2	59.6	59.2	22.9	24.7	53.6	53.6	53.7	53.8	53.7	0.027	0.174

TABLE 9 RAW DATA FOR EXPERIMENTAL RUN B2

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	7.6	23.0	22.9	21.9	22.6	22.9	22.9	22.9	23.0	22.9	0.000	0.000
10	7.6	46.4	45.8	22.0	22.8	38.2	38.1	38.2	38.3	38.2	0.350	0.350
20	7.6	57.1	56.6	22.2	23.0	48.5	48.4	48.5	48.7	48.5	0.370	0.370
30	7.6	62.8	62.2	22.2	23.1	54.0	53.9	54.1	54.2	54.1	0.387	0.387
40	7.6	66.7	66.1	21.9	23.1	57.5	57.4	57.5	57.7	57.5	0.408	0.408
50	7.6	69.0	68.4	21.8	23.1	59.4	59.3	59.5	59.6	59.5	0.423	0.423
60	7.6	70.4	69.8	21.8	23.1	60.7	60.6	60.8	60.9	60.8	0.427	0.427
70	7.6	71.5	70.8	21.8	23.2	61.5	61.4	61.6	61.7	61.6	0.437	0.437
80	7.6	72.5	71.8	21.8	23.2	62.5	62.4	62.5	62.7	62.5	0.440	0.440
90	7.6	73.0	72.3	21.9	23.3	62.9	62.9	63.0	63.2	63.0	0.439	0.439
100	7.6	73.5	72.8	21.9	23.4	63.2	63.2	63.3	63.5	63.3	0.447	0.447
110	7.6	73.8	73.1	21.8	23.3	63.7	63.6	63.7	63.9	63.7	0.444	0.444
120	7.6	74.2	73.5	21.8	23.4	63.9	63.8	64.0	64.2	64.0	0.451	0.451
130	7.6	74.3	73.6	22.0	23.5	63.9	63.8	64.0	64.1	64.0	0.452	0.452
140	7.6	74.4	73.7	21.8	23.5	64.0	63.9	64.1	64.2	64.1	0.453	0.453
150	7.6	74.9	74.2	21.7	23.6	64.5	64.3	64.5	64.7	64.5	0.455	0.455
160	7.6	74.9	74.2	21.9	23.6	64.4	64.3	64.5	64.6	64.5	0.457	0.457
170	7.6	75.2	74.5	22.1	23.6	64.7	64.6	64.8	65.0	64.8	0.458	0.458
180	7.6	75.7	74.9	22.0	23.7	65.0	64.9	65.1	65.3	65.1	0.462	0.462
190	7.6	76.0	75.2	22.0	23.8	65.4	65.3	65.4	65.6	65.4	0.460	0.460
200	7.6	76.4	75.6	22.1	23.8	65.7	65.6	65.8	65.9	65.8	0.465	0.465
210	7.6	76.4	75.7	22.0	23.8	65.7	65.6	65.8	66.0	65.8	0.465	0.465
220	7.6	76.6	75.8	22.1	23.8	65.8	65.6	65.8	66.0	65.8	0.471	0.471
230	7.6	76.5	75.7	22.1	23.8	65.7	65.6	65.8	65.9	65.8	0.469	0.469
240	7.6	76.2	75.5	22.3	24.0	65.4	65.3	65.5	65.6	65.5	0.469	0.469
250	7.6	74.6	73.8	22.0	23.9	65.7	65.7	65.8	66.0	65.8	0.080	0.082
260	7.6	74.6	73.8	22.3	24.0	65.7	65.7	65.9	66.0	65.8	0.081	0.082
270	7.6	74.8	74.0	22.3	24.0	65.8	65.7	65.8	66.0	65.8	0.068	0.139

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
280	7.6	74.7	74.0	22.1	23.9	65.8	65.6	65.8	66.0	65.8	0.068	0.138
290	7.6	74.5	73.8	22.1	23.9	65.6	65.5	65.7	65.9	65.7	0.068	0.138
300	7.6	74.7	73.9	22.3	24.0	65.5	65.4	65.6	65.8	65.6	0.058	0.182
310	7.6	74.8	74.0	22.0	23.9	65.6	65.5	65.6	65.8	65.6	0.059	0.184
320	7.6	74.7	74.0	22.1	23.9	65.5	65.4	65.6	65.7	65.6	0.059	0.184
330	7.6	74.7	74.0	22.2	23.9	65.3	65.2	65.4	65.5	65.4	0.053	0.215
340	7.6	75.0	74.3	21.9	23.8	65.8	65.7	65.9	66.0	65.9	0.052	0.212
350	7.6	74.9	74.3	22.3	23.9	65.6	65.5	65.7	65.9	65.7	0.052	0.213
360	7.6	74.9	74.2	22.5	24.2	65.5	65.4	65.5	65.7	65.5	0.046	0.241
370	7.6	74.7	74.0	22.3	24.1	65.2	65.2	65.3	65.5	65.3	0.046	0.240
380	7.6	74.9	74.2	22.1	24.0	65.6	65.4	65.6	65.8	65.6	0.046	0.238
390	7.6	75.4	74.7	21.8	23.8	65.9	65.9	66.0	66.1	66.0	0.041	0.262
400	7.6	75.5	74.8	21.8	23.7	66.0	65.9	66.1	66.2	66.1	0.041	0.262
410	7.6	75.6	74.9	21.9	23.8	66.2	66.1	66.3	66.4	66.3	0.041	0.260
420	7.6	75.8	75.1	22.1	23.8	66.3	66.2	66.3	66.5	66.3	0.036	0.281
430	7.6	75.9	75.2	21.9	23.8	66.3	66.2	66.4	66.6	66.4	0.036	0.282
440	7.6	76.2	75.5	21.9	23.8	66.6	66.5	66.6	66.8	66.6	0.037	0.285

TABLE 10 RAW DATA FOR EXPERIMENTAL RUN B3

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	10.1	25.1	25.1	24.0	24.4	25.1	25.0	25.0	25.1	25.1	0.000	0.000
10	10.1	55.9	55.2	24.0	24.5	45.0	44.7	44.8	45.0	44.9	0.469	0.469
20	10.1	70.9	70.0	24.0	24.6	59.3	59.1	59.2	59.4	59.3	0.509	0.509
30	10.1	78.5	77.6	24.0	24.7	66.3	66.0	66.2	66.3	66.2	0.533	0.533
40	10.1	82.9	82.0	23.9	24.8	70.2	69.8	70.0	70.2	70.1	0.555	0.555
50	10.1	85.9	85.0	23.9	24.8	72.9	72.5	72.7	73.0	72.8	0.569	0.569
60	10.1	87.8	86.9	24.0	24.9	74.6	74.2	74.5	74.7	74.5	0.582	0.582
70	10.1	89.2	88.3	23.8	24.9	75.9	75.6	75.8	76.0	75.8	0.588	0.588
80	10.1	90.3	89.3	23.8	24.9	76.9	76.5	76.7	77.0	76.8	0.593	0.593
90	10.1	91.1	90.2	23.7	25.0	77.6	77.2	77.4	77.7	77.5	0.598	0.598
100	10.1	91.5	90.6	23.7	25.1	77.9	77.5	77.7	77.9	77.8	0.606	0.606
110	10.1	92.3	91.3	23.7	25.1	78.5	78.1	78.4	78.6	78.4	0.610	0.610
120	10.1	92.9	91.9	23.8	25.2	79.2	78.8	79.0	79.3	79.1	0.607	0.607
130	10.1	93.0	92.1	23.8	25.2	79.3	78.9	79.1	79.4	79.2	0.612	0.612
140	10.1	93.1	92.1	23.8	25.3	79.2	78.9	79.1	79.3	79.1	0.615	0.615
150	10.1	92.9	92.0	23.8	25.4	79.3	78.9	79.2	79.4	79.2	0.605	0.605
160	10.1	94.5	93.5	24.0	25.4	80.3	79.9	80.2	80.4	80.2	0.634	0.634
170	10.1	95.2	94.1	24.2	25.6	80.9	80.5	80.8	81.0	80.8	0.637	0.637
180	10.1	95.6	94.6	23.8	25.5	81.3	80.8	81.1	81.3	81.1	0.641	0.641
190	10.1	95.9	94.8	23.8	25.5	81.4	81.0	81.2	81.5	81.3	0.645	0.645
200	10.1	96.0	95.0	23.7	25.5	81.7	81.4	81.5	81.7	81.6	0.641	0.641
210	10.1	96.6	95.5	23.9	25.5	82.2	81.9	82.1	82.3	82.1	0.640	0.640
220	10.1	96.7	95.7	23.9	25.6	82.5	82.1	82.3	82.5	82.4	0.639	0.639
230	10.1	96.8	95.7	24.2	25.7	82.5	82.1	82.3	82.6	82.4	0.637	0.637
240	10.1	96.4	95.3	24.2	25.7	82.2	81.8	82.0	82.2	82.1	0.635	0.635
250	10.1	96.4	95.3	24.2	25.8	82.2	81.7	82.0	82.2	82.0	0.636	0.636
260	10.1	96.3	95.3	24.4	25.9	82.1	81.7	81.9	82.2	82.0	0.636	0.636
270	10.1	94.8	93.8	25.1	26.7	83.2	82.7	83.0	83.2	83.0	0.100	0.101

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
280	10.1	95.2	94.2	25.4	26.9	83.8	83.4	83.7	83.9	83.7	0.098	0.099
290	10.1	95.9	94.8	25.5	27.3	84.5	84.1	84.3	84.5	84.4	0.097	0.098
300	10.1	96.0	95.0	26.0	27.4	84.7	84.3	84.5	84.7	84.6	0.096	0.097
310	10.1	97.3	96.3	26.1	27.6	85.5	85.1	85.3	85.6	85.4	0.083	0.171
320	10.1	96.7	95.6	26.2	27.8	85.0	84.7	84.9	85.0	84.9	0.083	0.170
330	10.1	96.4	95.3	26.4	27.9	84.8	84.4	84.6	84.7	84.6	0.082	0.170
340	10.1	95.7	94.7	25.5	27.0	84.0	83.6	83.8	84.0	83.9	0.083	0.172
350	10.1	95.3	94.2	24.9	26.5	83.4	83.0	83.2	83.4	83.3	0.084	0.173
360	10.1	96.1	95.0	25.9	26.9	84.0	83.6	83.9	84.1	83.9	0.071	0.238
370	10.1	96.2	95.1	25.3	26.9	84.0	83.6	83.9	84.1	83.9	0.071	0.239
380	10.1	95.8	94.7	25.0	26.7	83.4	83.0	83.2	83.5	83.3	0.071	0.241
390	10.1	95.4	94.3	24.7	26.6	82.8	82.5	82.7	82.9	82.7	0.061	0.294
400	10.1	95.3	94.2	24.5	26.3	82.7	82.4	82.7	82.9	82.7	0.061	0.294
410	10.1	94.9	93.8	24.2	26.2	82.3	82.0	82.2	82.4	82.2	0.061	0.294
420	10.1	94.3	93.2	24.3	26.2	81.7	81.4	81.6	81.9	81.7	0.061	0.294
430	10.1	94.5	93.5	25.1	26.7	82.2	81.9	82.1	82.3	82.1	0.060	0.292
440	10.1	94.5	93.4	24.1	26.3	81.8	81.5	81.7	81.9	81.7	0.055	0.326
450	10.1	94.1	93.0	24.1	26.2	81.6	81.3	81.5	81.7	81.5	0.056	0.315
460	10.1	94.5	93.4	24.2	26.2	81.4	81.1	81.4	81.6	81.4	0.058	0.327
470	10.1	95.3	94.2	23.9	26.0	82.2	81.9	82.1	82.3	82.1	0.058	0.328
480	10.1	96.0	94.9	24.1	26.1	82.6	82.4	82.6	82.8	82.6	0.053	0.364
490	10.1	96.5	95.4	24.1	26.0	83.0	82.7	83.0	83.2	83.0	0.053	0.366
500	10.1	96.7	95.6	24.1	26.0	83.3	83.0	83.3	83.5	83.3	0.053	0.365
510	10.1	97.4	96.3	24.1	26.0	83.6	83.5	83.7	83.9	83.7	0.051	0.387
520	10.1	96.2	95.2	24.0	26.1	83.0	82.9	83.1	83.3	83.1	0.048	0.370
530	10.1	95.7	94.6	24.1	26.0	82.5	82.4	82.6	82.9	82.6	0.048	0.367
540	10.1	95.9	94.8	23.9	25.9	82.6	82.4	82.6	82.8	82.6	0.048	0.374

TABLE 11 RAW DATA FOR EXPERIMENTAL RUN B4

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	5.2	22.7	22.6	21.0	21.5	21.6	21.6	21.6	21.7	21.6	0.000	0.000
10	5.2	36.8	36.2	20.3	21.2	31.7	31.6	31.6	31.8	31.7	0.225	0.225
20	5.2	42.9	42.1	20.5	21.1	37.6	37.5	37.5	37.6	37.6	0.232	0.232
30	5.2	46.3	45.4	20.4	21.1	40.8	40.7	40.7	40.8	40.8	0.240	0.240
40	5.2	48.8	47.9	20.6	21.2	42.9	42.9	42.9	43.0	42.9	0.247	0.247
50	5.2	50.1	49.2	20.6	21.1	44.3	44.3	44.3	44.4	44.3	0.253	0.253
60	5.2	50.7	49.8	20.7	21.1	44.9	44.8	44.9	45.0	44.9	0.253	0.253
70	5.2	51.2	50.3	20.8	21.2	45.4	45.3	45.3	45.4	45.4	0.253	0.253
80	5.2	51.6	50.7	20.8	21.2	45.8	45.7	45.7	45.8	45.8	0.254	0.254
90	5.2	51.7	50.9	20.7	21.2	45.9	45.8	45.8	45.9	45.9	0.258	0.258
100	5.2	51.8	51.0	20.6	21.1	46.0	46.0	46.0	46.1	46.0	0.260	0.260
110	5.2	51.8	51.0	20.4	20.9	46.0	45.9	45.9	46.0	46.0	0.260	0.260
120	5.2	51.8	50.9	20.0	20.8	45.7	45.7	45.7	45.7	45.7	0.260	0.260
125	5.2	50.6	49.9	19.8	20.5	46.1	46.0	46.0	46.1	46.1	0.069	0.069
130	5.2	50.7	49.9	19.6	20.4	46.1	46.1	46.1	46.2	46.1	0.068	0.068
135	5.2	50.7	50.0	19.4	20.2	46.2	46.1	46.1	46.2	46.2	0.068	0.068
140	5.2	50.7	50.0	19.5	20.2	46.2	46.1	46.2	46.2	46.2	0.068	0.068
145	5.2	50.9	50.1	19.7	20.3	46.1	46.0	46.0	46.1	46.1	0.054	0.108
150	5.2	50.8	50.0	19.1	20.1	45.9	45.8	45.9	45.9	45.9	0.054	0.108
155	5.2	50.7	49.9	19.3	20.0	45.9	45.8	45.8	45.9	45.9	0.054	0.108
160	5.2	50.6	49.9	19.2	19.9	45.8	45.7	45.8	45.8	45.8	0.054	0.108
165	5.2	50.6	49.8	19.2	19.9	45.5	45.5	45.5	45.6	45.5	0.045	0.135
170	5.2	50.7	50.0	18.8	19.8	45.7	45.6	45.7	45.7	45.7	0.045	0.135
175	5.2	50.8	50.1	18.8	19.8	45.7	45.7	45.7	45.8	45.7	0.045	0.135

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
180	5.2	50.8	50.1	18.8	19.8	45.8	45.7	45.7	45.8	45.8	0.045	0.135
185	5.2	50.9	50.2	18.9	19.8	45.7	45.6	45.6	45.7	45.7	0.039	0.156
190	5.2	50.9	50.2	19.1	20.1	45.7	45.6	45.6	45.7	45.7	0.039	0.156
195	5.2	50.9	50.2	19.3	20.2	45.7	45.6	45.6	45.7	45.7	0.039	0.155
200	5.2	50.9	50.2	19.2	20.2	45.7	45.7	45.6	45.7	45.7	0.039	0.155
205	5.2	51.1	50.3	19.6	20.5	45.8	45.7	45.7	45.8	45.8	0.034	0.169
210	5.2	51.2	50.4	19.5	20.6	45.8	45.7	45.7	45.8	45.8	0.034	0.169
215	5.2	51.1	50.3	19.3	20.3	45.7	45.7	45.7	45.8	45.7	0.034	0.169
220	5.2	51.1	50.4	19.0	20.0	45.7	45.7	45.7	45.7	45.7	0.034	0.169
225	5.2	51.3	50.5	18.9	19.9	45.7	45.6	45.6	45.7	45.7	0.031	0.188
230	5.2	51.5	50.7	19.0	19.8	45.8	45.8	45.8	45.9	45.8	0.031	0.188
235	5.2	51.7	50.9	19.0	19.7	46.0	46.0	46.0	46.1	46.0	0.031	0.186
240	5.2	51.4	50.7	18.9	19.7	45.9	45.9	45.9	46.0	45.9	0.031	0.186
245	5.2	51.6	50.8	19.4	20.0	46.0	46.0	46.0	46.1	46.0	0.027	0.189
250	5.2	51.7	51.0	19.9	20.4	46.2	46.2	46.2	46.3	46.2	0.027	0.189
255	5.2	51.8	51.1	20.1	20.6	46.4	46.3	46.4	46.4	46.4	0.026	0.187
260	5.2	52.1	51.3	20.9	21.1	46.7	46.6	46.7	46.8	46.7	0.026	0.187
265	5.2	52.3	51.5	20.1	21.2	46.8	46.7	46.7	46.8	46.8	0.024	0.198
270	5.2	52.3	51.5	19.9	21.1	46.8	46.7	46.7	46.8	46.8	0.024	0.198
275	5.2	52.3	51.5	19.8	20.9	46.7	46.7	46.7	46.8	46.7	0.024	0.198
280	5.2	52.2	51.4	19.6	20.4	46.6	46.6	46.6	46.7	46.6	0.024	0.198
285	5.2	52.2	51.4	19.3	20.0	46.5	46.4	46.5	46.5	46.5	0.023	0.207
290	5.2	52.2	51.5	19.3	20.0	46.5	46.5	46.5	46.6	46.5	0.023	0.207
295	5.2	52.4	51.6	19.6	20.1	46.6	46.6	46.6	46.6	46.6	0.023	0.207
300	5.2	52.5	51.7	20.3	20.4	46.8	46.7	46.8	46.9	46.8	0.023	0.207

TABLE 12 RAW DATA FOR EXPERIMENTAL RUN B5

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	7.5	21.5	21.6	21.1	22.0	21.5	21.5	21.7	21.7	21.6	0.000	0.000
10	7.5	43.2	42.5	22.5	22.9	36.6	36.5	36.8	36.9	36.7	0.354	0.354
20	7.5	52.6	51.6	20.4	21.6	45.6	45.5	45.7	45.7	45.6	0.358	0.358
30	7.5	56.7	55.8	19.8	20.8	49.5	49.4	49.6	49.5	49.5	0.367	0.367
40	7.5	59.7	58.8	21.8	22.2	52.7	52.6	52.9	52.8	52.8	0.368	0.368
50	7.5	61.9	60.8	21.2	22.8	54.8	54.7	55.0	54.9	54.9	0.369	0.369
60	7.5	62.5	61.5	19.4	21.4	55.2	55.1	55.4	55.2	55.2	0.371	0.371
70	7.5	63.3	62.3	20.4	21.2	55.3	55.2	55.4	55.3	55.3	0.375	0.375
80	7.5	64.3	63.4	20.8	22.4	56.4	56.3	56.5	56.4	56.4	0.375	0.375
90	7.5	64.2	63.4	20.3	22.1	56.2	56.1	56.4	56.2	56.2	0.375	0.375
100	7.5	64.2	63.3	19.9	21.4	56.1	56.0	56.2	56.1	56.1	0.375	0.375
110	7.5	63.9	63.1	19.4	21.0	55.8	55.7	56.0	55.8	55.8	0.375	0.375
120	7.5	64.0	63.1	19.4	20.9	55.8	55.7	55.9	55.8	55.8	0.375	0.375
125	7.5	62.6	61.9	19.5	20.9	56.3	56.1	56.4	56.3	56.3	0.095	0.095
130	7.5	62.5	61.8	19.2	20.7	56.5	56.4	56.6	56.5	56.5	0.095	0.095
135	7.5	62.4	61.7	19.8	20.8	56.4	56.3	56.4	56.3	56.4	0.095	0.095
140	7.5	62.7	61.9	21.0	21.5	56.7	56.6	56.8	56.7	56.7	0.095	0.095
145	7.5	63.6	62.8	20.7	22.0	57.3	57.2	57.4	57.3	57.3	0.076	0.151
150	7.5	63.7	62.9	19.9	21.3	57.3	57.2	57.4	57.3	57.3	0.076	0.151
155	7.5	63.7	62.9	19.9	21.0	57.2	57.1	57.4	57.3	57.3	0.075	0.150
160	7.5	63.5	62.7	19.8	20.9	57.0	56.9	57.1	57.0	57.0	0.075	0.150
165	7.5	63.5	62.7	19.7	21.0	56.9	56.8	57.0	56.9	56.9	0.063	0.187
170	7.5	63.4	62.6	19.4	20.9	56.7	56.6	56.8	56.7	56.7	0.063	0.186
175	7.5	63.3	62.6	19.7	20.9	56.6	56.5	56.7	56.6	56.6	0.062	0.186

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
180	7.5	63.8	63.1	21.8	22.1	57.2	57.1	57.3	57.2	57.2	0.062	0.186
185	7.5	64.1	63.3	21.2	22.3	57.3	57.2	57.4	57.3	57.3	0.054	0.217
190	7.5	64.0	63.2	20.6	21.8	57.1	57.0	57.3	57.2	57.2	0.054	0.216
195	7.5	63.9	63.2	20.1	21.4	57.0	56.8	57.0	56.9	56.9	0.054	0.216
200	7.5	63.8	63.0	19.9	21.1	56.8	56.7	56.9	56.8	56.8	0.054	0.216
205	7.5	63.8	63.1	19.7	21.1	56.6	56.5	56.7	56.6	56.6	0.048	0.238
210	7.5	63.8	63.0	19.5	21.2	56.6	56.5	56.8	56.7	56.7	0.048	0.237
215	7.5	63.7	62.9	19.5	21.2	56.6	56.5	56.7	56.6	56.6	0.048	0.236
220	7.5	63.8	63.0	20.2	21.3	56.7	56.6	56.8	56.7	56.7	0.048	0.236
225	7.5	63.9	63.1	21.1	21.8	56.5	56.4	56.7	56.6	56.6	0.042	0.254
230	7.5	64.1	63.3	21.2	22.2	57.0	56.9	57.1	57.0	57.0	0.042	0.252
235	7.5	64.1	63.3	20.4	21.6	56.9	56.8	57.0	56.9	56.9	0.042	0.252
240	7.5	64.0	63.2	19.9	21.3	56.8	56.7	56.9	56.8	56.8	0.042	0.252
245	7.5	63.9	63.1	19.6	21.2	56.6	56.6	56.8	56.7	56.7	0.038	0.267
250	7.5	63.8	63.1	19.2	20.9	56.5	56.5	56.7	56.6	56.6	0.038	0.267
255	7.5	63.6	62.9	19.3	20.8	56.3	56.2	56.4	56.3	56.3	0.038	0.266
260	7.5	63.6	62.8	18.9	20.6	56.2	56.1	56.3	56.2	56.2	0.038	0.266
265	7.5	63.6	62.9	19.1	20.6	56.1	56.1	56.3	56.1	56.2	0.035	0.278
270	7.5	63.4	62.7	18.9	20.6	56.0	55.9	56.1	56.0	56.0	0.035	0.278
275	7.5	63.3	62.6	19.0	20.6	56.0	55.9	56.1	56.0	56.0	0.035	0.278
280	7.5	63.4	62.6	18.9	20.6	55.9	55.8	56.1	56.0	56.0	0.035	0.278
285	7.5	63.8	63.0	18.9	20.6	56.2	56.2	56.4	56.3	56.3	0.032	0.286
290	7.5	63.7	62.9	18.8	20.5	56.2	56.1	56.3	56.2	56.2	0.032	0.286
295	7.5	63.7	62.9	18.7	20.3	56.1	56.1	56.3	56.2	56.2	0.032	0.286
300	7.5	63.7	62.9	18.6	20.3	56.2	56.1	56.3	56.2	56.2	0.032	0.286

TABLE 13 RAW DATA FOR EXPERIMENTAL RUN B6

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	10	24.1	24.2	22.9	22.7	23.9	23.9	24.1	24.1	24.0	0.030	0.031
10	10	53.0	51.9	23.6	23.7	43.1	42.9	43.2	43.2	43.1	0.446	0.446
20	10	65.2	63.7	23.5	23.8	55.1	54.9	55.2	55.1	55.1	0.475	0.475
30	10	70.4	69.0	22.5	22.6	60.1	59.8	60.2	60.0	60.0	0.483	0.483
40	10	73.2	71.7	22.2	22.2	62.5	62.3	62.6	62.5	62.5	0.494	0.494
50	10	75.2	73.7	22.9	23.0	64.4	64.2	64.5	64.4	64.4	0.497	0.497
60	10	76.8	75.2	22.9	23.2	65.9	65.6	66.0	65.8	65.8	0.503	0.503
70	10	77.3	75.8	22.0	22.1	66.2	65.9	66.2	66.1	66.1	0.512	0.512
80	10	77.5	76.0	21.6	21.8	66.2	66.0	66.3	66.1	66.2	0.518	0.518
90	10	78.4	76.9	21.2	21.5	67.0	66.8	67.1	67.0	67.0	0.522	0.522
100	10	78.5	77.0	20.9	21.2	67.0	66.8	67.1	67.0	67.0	0.525	0.525
110	10	78.5	77.0	20.9	21.2	67.0	66.8	67.1	67.0	67.0	0.525	0.525
120	10	78.5	77.0	20.9	21.0	67.0	66.8	67.1	66.9	67.0	0.525	0.525
125	10	77.4	75.9	22.2	22.7	68.9	68.6	68.8	68.8	68.8	0.122	0.122
130	10	78.0	76.4	22.3	22.8	69.5	69.2	69.4	69.3	69.4	0.122	0.122
135	10	77.2	75.8	21.3	21.7	68.9	68.6	68.8	68.7	68.8	0.121	0.122
140	10	77.1	75.7	21.3	21.6	68.8	68.5	68.8	68.6	68.7	0.122	0.122
145	10	76.7	75.5	21.5	21.4	67.9	67.8	68.0	67.8	67.9	0.100	0.201
150	10	76.9	75.6	21.8	21.8	68.1	67.9	68.2	68.0	68.1	0.100	0.201
155	10	77.6	76.3	22.0	22.5	68.8	68.7	68.9	68.7	68.8	0.100	0.201
160	10	77.5	76.3	21.8	22.3	68.7	68.6	68.8	68.6	68.7	0.100	0.201
165	10	77.1	75.7	20.4	20.7	67.5	67.3	67.5	67.2	67.4	0.088	0.263
170	10	77.2	75.8	20.5	20.8	67.6	67.4	67.7	67.4	67.5	0.088	0.263
175	10	77.3	76.0	20.7	20.9	67.7	67.5	67.7	67.5	67.6	0.088	0.263

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
180	10	77.4	76.1	20.9	21.0	67.9	67.7	67.9	67.7	67.8	0.088	0.263
185	10	79.0	77.6	21.2	21.7	69.0	69.0	69.2	69.0	69.1	0.075	0.302
190	10	78.8	77.3	20.7	21.0	68.8	68.6	68.8	68.6	68.7	0.075	0.302
195	10	78.6	77.2	20.5	20.8	68.6	68.5	68.7	68.5	68.6	0.075	0.302
200	10	78.4	77.0	20.3	20.7	68.4	68.2	68.5	68.2	68.3	0.075	0.302
205	10	78.1	76.8	20.6	20.6	68.0	67.9	68.1	67.9	68.0	0.066	0.328
210	10	78.1	76.8	20.5	20.7	68.0	67.9	68.1	67.9	68.0	0.066	0.328
215	10	78.3	77.0	21.3	21.5	68.4	68.2	68.5	68.3	68.4	0.066	0.328
220	10	78.8	77.4	21.6	22.1	68.8	68.7	68.9	68.8	68.8	0.066	0.328
225	10	79.6	78.1	21.6	22.1	69.3	69.2	69.5	69.3	69.3	0.058	0.348
230	10	79.5	78.0	21.2	21.7	69.3	69.2	69.4	69.2	69.3	0.058	0.347
235	10	79.0	77.6	20.7	21.0	68.8	68.6	68.9	68.6	68.7	0.058	0.347
240	10	78.7	77.3	20.3	20.7	68.4	68.3	68.5	68.3	68.4	0.058	0.347
245	10	79.2	77.7	21.5	22.1	68.9	68.8	69.0	68.9	68.9	0.052	0.364
250	10	79.0	77.6	20.9	21.4	68.8	68.6	68.8	68.7	68.7	0.052	0.364
255	10	78.8	77.4	19.9	21.0	68.5	68.3	68.5	68.3	68.4	0.052	0.364
260	10	78.4	77.1	19.3	20.7	68.2	68.0	68.3	68.1	68.2	0.052	0.364
265	10	78.3	76.9	19.4	20.5	67.8	67.7	67.9	67.7	67.8	0.048	0.383
270	10	79.1	77.7	21.3	21.9	68.7	68.6	68.8	68.6	68.7	0.047	0.380
275	10	79.5	78.1	20.3	21.8	69.0	68.9	69.2	69.0	69.0	0.047	0.380
280	10	79.5	78.0	20.2	21.6	69.0	68.9	69.2	68.9	69.0	0.047	0.381
285	10	78.8	77.4	19.2	20.5	68.1	68.0	68.2	68.0	68.1	0.044	0.395
290	10	78.8	77.4	20.5	21.2	68.2	68.1	68.3	68.1	68.2	0.044	0.394
295	10	79.9	78.4	20.4	21.8	69.3	69.2	69.4	69.2	69.3	0.044	0.394
300	10	79.4	78.1	19.8	20.9	68.8	68.7	68.9	68.7	68.8	0.044	0.394

TABLE 14 RAW DATA FOR EXPERIMENTAL RUN B7

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	5.1	20.1	20.1	20.8	21.6	20.2	20.2	20.3	20.4	20.3	0.000	0.000
10	5.1	34.8	34.6	19.8	22.6	29.5	29.7	29.8	29.9	29.7	0.215	0.215
20	5.1	41.4	41.2	20.0	22.9	35.9	36.1	36.2	36.3	36.1	0.223	0.223
30	5.1	45.5	45.4	20.6	22.7	40.0	40.2	40.3	40.4	40.2	0.226	0.227
40	5.1	48.2	48.1	19.6	22.9	42.4	42.7	42.7	42.8	42.7	0.236	0.237
50	5.1	49.3	49.2	18.7	22.3	43.3	43.5	43.6	43.7	43.5	0.243	0.243
60	5.1	49.9	49.8	19.4	22.8	43.8	44.1	44.1	44.2	44.1	0.247	0.247
70	5.1	51.1	51.0	20.6	24.3	45.1	45.3	45.4	45.5	45.3	0.246	0.246
80	5.1	51.9	51.4	19.2	23.2	45.3	45.5	45.6	45.7	45.5	0.253	0.253
90	5.1	52.0	51.5	19.6	23.8	45.3	45.6	45.6	45.7	45.6	0.255	0.255
100	5.1	52.3	51.7	19.8	23.7	45.5	45.8	45.9	46.0	45.8	0.254	0.254
110	5.1	52.9	52.4	20.0	24.4	46.6	46.6	46.7	46.8	46.7	0.253	0.253
120	5.1	52.9	52.4	19.0	23.4	46.5	46.6	46.6	46.7	46.6	0.252	0.252
125	5.1	51.9	51.4	19.3	23.6	47.0	47.0	47.0	47.1	47.0	0.066	0.066
130	5.1	52.2	51.7	19.2	23.9	47.3	47.4	47.4	47.4	47.4	0.066	0.066
135	5.1	52.0	51.4	19.1	23.7	47.0	47.1	47.0	47.1	47.1	0.066	0.066
140	5.1	51.8	51.3	18.9	23.6	46.9	47.0	46.9	47.0	47.0	0.066	0.066
145	5.1	51.5	51.1	19.1	23.8	46.4	46.5	46.5	46.6	46.5	0.052	0.105
150	5.1	52.0	51.6	19.1	23.9	46.9	47.0	46.9	47.0	47.0	0.052	0.105
155	5.1	51.9	51.5	18.9	23.7	46.8	46.9	46.9	47.0	46.9	0.052	0.105
160	5.1	51.7	51.3	19.3	24.0	46.7	46.8	46.7	46.8	46.8	0.052	0.105
165	5.1	51.9	51.6	19.1	23.9	46.7	46.8	46.8	46.9	46.8	0.043	0.130
170	5.1	51.9	51.5	18.9	23.7	46.7	46.8	46.7	46.9	46.8	0.043	0.130
175	5.1	51.8	51.5	18.7	23.7	46.6	46.7	46.7	46.8	46.7	0.043	0.130

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
180	5.1	51.7	51.4	18.8	23.6	46.5	46.6	46.5	46.7	46.6	0.043	0.130
185	5.1	51.9	51.5	19.2	24.1	46.5	46.6	46.6	46.7	46.6	0.037	0.147
190	5.1	52.2	51.8	19.6	24.4	46.8	46.9	46.9	47.0	46.9	0.037	0.146
195	5.1	52.2	51.9	19.4	24.3	46.8	46.9	46.9	47.0	46.9	0.037	0.147
200	5.1	52.2	51.8	19.2	24.2	46.8	46.9	46.9	46.9	46.9	0.037	0.147
205	5.1	52.4	52.1	19.1	24.0	46.8	46.9	46.9	46.9	46.9	0.033	0.166
210	5.1	52.7	52.3	18.9	23.9	47.0	47.1	47.1	47.2	47.1	0.033	0.166
215	5.1	52.8	52.5	18.9	23.8	47.2	47.4	47.3	47.4	47.3	0.033	0.166
220	5.1	52.7	52.6	18.8	23.6	47.2	47.3	47.3	47.4	47.3	0.033	0.166
225	5.1	52.9	52.8	18.7	23.6	47.3	47.4	47.4	47.5	47.4	0.029	0.178
230	5.1	52.9	52.8	18.5	23.5	47.3	47.4	47.4	47.5	47.4	0.029	0.178
235	5.1	52.5	52.4	18.5	23.4	47.0	47.1	47.0	47.2	47.1	0.029	0.176
240	5.1	52.5	52.4	18.4	23.3	46.9	47.0	47.0	47.1	47.0	0.029	0.176
245	5.1	52.4	52.3	18.6	23.4	46.7	46.9	46.8	46.9	46.8	0.026	0.187
250	5.1	52.5	52.4	19.4	23.8	46.9	47.0	46.9	47.0	47.0	0.026	0.185
255	5.1	52.8	52.7	19.4	23.6	47.2	47.3	47.3	47.4	47.3	0.026	0.185
260	5.1	52.5	52.6	18.8	23.6	47.6	47.8	47.7	47.8	47.7	0.026	0.185
265	5.1	52.3	52.4	18.7	23.5	47.7	47.9	47.8	47.9	47.8	0.023	0.188
270	5.1	52.5	52.4	18.5	23.4	47.9	47.2	47.2	47.3	47.4	0.023	0.188
275	5.1	52.4	52.3	18.5	23.3	47.9	47.2	47.2	47.3	47.4	0.023	0.188
280	5.1	52.5	52.4	18.4	23.4	47.9	47.2	47.1	47.3	47.4	0.023	0.188
285	5.1	52.8	52.7	18.6	23.8	48.0	47.3	47.2	47.4	47.5	0.021	0.195
290	5.1	52.5	52.6	19.4	23.3	48.1	47.3	47.3	47.4	47.5	0.021	0.195
295	5.1	52.9	52.8	19.4	23.4	48.1	47.3	47.3	47.4	47.5	0.021	0.194
300	5.1	52.5	52.4	19.4	23.8	48.2	47.5	47.4	47.6	47.7	0.021	0.195

TABLE 15 RAW DATA FOR EXPERIMENTAL RUN B8

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	7.5	21.3	21.2	21.0	21.3	21.1	21.1	21.1	21.2	21.1	0.000	0.000
10	7.5	40.1	39.7	20.9	21.2	31.7	31.9	31.9	32.0	31.9	0.341	0.341
20	7.5	51.7	51.2	20.8	21.1	43.0	43.3	43.3	43.4	43.3	0.354	0.354
30	7.5	57.5	57.0	20.8	21.0	48.4	48.8	48.7	48.8	48.7	0.371	0.371
40	7.5	60.6	60.2	20.8	21.0	51.6	51.9	51.9	52.1	51.9	0.379	0.379
50	7.5	62.5	62.1	20.7	21.0	53.4	53.8	53.7	53.9	53.7	0.386	0.386
60	7.5	63.9	63.6	20.6	21.0	54.6	55.0	55.0	55.1	54.9	0.397	0.397
70	7.5	64.6	64.2	20.4	20.9	55.3	55.7	55.6	55.7	55.6	0.403	0.403
80	7.5	65.0	64.6	20.5	21.0	55.6	56.0	55.9	56.1	55.9	0.406	0.406
90	7.5	65.6	65.2	20.5	21.0	56.0	56.4	56.3	56.5	56.3	0.408	0.408
100	7.5	65.9	65.5	20.5	21.0	56.4	56.7	56.6	56.8	56.6	0.415	0.415
110	7.5	66.3	65.9	20.4	21.0	56.7	57.1	57.0	57.2	57.0	0.415	0.415
120	7.5	66.8	66.4	20.4	21.0	57.0	57.3	57.3	57.4	57.3	0.415	0.415
125	7.5	65.5	65.1	20.4	21.0	57.7	58.0	58.0	58.2	58.0	0.106	0.106
130	7.5	65.6	65.2	20.4	20.9	57.9	58.3	58.3	58.4	58.2	0.106	0.106
135	7.5	65.7	65.3	20.3	20.9	58.0	58.4	58.4	58.5	58.3	0.105	0.105
140	7.5	65.6	65.2	20.5	20.9	57.7	58.0	57.9	58.2	58.0	0.105	0.105
145	7.5	65.7	65.3	20.6	20.9	57.5	57.9	57.8	58.1	57.8	0.084	0.168
150	7.5	65.6	65.2	20.6	20.8	57.4	57.8	57.7	57.9	57.7	0.084	0.168
155	7.5	65.5	65.1	20.6	20.8	57.4	57.8	57.7	57.9	57.7	0.084	0.167
160	7.5	65.6	65.1	20.6	20.7	57.3	57.6	57.5	57.8	57.6	0.084	0.167
165	7.5	65.5	65.1	20.6	20.6	56.9	57.3	57.2	57.5	57.2	0.069	0.215
170	7.5	65.5	65.1	20.4	20.4	57.0	57.4	57.3	57.5	57.3	0.068	0.215
175	7.5	65.5	65.1	20.5	20.4	57.0	57.3	57.2	57.5	57.3	0.068	0.215

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
180	7.5	65.5	65.2	20.5	20.4	57.0	57.4	57.3	57.5	57.3	0.068	0.215
185	7.5	65.5	65.1	20.5	20.9	57.0	57.3	57.3	57.5	57.3	0.059	0.237
190	7.5	65.7	65.2	20.7	21.4	57.2	57.5	57.5	57.7	57.5	0.059	0.236
195	7.5	65.9	65.5	20.8	21.1	57.5	57.8	57.8	58.0	57.8	0.059	0.236
200	7.5	65.9	65.4	20.8	21.1	57.3	57.6	57.5	57.8	57.6	0.059	0.236
205	7.5	65.7	65.3	20.5	20.9	56.9	57.3	57.2	57.4	57.2	0.052	0.261
210	7.5	66.0	65.6	20.7	21.4	57.2	57.6	57.5	57.7	57.5	0.052	0.261
215	7.5	66.0	65.6	20.6	20.6	57.2	57.5	57.5	57.7	57.5	0.052	0.260
220	7.5	65.9	65.5	20.5	20.1	57.0	57.4	57.3	57.5	57.3	0.052	0.260
225	7.5	65.9	65.4	20.3	19.9	56.8	57.3	57.2	57.3	57.2	0.046	0.278
230	7.5	65.7	65.3	20.3	19.9	56.6	57.2	57.0	57.2	57.0	0.046	0.278
235	7.5	66.0	65.6	20.5	20.4	57.0	57.5	57.4	57.6	57.4	0.046	0.276
240	7.5	66.3	65.9	20.7	21.0	57.4	57.9	57.8	58.0	57.8	0.046	0.276
245	7.5	65.8	65.4	20.0	20.2	56.5	57.0	56.9	57.1	56.9	0.042	0.296
250	7.5	65.8	65.4	20.0	20.2	56.5	57.0	56.8	57.1	56.9	0.042	0.296
255	7.5	65.8	65.4	20.3	20.8	56.6	57.0	57.0	57.2	57.0	0.042	0.296
260	7.5	65.9	65.5	20.6	20.6	56.7	57.2	57.1	57.4	57.1	0.042	0.296
265	7.5	66.0	65.7	20.6	20.6	56.8	57.2	57.2	57.4	57.2	0.038	0.305
270	7.5	65.9	65.5	20.2	20.5	56.7	57.1	57.0	57.3	57.0	0.038	0.305
275	7.5	65.6	65.3	20.1	20.4	56.4	56.8	56.8	57.0	56.8	0.038	0.304
280	7.5	65.9	65.5	20.6	21.3	56.7	57.1	57.1	57.3	57.1	0.038	0.303
285	7.5	66.7	66.4	20.8	21.1	57.5	57.9	57.9	58.1	57.9	0.034	0.313
290	7.5	66.7	66.3	20.4	20.6	57.5	57.9	57.9	58.0	57.8	0.034	0.313
295	7.5	66.8	66.4	20.7	21.2	57.5	57.9	57.9	58.1	57.9	0.034	0.313
300	7.5	66.9	66.6	21.0	22.0	57.7	58.1	58.0	58.3	58.0	0.034	0.313

TABLE 16 RAW DATA FOR EXPERIMENTAL RUN B9

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
0	10.3	22.0	21.4	20.7	21.2	22.1	22.0	22.0	22.1	22.1	0.000	0.000
10	10.3	51.6	51.7	20.9	21.3	40.8	40.8	40.7	40.8	40.8	0.444	0.444
20	10.3	64.0	64.0	20.9	21.4	53.2	53.2	53.1	53.2	53.2	0.465	0.465
30	10.3	69.9	69.8	20.8	21.4	59.1	59.1	59.1	59.1	59.1	0.468	0.468
40	10.3	73.2	73.1	20.8	21.5	62.0	61.9	61.8	62.0	61.9	0.488	0.488
50	10.3	75.4	75.3	20.7	21.5	63.9	63.8	63.8	63.9	63.9	0.497	0.497
60	10.3	77.0	76.8	20.8	21.7	65.3	65.2	65.2	65.3	65.3	0.505	0.505
70	10.3	77.9	77.7	20.8	21.8	66.1	66.1	66.1	66.1	66.1	0.506	0.506
80	10.3	78.7	78.5	20.8	21.8	66.7	66.7	66.6	66.7	66.7	0.507	0.507
90	10.3	78.6	78.5	20.6	21.6	66.8	66.8	66.7	66.8	66.8	0.508	0.508
100	10.3	78.7	78.6	20.5	21.4	66.7	66.7	66.6	66.7	66.7	0.511	0.511
110	10.3	78.6	78.5	20.4	21.4	66.7	66.7	66.6	66.7	66.7	0.511	0.511
120	10.3	78.8	78.7	20.4	21.4	66.9	66.9	66.8	66.9	66.9	0.511	0.511
125	10.3	76.7	76.6	20.2	21.5	67.5	67.5	67.5	67.5	67.5	0.125	0.125
130	10.3	76.7	76.6	20.2	21.4	67.6	67.5	67.5	67.6	67.6	0.125	0.125
135	10.3	76.7	76.6	20.1	21.4	67.6	67.5	67.4	67.6	67.5	0.125	0.125
140	10.3	76.6	76.5	20.0	21.4	67.5	67.4	67.4	67.5	67.5	0.125	0.125
145	10.3	77.0	76.8	20.0	21.4	67.2	67.0	67.1	67.2	67.1	0.100	0.203
150	10.3	77.1	76.9	19.9	21.5	67.4	67.2	67.3	67.4	67.3	0.100	0.201
155	10.3	77.0	76.8	20.0	21.4	67.3	67.2	67.2	67.3	67.3	0.100	0.201
160	10.3	77.0	76.9	19.9	21.3	67.3	67.2	67.2	67.3	67.3	0.100	0.201
165	10.3	77.0	76.9	19.8	21.3	67.0	66.9	66.9	67.0	67.0	0.083	0.250
170	10.3	77.1	76.9	19.8	21.3	67.1	67.0	67.0	67.1	67.1	0.083	0.250
175	10.3	76.9	76.8	19.7	21.3	67.0	66.8	66.8	67.0	66.9	0.083	0.250

Time(Min)	Power(P)	T_s(°C)	T_c(°C)	T_a(°C)	T_{ins}(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)	V_{ref} (V)	V_{te}(V)
180	10.3	77.3	77.2	19.7	21.3	67.1	66.9	66.9	67.1	67.0	0.083	0.250
185	10.3	77.9	77.8	19.7	21.2	67.2	67.0	67.0	67.2	67.1	0.074	0.296
190	10.3	78.3	78.1	19.8	21.4	67.7	67.5	67.5	67.7	67.6	0.074	0.296
195	10.3	78.4	78.3	19.8	21.5	67.9	67.7	67.7	67.9	67.8	0.074	0.296
200	10.3	78.7	78.6	19.9	21.6	68.1	67.9	67.9	68.1	68.0	0.074	0.296
205	10.3	79.3	79.2	20.0	21.8	68.6	68.5	68.5	68.6	68.6	0.064	0.321
210	10.3	79.3	79.1	20.1	21.9	68.7	68.6	68.6	68.7	68.7	0.064	0.321
215	10.3	79.5	79.4	20.2	22.0	68.9	68.7	68.7	68.9	68.8	0.064	0.321
220	10.3	79.7	79.5	20.3	22.2	69.0	68.8	68.9	69.0	68.9	0.064	0.321
225	10.3	79.7	79.5	20.3	22.2	68.7	68.5	68.6	68.7	68.6	0.057	0.347
230	10.3	79.8	79.7	20.4	22.3	68.8	68.6	68.7	68.8	68.7	0.057	0.347
235	10.3	79.8	79.6	20.5	22.4	68.9	68.7	68.8	68.9	68.8	0.057	0.344
240	10.3	80.0	79.8	20.6	22.4	69.1	69.0	69.0	69.1	69.1	0.057	0.344
245	10.3	80.1	80.0	20.7	22.4	69.1	68.9	69.0	69.1	69.0	0.051	0.363
250	10.3	80.4	80.2	20.8	22.5	69.3	69.2	69.2	69.3	69.3	0.051	0.363
255	10.3	80.5	80.3	20.8	22.6	69.4	69.3	69.3	69.4	69.4	0.051	0.363
260	10.3	80.7	80.5	20.9	22.7	69.6	69.4	69.5	69.6	69.5	0.051	0.363
265	10.3	80.6	80.4	21.0	22.7	69.3	69.2	69.2	69.3	69.3	0.047	0.379
270	10.3	80.6	80.5	20.9	22.5	69.5	69.3	69.4	69.5	69.4	0.047	0.379
275	10.3	80.6	80.4	20.9	22.4	69.3	69.2	69.2	69.3	69.3	0.047	0.379
280	10.3	80.4	80.3	20.8	22.3	69.2	69.1	69.1	69.2	69.2	0.047	0.379
285	10.3	80.3	80.2	20.7	22.2	69.1	68.9	68.9	69.1	69.0	0.043	0.392
290	10.3	80.4	80.3	20.7	22.2	69.0	68.9	68.9	69.0	69.0	0.043	0.392
295	10.3	80.1	80.0	20.6	22.0	68.9	68.7	68.8	68.9	68.8	0.043	0.392
300	10.3	80.0	80.0	20.4	21.8	68.8	68.6	68.7	68.8	68.7	0.043	0.392

TABLE 17 RAW DATA FOR EXPERIMENTAL RUN C1

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
1	5.1	3.99	0.80	3.2	22.6	23.3	18.6	17.9	29.5	29.4	29.6	29.9	29.6
10	5.0	4.03	0.80	3.2	22.8	23.6	37.2	36.8	50.1	49.9	50.1	50.3	50.1
20	5.0	4.03	0.80	3.2	22.7	23.7	46.9	46.5	59.6	59.5	59.7	59.9	59.7
30	5.1	4.05	0.80	3.2	22.7	23.7	52.1	51.7	63.9	63.8	63.9	64.2	64.0
40	5.1	4.03	0.80	3.2	22.6	23.7	54.0	53.6	66.6	66.4	66.6	66.9	66.6
50	5.1	4.04	0.80	3.2	22.8	23.8	56.4	56.0	68.7	68.5	68.7	68.9	68.7
60	5.1	4.03	0.80	3.2	22.6	23.7	57.8	57.4	70.2	70.0	70.2	70.4	70.2
70	5.1	4.03	0.80	3.2	22.7	23.8	58.7	58.2	71.0	70.8	71.0	71.3	71.0
80	5.1	4.04	0.80	3.2	22.5	23.8	59.7	59.2	71.4	71.2	71.4	71.7	71.4
90	5.1	4.04	0.80	3.2	22.5	23.8	60.0	59.5	71.8	71.6	71.8	72.0	71.8
100	5.1	4.04	0.80	3.2	22.9	24.0	60.7	60.2	72.7	72.5	72.7	73.0	72.7
110	5.1	4.04	0.80	3.2	22.4	24.0	60.8	60.3	72.6	72.4	72.6	72.8	72.6
120	5.1	4.05	0.80	3.2	22.7	24.0	61.0	60.6	72.2	72.1	72.3	72.6	72.3
130	5.1	4.05	0.80	3.2	22.7	24.1	60.9	60.5	72.3	72.2	72.4	72.6	72.4
140	5.1	4.05	0.80	3.2	22.8	24.2	61.1	60.7	72.3	72.1	72.3	72.6	72.3
150	5.1	4.05	0.80	3.2	22.8	24.4	61.1	60.6	72.3	72.1	72.4	72.6	72.4
160	5.1	6.00	1.46	8.8	23.2	24.4	55.8	55.0	75.6	75.3	75.7	76.1	75.7
170	5.1	6.08	1.37	8.3	22.9	24.4	64.2	63.7	88.6	88.4	88.7	89.0	88.7
180	5.1	6.09	1.37	8.3	22.9	24.4	68.0	67.5	92.4	92.1	92.5	92.8	92.5
190	5.1	6.09	1.37	8.3	23.0	24.5	69.8	69.4	94.1	93.7	94.2	94.4	94.1
200	5.1	6.09	1.37	8.3	22.9	24.4	71.3	70.8	95.6	95.3	95.7	95.9	95.6
210	5.1	6.09	1.37	8.3	23.4	24.6	72.1	71.6	96.1	95.8	96.2	96.5	96.2
220	5.1	6.09	1.37	8.3	23.6	24.9	72.4	72.0	96.6	96.3	96.7	96.9	96.6
230	5.1	6.09	1.37	8.3	23.9	25.3	73.0	72.6	96.9	96.6	97.1	97.3	97.0

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
240	5.1	6.09	1.37	8.3	24.3	25.7	74.2	73.7	98.0	97.7	98.1	98.4	98.1
250	5.1	6.09	1.37	8.3	24.4	25.8	74.8	74.3	98.4	98.1	98.5	98.8	98.5
260	5.1	6.09	1.37	8.3	24.8	26.0	75.4	74.9	99.3	99.0	99.4	99.7	99.4
270	5.1	6.10	1.37	8.4	24.9	26.2	76.1	75.6	99.4	99.0	99.5	99.7	99.4
280	5.1	6.09	1.37	8.3	25.2	26.3	76.6	76.1	100.8	100.5	100.9	101.2	100.9
290	5.1	6.09	1.37	8.3	25.7	26.6	77.2	76.7	101.1	100.9	101.2	101.5	101.2
300	5.1	6.09	1.37	8.3	25.8	26.6	77.7	77.3	101.6	101.3	101.7	101.9	101.6
310	5.1	6.10	1.37	8.4	25.8	26.8	78.1	77.6	101.7	101.4	101.7	102.0	101.7
320	5.1	6.10	1.37	8.4	26.1	26.9	78.3	77.8	101.9	101.5	101.9	102.2	101.9
330	5.1	6.10	1.37	8.4	26.2	27.1	78.2	77.7	101.9	101.6	101.9	102.2	101.9
340	5.1	6.10	1.37	8.4	26.2	27.2	78.6	78.0	102.2	101.8	102.2	102.5	102.2
350	5.1	7.97	1.88	15.0	26.4	27.4	74.4	73.6	105.9	105.4	106.0	106.3	105.9
360	5.1	8.00	1.79	14.3	26.3	27.4	86.6	86.2	120.8	120.3	120.9	121.3	120.8
370	5.1	8.00	1.79	14.3	26.4	27.5	90.5	90.1	124.6	124.1	124.7	125.0	124.6
380	5.1	8.01	1.79	14.3	26.6	27.6	92.9	92.4	126.5	126.1	126.6	127.0	126.6
390	5.1	8.01	1.79	14.3	26.5	27.7	93.8	93.4	127.4	127.0	127.6	127.9	127.5
400	5.1	8.01	1.79	14.3	26.2	27.4	94.4	93.9	127.8	127.4	128.0	128.2	127.9
410	5.1	8.01	1.79	14.3	25.8	27.2	94.3	93.8	127.4	127.0	127.6	127.8	127.5
420	5.1	8.01	1.79	14.3	25.6	27.0	94.1	93.6	127.2	126.7	127.3	127.6	127.2
430	5.1	8.01	1.79	14.3	25.5	26.9	94.7	94.2	127.6	127.1	127.8	128.1	127.7
440	5.1	8.01	1.79	14.3	25.2	26.8	94.4	93.9	127.1	126.7	127.3	127.6	127.2
450	5.1	8.01	1.79	14.3	25.0	26.7	94.4	93.9	127.2	126.7	127.3	127.7	127.2

TABLE 18 RAW DATA FOR EXPERIMENTAL RUN C2

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	7.4	4.02	0.86	3.4	24.1	24.4	26.3	26.4	29.3	29.3	29.3	29.4	29.3
10	7.3	4.02	0.86	3.4	23.9	24.5	44.5	43.8	55.9	55.8	55.9	56.2	56.0
20	7.3	4.02	0.86	3.5	23.6	24.4	56.9	56.3	67.9	67.7	67.9	68.2	67.9
30	7.1	4.02	0.86	3.4	23.6	24.5	62.8	62.3	74.0	73.8	74.0	74.3	74.0
40	7.1	4.02	0.86	3.4	23.6	24.5	66.2	65.6	77.6	77.4	77.6	77.9	77.6
50	7.4	4.02	0.86	3.4	23.4	24.5	68.2	67.6	79.5	79.3	79.6	79.8	79.6
60	7.3	4.02	0.86	3.4	23.5	24.5	69.5	68.9	80.7	80.5	80.7	81.0	80.7
70	7.4	4.02	0.86	3.4	23.4	24.6	70.6	70.0	81.9	81.7	82.0	82.2	82.0
80	7.4	4.02	0.86	3.4	23.5	24.6	71.7	71.0	82.8	82.6	82.8	83.1	82.8
90	7.3	4.02	0.86	3.4	23.4	24.6	72.1	71.4	83.3	83.1	83.3	83.6	83.3
100	7.3	4.02	0.86	3.5	23.4	24.7	72.9	72.2	83.8	83.5	83.8	84.0	83.8
110	7.3	4.02	0.86	3.4	23.4	24.8	73.0	72.3	83.7	83.4	83.7	84.0	83.7
120	7.3	4.02	0.86	3.5	23.4	24.8	73.2	72.5	84.0	83.7	84.0	84.2	84.0
130	7.3	4.02	0.86	3.5	23.4	24.8	73.5	72.8	84.3	84.0	84.3	84.5	84.3
140	7.3	4.02	0.86	3.5	23.5	24.9	73.5	72.8	84.3	84.0	84.3	84.5	84.3
150	7.3	4.02	0.86	3.5	23.4	24.9	73.9	73.2	84.7	84.4	84.7	84.9	84.7
160	7.3	4.03	0.86	3.5	23.5	25.0	74.1	73.4	84.4	84.1	84.4	84.6	84.4
170	7.3	4.02	0.86	3.5	23.3	25.0	73.8	73.1	84.4	84.2	84.4	84.7	84.4
180	7.3	4.03	0.86	3.5	23.3	25.0	74.1	73.4	84.6	84.3	84.6	84.8	84.6
190	7.3	4.02	0.86	3.5	23.3	25.0	74.7	73.9	85.2	84.9	85.2	85.4	85.2
200	7.3	4.03	0.86	3.5	23.4	24.9	75.3	74.6	85.8	85.6	85.9	86.1	85.9
210	7.3	4.03	0.86	3.5	23.4	24.9	75.8	75.0	86.1	85.8	86.1	86.3	86.1
220	7.3	5.94	1.48	8.8	23.9	25.2	69.7	68.8	90.4	90.1	90.4	90.8	90.4
230	7.3	6.03	1.41	8.5	23.6	25.2	81.0	80.3	103.7	103.4	103.8	104.1	103.8
240	7.3	6.03	1.41	8.5	23.8	25.3	83.4	82.6	106.0	105.7	106.0	106.4	106.0
250	7.3	6.03	1.41	8.5	23.9	25.5	84.3	83.5	106.8	106.4	106.9	107.2	106.8

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
260	7.3	6.03	1.41	8.5	23.5	25.3	85.3	84.7	108.1	107.7	108.2	108.5	108.1
270	7.3	6.03	1.41	8.5	24.0	25.5	86.3	85.6	108.9	108.5	109.0	109.3	108.9
280	7.3	6.03	1.41	8.5	25.0	25.9	86.8	86.1	109.6	109.2	109.7	109.9	109.6
290	7.3	6.03	1.41	8.5	25.3	26.7	87.6	86.9	110.3	110.0	110.4	110.7	110.4
300	7.3	6.03	1.41	8.5	25.1	26.7	87.6	86.9	110.3	109.9	110.3	110.6	110.3
310	7.3	6.04	1.41	8.5	24.6	26.4	87.4	86.7	109.5	109.2	109.6	109.8	109.5
320	7.3	6.04	1.41	8.5	24.7	26.1	86.8	86.1	109.1	108.7	109.1	109.5	109.1
330	7.3	6.03	1.41	8.5	24.1	26.0	86.7	85.9	109.0	108.6	109.0	109.3	109.0
340	7.3	6.03	1.41	8.5	24.3	26.0	86.8	86.1	109.3	108.9	109.4	109.7	109.3
350	7.3	6.04	1.41	8.5	24.4	26.1	87.1	86.4	109.5	109.0	109.5	109.8	109.5
360	7.3	6.03	1.41	8.5	24.2	26.1	86.9	86.2	109.2	108.9	109.3	109.6	109.3
370	7.4	7.96	1.95	15.5	24.8	26.2	82.8	82	114.6	114.1	114.7	115.1	114.6
380	7.5	8.02	1.88	15.0	24.3	26.1	96.4	95.7	128.9	128.4	129.0	129.3	128.9
390	7.6	8.02	1.88	15.0	24.1	25.9	99.7	99.0	132.0	131.6	132.1	132.4	132.0
400	7.7	8.02	1.88	15.1	24.1	26.0	101.4	100.6	133.4	132.9	133.5	133.8	133.4
410	7.8	8.03	1.88	15.1	24.0	25.9	102.9	102.1	134.8	134.3	134.9	135.2	134.8
420	7.8	8.03	1.88	15.1	24.1	25.9	103.9	103.2	135.6	135.0	135.6	136.0	135.6
430	7.9	8.03	1.88	15.1	24.4	26.3	104.9	104.2	136.7	136.1	136.8	137.2	136.7
440	8.0	8.03	1.88	15.1	24.3	26.1	105.4	104.6	137.0	136.4	137.1	137.4	137.0
450	8.1	8.03	1.88	15.1	24.3	26.1	105.4	104.6	137.0	136.4	137.0	137.3	136.9
460	8.2	8.03	1.88	15.1	24.3	26.1	105.4	104.6	136.8	136.3	137.0	137.3	136.9
470	8.3	8.03	1.88	15.1	24.3	26.1	105.4	104.6	136.6	136.0	136.7	137.0	136.6
480	8.3	8.03	1.88	15.1	24.3	26.1	106.0	105.2	137.2	136.6	137.3	137.6	137.2
490	8.4	8.03	1.88	15.1	24.3	26.1	105.9	105.1	136.9	136.4	137.0	137.4	136.9
500	8.5	8.03	1.88	15.1	23.8	26.0	105.7	104.9	136.8	136.3	136.9	137.3	136.8
510	8.6	8.03	1.88	15.1	23.7	26.0	106.0	105.2	137.1	136.5	137.2	137.5	137.1

TABLE 19 RAW DATA FOR EXPERIMENTAL RUN C3

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	10.01	3.82	1.09	4.15	24.2	24.7	24.6	24.6	24.5	24.5	24.5	24.6	24.5
10	10.01	3.82	0.94	3.57	24.3	25.2	48.8	48.0	58.9	58.7	58.9	59.2	58.9
20	10.01	3.81	0.94	3.56	24.6	25.2	65.0	64.2	75.4	75.1	75.4	75.6	75.4
30	10.01	3.81	0.94	3.56	24.5	25.3	72.6	71.8	82.9	82.7	83.0	83.2	83.0
40	10.01	3.81	0.94	3.56	24.6	25.5	77.1	76.2	86.9	86.6	86.9	87.1	86.9
50	10.01	3.81	0.94	3.57	24.7	25.6	80.1	79.2	89.6	89.3	89.6	89.8	89.6
60	10.01	3.82	0.94	3.57	24.7	25.6	82.7	81.8	91.8	91.6	91.9	92.1	91.9
70	10.01	3.82	0.94	3.57	24.6	25.7	84.3	83.3	93.2	92.9	93.2	93.4	93.2
80	10.01	3.82	0.94	3.57	24.8	25.8	85.3	84.4	93.9	93.7	94.0	94.2	94.0
90	10.01	3.82	0.94	3.57	24.9	25.9	85.9	84.9	94.5	94.2	94.5	94.7	94.5
100	10.01	3.82	0.94	3.57	24.8	26.0	86.3	85.4	95.1	94.7	95.1	95.3	95.1
110	10.01	3.82	0.94	3.57	24.9	26.2	86.7	85.8	95.3	95.1	95.3	95.6	95.3
120	10.01	3.81	0.94	3.57	24.8	26.2	86.6	85.6	95.2	95.0	95.2	95.4	95.2
130	10.01	3.82	0.94	3.57	24.8	26.2	86.9	85.9	95.3	95.0	95.3	95.5	95.3
140	10.01	3.82	0.94	3.57	24.9	26.2	86.6	85.6	95.4	95.1	95.4	95.6	95.4
150	10.01	3.82	0.94	3.57	24.7	26.3	87.0	86.1	95.4	95.1	95.5	95.7	95.4
160	10.01	3.82	0.94	3.57	24.8	26.3	88.1	87.1	96.3	96.0	96.3	96.6	96.3
170	10.01	3.81	0.94	3.57	24.6	26.3	88.3	87.3	96.6	96.3	96.6	96.8	96.6
180	10.01	3.82	0.94	3.57	24.7	26.4	88.6	87.6	96.7	96.4	96.7	96.9	96.7
190	10.01	3.82	0.94	3.57	24.7	26.4	89.1	88.1	97.1	96.9	97.2	97.4	97.2
200	10.01	6.01	1.53	9.17	25.2	26.6	83.7	82.5	103.7	103.4	103.8	104.1	103.8
210	10.01	6.02	1.46	8.77	25.0	26.5	94.2	93.2	115.5	115.1	115.6	115.8	115.5
220	10.01	6.03	1.46	8.77	25.0	26.6	97.1	96.1	117.8	117.6	118.0	118.2	117.9
230	10.01	6.03	1.46	8.78	24.9	26.7	98.9	97.9	119.5	119.2	119.6	119.9	119.6
240	10.01	6.03	1.46	8.78	25.0	26.7	100.0	99.0	120.6	120.3	120.7	121.0	120.7
250	10.01	6.03	1.46	8.78	25.1	26.8	100.8	99.7	121.2	120.9	121.3	121.5	121.2
260	10.01	6.03	1.46	8.78	25.0	26.7	101.3	100.2	121.8	121.4	121.9	122.2	121.8
270	10.01	6.03	1.46	8.78	25.0	26.7	102.1	101.1	122.6	122.2	122.7	123.0	122.6
280	10.01	8.06	2.03	16.36	25.5	26.9	98.1	96.8	125.8	125.3	126.0	126.3	125.9
290	10.01	8.07	1.95	15.72	25.1	26.8	110.3	109.2	141.0	140.4	141.2	141.5	141.0
300	10.01	8.07	1.95	15.73	25.0	26.7	115.9	114.9	146.2	145.6	146.3	146.6	146.2
310	10.01	8.07	1.95	15.73	24.8	26.7	118.6	117.6	148.4	147.9	148.5	148.8	148.4
320	10.01	8.07	1.95	15.73	25.5	27.0	119.3	118.2	149.2	148.6	149.3	149.7	149.2
330	10.01	8.08	1.95	15.74	24.9	26.8	119.5	118.4	149.3	148.7	149.4	149.7	149.3
340	10.01	8.08	1.95	15.74	25.2	26.9	119.7	118.7	149.2	148.7	149.4	149.8	149.3

TABLE 20 RAW DATA FOR EXPERIMENTAL RUN C4

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	5.13	2.408	0.895	2.16	19.5	20.5	21.6	21.5	21.3	21.3	21.3	21.5	21.4
10	5.12	2.408	0.895	2.16	20.8	21.8	29.3	28.9	39.7	39.6	39.7	39.7	39.7
20	5.12	2.040	0.805	1.64	19.8	21.4	37.3	37.0	49.3	49.3	49.4	49.5	49.4
30	5.12	2.027	0.807	1.64	19.0	20.8	41.7	41.4	52.6	52.5	52.6	52.6	52.6
40	5.12	2.030	0.802	1.63	20.5	21.9	43.4	43.1	54.2	54.1	54.3	54.3	54.2
50	5.11	2.024	0.798	1.62	20.3	22.7	44.9	44.6	55.7	55.7	55.8	55.7	55.7
60	5.05	2.025	0.800	1.62	19.0	21.0	45.1	44.8	55.7	55.6	55.8	55.7	55.7
70	5.13	2.026	0.799	1.62	19.9	21.4	45.5	45.1	56.0	55.9	56.1	56.0	56.0
80	5.10	2.026	0.794	1.61	21.2	23.0	46.3	46.0	57.0	57.0	57.1	57.0	57.0
90	5.10	2.026	0.797	1.61	19.4	21.6	46.5	46.1	57.0	57.0	57.1	57.0	57.0
100	5.01	2.006	0.787	1.58	19.2	21.1	46.2	45.8	56.5	56.5	56.6	56.5	56.5
110	5.01	1.995	0.771	1.54	21.1	22.7	46.6	46.2	57.0	57.0	57.1	57.0	57.0
120	5.04	1.969	0.774	1.52	19.9	22.4	47.3	46.9	57.4	57.4	57.5	57.5	57.5
130	4.99	4.135	1.503	6.21	18.9	21.3	45.1	44.7	69.4	69.3	69.5	69.3	69.4
140	4.98	4.082	1.457	5.95	20.0	21.8	49.4	49.1	73.6	73.6	73.7	73.5	73.6
150	5.01	4.083	1.445	5.90	21.1	23.3	51.8	51.5	76.0	76.0	76.2	75.9	76.0
160	5.02	4.079	1.445	5.89	19.2	21.7	52.5	52.2	76.4	76.4	76.6	76.4	76.5
170	5.01	4.077	1.443	5.88	18.8	21.0	52.4	52.1	76.3	76.2	76.4	76.2	76.3
180	5.02	4.078	1.437	5.86	20.6	22.5	53.0	52.8	77.1	77.1	77.3	77.0	77.1
190	5.01	4.076	1.439	5.87	19.6	22.4	53.6	53.3	77.5	77.5	77.7	77.4	77.5
200	5.01	4.073	1.444	5.88	18.8	21.2	52.9	52.7	76.7	76.7	76.9	76.7	76.8
210	5.02	4.068	1.443	5.87	19.5	21.3	52.4	52.1	76.1	76.1	76.3	76.1	76.2
220	5.00	4.060	1.438	5.84	21.1	23.2	53.1	53.0	77.0	77.0	77.2	77.0	77.1
230	5.01	4.143	1.461	6.05	19.1	21.6	53.3	53.0	76.4	76.4	76.6	76.4	76.5
240	5.01	3.975	1.403	5.58	18.7	21.1	52.7	52.5	75.0	75.0	75.2	75.0	75.1
250	5.11	6.031	2.084	12.57	19.1	21.2	59.8	59.7	95.3	95.4	95.6	95.3	95.4
260	5.13	5.915	1.945	11.50	18.8	21.4	62.3	62.3	97.0	97.0	97.2	96.9	97.0
270	5.13	6.256	2.022	12.65	18.8	21.1	64.2	64.1	100.7	100.6	100.9	100.5	100.7
280	5.13	6.084	1.952	11.88	18.8	21.1	65.5	65.5	100.9	101.0	101.2	100.8	101.0
290	5.14	6.081	1.985	12.07	19.0	21.0	65.6	65.5	100.9	100.9	101.2	100.8	101.0
300	5.15	6.083	1.983	12.06	18.9	21.1	65.8	65.8	101.1	101.0	101.3	101.0	101.1
310	5.07	6.083	1.952	11.87	19.1	21.2	66.3	66.1	101.9	101.6	101.1	101.4	101.5
320	5.14	6.084	1.952	11.88	18.8	21.4	66.6	66.4	101.3	101.9	101.5	101.8	101.6
330	5.07	6.084	1.950	11.86	18.8	21.1	66.8	66.6	101.2	101.8	101.4	101.7	101.5
340	5.14	6.083	1.951	11.87	18.8	21.1	67.0	66.8	101.5	101.1	101.7	101.0	101.3
350	5.07	6.083	1.951	11.87	19.0	21.0	67.0	66.8	101.4	101.2	101.6	101.0	101.3
360	5.07	6.085	1.949	11.86	18.9	21.1	66.7	66.5	101.3	101.0	101.5	101.8	101.4

TABLE 21 RAW DATA FOR EXPERIMENTAL RUN C5

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	7.508	2.007	0.947	1.901	20.0	20.3	17.1	16.4	24.9	24.9	25.0	25.0	25.0
10	7.405	1.988	0.851	1.692	20.9	21.8	37.3	36.6	46.3	46.3	46.4	46.4	46.4
20	7.462	2.027	0.819	1.660	19.4	20.6	46.2	45.8	55.7	55.7	55.8	55.7	55.7
30	7.665	2.027	0.815	1.652	19.4	20.5	50.6	50.2	59.5	59.4	59.5	59.5	59.5
40	7.674	2.022	0.800	1.618	20.7	22.0	54.4	54.0	63.0	63.0	63.2	63.0	63.1
50	7.665	2.015	0.800	1.612	19.8	21.7	56.3	56.0	64.8	64.8	64.9	64.7	64.8
60	7.674	2.014	0.803	1.617	19.3	21.1	57.1	56.8	65.4	65.4	65.5	65.4	65.4
70	7.682	2.015	0.803	1.618	19.3	21.1	57.5	57.2	65.8	65.8	65.9	65.8	65.8
80	7.691	2.015	0.796	1.604	20.4	22.5	58.8	58.5	67.2	67.2	67.3	67.2	67.2
90	7.499	2.012	0.796	1.602	19.0	21.3	58.7	58.4	66.9	66.8	67.0	66.9	66.9
100	7.508	2.010	0.808	1.624	18.8	20.9	58.4	58.1	66.6	66.6	66.7	66.6	66.6
110	7.491	2.030	0.800	1.624	18.9	21.0	58.1	57.8	66.5	66.5	66.6	66.5	66.5
120	7.482	1.986	0.773	1.535	19.8	21.9	58.6	58.3	66.8	66.7	66.9	66.8	66.8
130	7.473	4.122	1.466	6.043	19.4	21.6	57.2	56.9	79.5	79.5	79.7	79.5	79.6
140	7.353	4.132	1.447	5.979	18.9	21.2	60.8	60.6	83.3	83.3	83.5	83.2	83.3
150	7.362	4.107	1.444	5.931	19.2	21.3	61.9	61.7	84.2	84.2	84.4	84.2	84.3
160	7.456	4.109	1.442	5.925	19.0	21.3	62.3	62.2	84.6	84.6	84.8	84.5	84.6
170	7.387	4.108	1.438	5.907	19.6	22.0	62.8	62.7	85.2	85.2	85.3	85.2	85.2
180	7.353	4.114	1.441	5.928	19.1	21.5	62.8	62.7	85.2	85.1	85.3	85.1	85.2
190	7.353	4.118	1.442	5.938	18.6	21.3	62.8	62.7	85.2	85.2	85.4	85.2	85.3
200	7.362	4.116	1.443	5.939	18.5	21.1	62.9	62.7	85.2	85.2	85.3	85.1	85.2
210	7.387	4.114	1.441	5.928	18.5	21.1	62.7	62.6	85.2	85.1	85.3	85.0	85.2
220	7.370	4.118	1.441	5.934	19.2	21.6	62.9	62.8	85.4	85.4	85.5	85.3	85.4
230	7.508	4.115	1.441	5.930	18.8	21.4	62.9	62.8	85.3	85.3	85.5	85.3	85.4
240	7.491	4.116	1.441	5.931	18.4	21.1	62.9	62.8	85.3	85.3	85.4	85.2	85.3
250	7.482	6.086	1.997	12.154	18.4	21.1	66.5	66.5	100.3	100.3	100.5	100.2	100.3
260	7.482	6.090	1.986	12.095	18.5	21.2	71.5	71.5	105.2	105.2	105.4	105.1	105.2
270	7.517	6.097	1.978	12.060	18.4	21.2	73.0	73.1	106.6	106.5	106.7	106.4	106.6
280	7.508	6.101	1.992	12.153	19.0	21.4	74.2	74.3	107.7	107.6	107.9	107.5	107.7
290	7.526	6.096	1.978	12.058	19.5	22.0	75.6	75.7	109.1	109.2	109.3	109.0	109.2
300	7.526	6.097	1.969	12.005	18.8	21.6	75.9	76.0	109.3	109.3	109.4	109.1	109.3
310	7.552	6.099	1.989	12.131	19.1	21.6	76.1	76.1	109.4	109.4	109.6	109.2	109.4
320	7.543	6.174	1.980	12.225	20.5	23.3	77.4	77.5	111.0	111.2	111.3	111.0	111.1
330	7.682	6.176	1.982	12.241	19.1	22.2	77.5	77.6	111.1	111.1	111.2	110.9	111.1
340	7.877	6.148	1.980	12.173	18.6	21.6	77.3	77.4	110.7	110.6	110.8	110.5	110.7
350	7.885	6.144	1.977	12.147	18.9	21.5	77.4	77.5	110.5	110.5	110.7	110.4	110.5
360	8.019	6.142	1.967	12.081	20.1	22.4	78.2	78.3	111.4	111.4	111.5	111.3	111.4

TABLE 22 RAW DATA FOR EXPERIMENTAL RUN C6

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	10.01	2.054	0.852	1.75	18.3	19.8	22.5	22.3	22.2	22.0	22.1	22.3	22.2
10	10.01	2.041	0.776	1.58	17.8	19.1	47.5	46.7	53.7	53.5	53.6	53.8	53.7
20	10.01	2.030	0.758	1.54	18.4	19.0	56.8	55.7	62.9	62.7	62.8	62.9	62.8
30	10.01	2.024	0.735	1.49	20.4	20.8	62.5	61.3	68.3	68.1	68.2	68.4	68.3
40	10.01	2.021	0.730	1.48	18.4	19.8	65.2	64.0	70.6	70.4	70.5	70.5	70.5
50	10.01	2.018	0.741	1.50	18.1	19.3	66.2	65.0	71.8	71.5	71.7	71.8	71.7
60	10.01	2.018	0.751	1.52	18.2	19.3	66.8	65.7	72.4	72.2	72.3	72.4	72.3
70	10.01	2.017	0.756	1.52	18.3	19.3	67.4	66.2	73.0	72.8	72.9	73.0	72.9
80	10.01	2.016	0.754	1.52	18.0	19.5	68.1	67.0	73.8	73.6	73.6	73.7	73.7
90	10.01	2.015	0.750	1.51	19.6	20.3	69.1	68.0	74.8	74.6	74.8	74.9	74.8
100	10.01	2.014	0.760	1.53	19.1	20.4	69.3	68.3	74.7	74.5	74.7	74.7	74.7
110	10.01	2.013	0.746	1.50	18.6	19.7	69.4	68.3	74.3	74.1	74.2	74.3	74.2
120	10.01	2.014	0.745	1.50	18.8	19.6	69.5	68.5	74.6	74.4	74.5	74.6	74.5
130	10.01	4.014	1.304	5.23	19.2	19.8	67.8	66.9	85.3	85.0	85.3	85.5	85.3
140	10.01	4.018	1.298	5.22	21.1	21.5	72.0	71.0	89.6	89.3	89.5	89.6	89.5
150	10.01	4.017	1.295	5.20	21.3	21.9	73.8	72.7	91.1	90.8	91.0	91.2	91.0
160	10.01	4.018	1.312	5.27	20.3	20.4	74.0	73.2	91.5	91.2	91.3	91.6	91.4
170	10.01	4.016	1.307	5.25	20.8	21.2	74.1	73.4	91.7	91.4	91.6	91.9	91.7
180	10.01	4.017	1.306	5.25	21.5	22.2	75.3	74.5	92.9	92.6	92.8	93.0	92.8
190	10.01	4.018	1.310	5.26	20.2	20.4	75.2	74.4	92.6	92.3	92.5	92.7	92.5
200	10.01	4.017	1.309	5.26	20.0	20.3	75.6	74.7	93.0	92.8	92.9	93.2	93.0
210	10.01	4.017	1.306	5.25	21.2	21.8	76.2	75.4	93.5	93.2	93.3	93.5	93.4
220	10.01	4.018	1.306	5.25	21.0	21.1	76.8	75.9	94.0	93.9	93.9	94.1	94.0
230	10.01	4.018	1.309	5.26	19.4	20.0	76.6	75.8	93.9	93.6	93.6	93.8	93.7
240	10.01	4.016	1.305	5.24	20.7	21.0	77.0	76.1	94.2	94.0	94.1	94.3	94.2
250	10.01	6.025	1.829	11.02	21.9	22.1	79.3	78.3	107.9	107.6	107.8	108.2	107.9
260	10.01	6.025	1.829	11.02	19.6	19.9	83.6	82.4	111.9	111.6	111.7	112.0	111.8
270	10.01	6.025	1.830	11.03	20.3	20.4	84.3	83.1	112.5	112.1	112.4	112.8	112.5
280	10.01	6.025	1.823	10.98	21.0	21.2	84.9	83.8	113.3	112.9	113.1	113.5	113.2
290	10.01	6.025	1.816	10.94	21.8	21.8	85.8	84.7	114.2	113.8	114.0	114.3	114.1
300	10.01	6.025	1.816	10.94	21.8	22.2	86.5	85.4	114.9	114.5	114.7	115.0	114.8
310	10.01	6.025	1.822	10.98	22.2	22.4	86.8	86.5	115.1	114.8	115.0	115.3	115.1
320	10.01	6.026	1.823	10.99	21.3	21.9	86.8	86.6	114.9	114.5	114.7	115.1	114.8
330	10.01	6.027	1.822	10.98	20.8	21.0	86.5	86.2	114.5	114.2	114.3	114.7	114.4
340	10.01	6.025	1.816	10.94	20.1	20.5	86.2	86.0	114.2	113.8	114.0	114.3	114.1
350	10.01	6.025	1.816	10.94	21.0	21.2	86.5	85.4	114.9	114.5	114.7	115.0	114.8
360	10.01	6.025	1.816	10.94	21.8	21.8	86.8	86.5	115.1	114.8	115.0	115.3	115.1

TABLE 23 RAW DATA FOR EXPERIMENTAL RUN C7

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	5.07	2.161	0.813	1.76	19.2	20.4	15.5	15.2	22.4	22.6	22.4	22.8	22.6
10	5.07	2.002	0.813	1.63	19.2	20.5	29.5	29.5	40.0	40.2	40.1	40.3	40.2
20	5.07	2.076	0.822	1.71	19.3	20.7	36.5	36.6	47.6	47.8	47.6	47.9	47.7
30	5.07	2.075	0.819	1.70	19.4	20.9	40.5	40.6	51.6	51.8	51.7	51.9	51.8
40	5.07	2.077	0.816	1.69	19.3	21.1	42.7	42.9	53.8	54.0	53.9	54.1	54.0
50	5.07	2.078	0.814	1.69	19.3	21.2	44.1	44.2	55.1	55.3	55.2	55.3	55.2
60	5.14	2.079	0.814	1.69	19.4	21.3	44.9	45.0	55.8	56.0	55.9	56.1	56.0
70	5.14	2.080	0.811	1.69	19.3	21.5	45.8	45.8	56.6	56.8	56.6	56.9	56.7
80	5.07	2.082	0.812	1.69	19.6	21.7	46.3	46.4	57.1	57.3	57.2	57.4	57.3
90	5.07	2.083	0.813	1.69	19.7	21.8	46.5	46.6	57.3	57.5	57.4	57.6	57.5
100	5.14	2.084	0.813	1.69	19.5	21.9	46.8	46.9	57.5	57.7	57.6	57.8	57.7
110	5.14	2.084	0.813	1.69	19.5	21.8	46.9	47.0	57.6	57.8	57.7	57.9	57.8
120	5.14	2.085	0.813	1.70	19.5	21.8	47.3	47.3	58.0	58.2	58.1	58.3	58.2
130	5.07	4.061	1.448	5.88	20.0	22.2	47.3	47.4	70.6	71.0	70.6	70.9	70.8
140	5.07	4.069	1.439	5.86	19.6	22.2	51.1	51.2	74.4	74.8	74.5	74.8	74.6
150	5.07	4.073	1.436	5.85	19.6	22.3	52.7	52.9	76.1	76.4	76.1	76.4	76.3
160	5.07	4.074	1.433	5.84	19.6	22.1	53.4	53.6	76.7	77.1	76.8	77.0	76.9
170	5.07	4.074	1.433	5.84	19.7	22.4	53.8	54.0	76.9	77.3	77.0	77.3	77.1
180	5.07	4.076	1.433	5.84	19.8	22.4	54.4	54.6	77.6	77.9	77.7	77.9	77.8
190	5.07	4.077	1.432	5.84	20.2	22.7	54.5	54.7	77.5	77.8	77.5	77.8	77.7
200	5.07	4.077	1.430	5.83	20.1	22.7	54.9	55.0	77.9	78.3	78.0	78.3	78.1
210	5.07	4.079	1.428	5.82	20.1	22.9	55.0	55.2	78.1	78.4	78.1	78.4	78.3
220	5.07	4.081	1.428	5.83	19.9	22.9	55.4	55.5	78.4	78.8	78.5	78.7	78.6
230	5.07	4.081	1.428	5.83	20.0	22.8	55.3	55.5	78.3	78.7	78.5	78.7	78.6
240	5.14	4.082	1.428	5.83	20.1	22.8	55.5	55.6	78.4	78.8	78.6	78.9	78.7
250	5.07	6.055	2.082	12.61	20.6	23.4	62.1	62.4	96.3	96.9	96.4	96.8	96.6
260	5.07	6.063	1.980	12.00	20.1	23.3	65.9	66.2	99.9	100.5	100.0	100.4	100.2
270	5.07	6.064	1.966	11.92	20.2	23.4	67.3	67.6	101.1	101.8	101.3	101.6	101.5
280	5.07	6.066	1.960	11.89	20.0	23.4	68.3	68.6	102.1	102.7	102.2	102.5	102.4
290	5.07	6.066	1.954	11.85	20.1	23.3	68.7	69.0	102.4	103.0	102.5	102.9	102.7
300	5.07	6.068	1.954	11.86	20.0	23.5	69.1	69.4	102.7	103.4	102.9	103.3	103.1
310	5.07	6.068	1.952	11.84	20.0	23.4	69.3	69.7	102.9	103.6	103.1	103.4	103.3
320	5.14	6.069	1.952	11.85	19.9	23.2	69.6	70.0	103.3	103.9	103.5	103.8	103.6
330	5.07	6.069	1.950	11.83	20.1	23.1	69.8	70.0	103.2	103.8	103.4	103.7	103.5
340	5.14	6.067	1.951	11.84	20.1	23.4	70.0	70.3	103.5	104.1	103.7	104.0	103.8
350	5.07	6.067	1.951	11.84	19.8	23.5	70.0	70.3	103.4	104.2	103.6	104.0	103.8
360	5.07	6.068	1.949	11.83	19.7	23.3	69.7	70.0	103.3	104.0	103.5	103.8	103.7

TABLE 24 RAW DATA FOR EXPERIMENTAL RUN C8

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	7.58	2.097	0.962	2.02	20.3	21.0	20.3	20.3	20.2	20.2	20.2	20.4	20.3
10	7.58	2.097	0.885	1.86	19.3	20.7	34.4	34.5	44.4	44.5	44.5	44.6	44.5
20	7.59	2.099	0.851	1.79	18.8	20.5	44.5	44.7	54.6	54.7	54.7	54.7	54.7
30	7.59	2.099	0.833	1.75	18.9	20.9	49.3	49.5	59.0	59.1	59.2	59.2	59.1
40	7.59	2.097	0.826	1.73	20.8	22.7	52.4	52.6	62.0	62.2	62.2	62.1	62.1
50	7.60	2.067	0.815	1.68	19.4	22.2	54.5	54.7	63.5	63.6	63.6	63.6	63.6
60	7.52	2.052	0.807	1.66	18.8	21.7	55.2	55.4	64.1	64.2	64.3	64.2	64.2
70	7.51	2.048	0.804	1.65	18.8	21.7	55.2	55.4	64.0	64.1	64.2	64.1	64.1
80	7.46	2.052	0.803	1.65	20.2	22.6	56.0	56.1	64.9	65.0	65.0	65.0	65.0
90	7.46	2.050	0.803	1.65	19.4	22.6	56.7	56.8	65.5	65.6	65.6	65.6	65.6
100	7.46	2.056	0.807	1.66	19.1	22.1	56.6	56.7	65.3	65.4	65.5	65.5	65.4
110	7.64	2.058	0.807	1.66	18.9	22.3	56.8	56.9	65.5	65.6	65.6	65.6	65.6
120	7.45	2.056	0.805	1.66	19.2	22.2	57.0	57.1	65.7	65.8	65.9	65.8	65.8
130	7.46	4.065	1.428	5.80	19.4	22.9	57.1	57.2	78.8	78.9	78.9	78.8	78.9
140	7.46	4.022	1.422	5.72	19.1	23.1	60.2	60.4	81.7	81.8	81.9	81.8	81.8
150	7.64	4.039	1.417	5.72	19.7	23.6	61.5	61.6	83.0	83.1	83.1	83.0	83.1
160	7.64	4.058	1.414	5.74	20.3	24.4	63.1	63.3	84.7	84.9	84.9	84.8	84.8
170	7.64	4.054	1.415	5.74	19.0	23.6	63.6	63.8	85.0	85.1	85.2	85.1	85.1
180	7.57	4.055	1.415	5.74	18.8	23.4	63.6	63.8	85.0	85.2	85.2	85.1	85.1
190	7.54	4.044	1.416	5.73	19.0	23.5	63.7	63.9	85.0	85.1	85.2	85.1	85.1
200	7.54	4.027	1.417	5.71	19.9	24.2	63.9	64.1	85.3	85.5	85.5	85.3	85.4
210	7.55	4.067	1.420	5.78	19.4	24.1	63.8	64.0	85.4	85.6	85.6	85.4	85.5
220	7.64	4.112	1.430	5.88	19.2	24.1	63.7	63.9	85.5	85.7	85.7	85.6	85.6
230	7.63	4.114	1.428	5.87	19.3	24.2	64.0	64.1	85.8	86.0	85.9	85.8	85.9
240	7.64	4.114	1.430	5.88	19.0	23.8	64.1	64.2	85.8	85.9	85.9	85.8	85.9
250	7.64	6.112	1.953	11.94	19.2	24.0	68.5	68.8	101.3	101.5	101.5	101.3	101.4
260	7.64	6.122	1.973	12.08	18.7	23.7	73.4	73.8	106.1	106.3	106.4	106.2	106.3
270	7.64	6.121	1.967	12.04	18.6	23.6	75.0	75.4	107.4	107.7	107.7	107.6	107.6
280	7.64	6.123	1.962	12.01	18.7	23.7	75.9	76.3	108.3	108.6	108.6	108.4	108.5
290	7.64	6.121	1.956	11.97	19.7	24.3	76.7	77.1	109.1	109.3	109.3	109.2	109.2
300	7.46	6.125	1.957	11.99	19.5	24.3	77.4	77.8	109.6	109.8	109.9	109.8	109.8
310	7.46	6.124	1.961	12.01	19.0	24.0	77.3	77.7	109.5	109.7	109.8	109.6	109.7
320	7.64	6.125	1.961	12.01	18.9	24.0	77.3	77.7	109.5	109.8	109.8	109.6	109.7
330	7.64	6.125	1.960	12.01	18.9	23.9	77.3	77.7	109.4	109.7	109.7	109.5	109.6
340	7.64	6.127	1.956	11.98	18.9	24.0	77.7	78.1	110.0	110.2	110.2	110.0	110.1
350	7.64	6.127	1.959	12.00	18.8	24.1	78.2	78.6	110.4	110.7	110.7	110.5	110.6
360	7.64	6.124	1.958	11.99	18.8	24.0	77.9	78.2	109.8	110.1	110.1	110.0	110.0

TABLE 25 RAW DATA FOR EXPERIMENTAL RUN C9

Time(Min)	P_{EH}(W)	V_{te}(V)	I_{te}(A)	P_{te}(W)	T_a(°C)	T_{ins}(°C)	T_s(°C)	T_c(°C)	T_{f1}(°C)	T_{f2}(°C)	T_{f3}(°C)	T_{f4}(°C)	T_{fm}(°C)
0	10.11	2.055	0.875	1.80	20.8	21.4	20.5	20.5	20.5	20.5	20.5	20.7	20.6
10	10.11	2.055	0.813	1.67	20.5	20.3	40.3	39.9	47.2	47.5	47.7	47.8	47.6
20	10.11	2.025	0.813	1.65	20.4	20.8	54.3	54.0	60.7	61.1	61.3	61.4	61.1
30	10.16	2.027	0.813	1.65	20.7	22.4	61.3	60.9	67.4	67.9	68.0	68.1	67.9
40	10.11	2.037	0.813	1.66	20.6	21.3	64.8	64.5	70.7	71.2	71.3	71.5	71.2
50	10.11	2.040	0.813	1.66	20.4	20.6	66.3	66.0	72.0	72.4	72.6	72.8	72.5
60	10.15	2.038	0.807	1.64	20.3	21.4	67.5	67.2	73.2	73.6	73.8	73.9	73.6
70	10.13	2.038	0.807	1.64	20.5	22.6	69.3	68.9	74.9	75.4	75.6	75.7	75.4
80	10.17	2.034	0.807	1.64	20.4	21.2	69.7	69.4	75.1	75.6	75.7	75.9	75.6
90	10.20	2.035	0.807	1.64	20.3	20.9	69.8	69.5	75.1	75.6	75.8	75.9	75.6
100	10.24	2.043	0.807	1.65	20.3	21.9	70.2	70.0	75.7	76.2	76.4	76.5	76.2
110	10.29	2.045	0.804	1.64	20.4	22.1	70.9	70.6	76.4	76.9	77.1	77.2	76.9
120	9.95	2.042	0.808	1.65	20.3	21.2	70.5	70.2	75.9	76.3	76.5	76.7	76.4
130	9.97	3.962	1.381	5.47	18.9	21.3	71.8	71.5	89.0	89.6	89.9	90.0	89.6
140	9.98	4.044	1.404	5.68	19.3	21.3	73.2	72.9	90.3	90.9	91.2	91.3	90.9
150	9.98	4.019	1.387	5.57	19.8	22.3	74.6	74.4	92.1	92.8	93.0	93.2	92.8
160	9.97	4.018	1.386	5.57	19.1	21.5	75.2	74.9	92.5	93.2	93.5	93.6	93.2
170	9.98	4.015	1.384	5.56	18.8	21.3	75.2	74.9	92.4	93.1	93.4	93.5	93.1
180	10.11	4.012	1.386	5.56	18.5	21.1	75.9	75.6	92.8	93.5	93.8	93.9	93.5
190	10.10	4.010	1.381	5.54	19.4	21.7	76.0	75.7	93.0	93.7	93.9	94.1	93.7
200	10.19	4.007	1.378	5.52	19.6	22.2	76.8	76.5	93.9	94.5	94.8	95.0	94.6
210	10.11	3.986	1.382	5.51	18.8	21.4	76.7	76.4	93.5	94.2	94.4	94.6	94.2
220	10.17	4.021	1.392	5.60	18.5	21.1	76.5	76.2	93.6	94.3	94.5	94.7	94.3
230	10.10	4.008	1.380	5.53	18.7	21.2	76.6	76.3	93.5	94.1	94.4	94.6	94.2
240	10.13	4.001	1.378	5.51	19.3	21.7	76.8	76.4	93.6	94.3	94.6	94.7	94.3
250	10.15	6.037	1.931	11.66	19.0	21.6	80.7	80.5	108.2	109.1	109.5	109.8	109.2
260	10.15	6.055	1.925	11.66	18.8	21.3	85.7	85.5	113.1	114.1	114.4	114.6	114.1
270	10.16	6.035	1.919	11.58	18.6	21.3	87.4	87.2	114.2	115.2	115.7	115.8	115.2
280	10.12	6.027	1.917	11.55	18.5	21.3	87.9	87.6	114.7	115.7	116.1	116.2	115.7
290	10.19	6.033	1.919	11.58	18.8	21.4	88.3	88.2	115.1	116.1	116.6	116.6	116.1
300	10.20	6.036	1.919	11.58	19.1	21.6	88.7	88.6	115.6	116.6	117.0	117.1	116.6
310	10.20	6.040	1.919	11.59	18.9	21.6	89.2	88.9	115.9	116.9	117.3	117.4	116.9
320	10.16	6.042	1.919	11.59	18.7	21.4	89.2	89.0	116.0	116.9	117.3	117.5	116.9
330	10.17	6.044	1.919	11.60	18.7	21.3	89.5	89.3	116.3	117.3	117.7	117.8	117.3
340	10.16	6.045	1.919	11.60	18.5	21.3	89.1	88.9	116.1	117.0	117.4	117.6	117.0
350	10.19	6.044	1.919	11.60	18.7	21.4	89.0	88.7	116.0	116.9	117.3	117.5	116.9
360	10.20	6.041	1.919	11.59	18.9	21.4	88.9	88.7	115.7	116.7	117.1	117.2	116.7