อุปกรณ์อิเล็กทรอนิกส์แบบพกพาเชิงนวัตกรรมให้กำลังโดยเครื่องกำเนิดไฟฟ้าความร้อนจากความร้อนเหลือทิ้ง

นายสุรปรีช์ เมาลีกุล

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INNOVATIVE PORTABLE ELECTRONIC DEVICES POWERED BY THERMOELECTRIC GENERATORS FROM WASTE HEAT

Mr. Surapree Maolikul

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Technopreneurship and Innovation Management
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Thesis Title	INNOVATIVE PORTABLE ELECTRONIC DEVICES POWERED BY THERMOELECTRIC GENERATORS FROM WASTE HEAT
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สุรปรีช์ เมาลีกุล : อุปกรณ์อิเล็กทรอนิกส์แบบพกพาเชิงนวัตกรรมให้กำลังโดยเครื่องกำเนิดไฟฟ้าความร้อนจากความร้อนเหลือทิ้ง. (INNOVATIVE PORTABLE ELECTRONIC DEVICES POWERED BY THERMOELECTRIC GENERATORS FROM WASTE HEAT) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : ผศ.ดร.สมชาย เกียรติกมลชัย, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม : อ.ดร.ถิระ ฉวรรณกุล, 246 หน้า.

งานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาเครื่องกำเนิดไฟฟ้าความร้อนต้นแบบจากความร้อนเหลือทิ้งด้วยเทคโนโลยีเทอร์โมอิเล็กทริกและสร้างมูลค่าเชิงพาณิชย์ในรูปแบบของแหล่งจ่ายไฟฟ้าสำรองให้แก่อุปกรณ์อิเล็กทรอนิกส์แบบพกพา สำหรับตลาดภายในประเทศ การประเมินทางเทคนิคโดยใช้โมดูลเทอร์โมอิเล็กทริกขนาด 4 ซม.× 4 ซม. จำนวน 4 ชิ้น ถ่ายเทความร้อนจากน้ำที่อุณหภูมิต่างๆ พบว่าให้กำลังไฟฟ้าขาออกในช่วง 2.1-100.8 mW ในย่านแรงดันไฟฟ้า 0.16-1.08V ขณะที่การวิจัยธุรกิจโดยเก็บข้อมูลกลุ่มตัวอย่างจากแบบสอบถามจำนวน 400 ตัวอย่าง ที่ระดับนัยสำคัญ (α) 0.05 และการสัมภาษณ์เชิงลึก พบอุปกรณ์อิเล็กทรอนิกส์ 12 ประเภทและแหล่งความร้อนหรือความเย็น 11 อย่าง ที่มีศักยภาพในการพัฒนาผลิตภัณฑ์ ได้มีการจัดลำดับความสำคัญของปัญหาเรื่องแหล่งจ่ายไฟฟ้าพกพา และพิจารณาปัจจัยในการเลือกซื้อผลิตภัณฑ์ในระดับสำคัญที่สุดจากผลสำรวจ เพื่อแปลงสู่ความต้องการเชิงเทคนิคในการพัฒนาผลิตภัณฑ์ใหม่ด้วยเทคนิค QFD และ TRIZ ผลิตภัณฑ์ต้นแบบประกอบด้วย 8 องค์ประกอบ ใช้โมดูลฯ ขนาดเดิม จำนวน 3 ชิ้น การทดสอบผลิตภัณฑ์ต้นแบบใน 5 สภาวะแหล่งความร้อน/ความเย็นที่ใช้งานพบว่า ผลิตภัณฑ์ต้นแบบให้พลังงานสูงสุด 4.82 วัตต์ มีจุดเด่นคือชาร์จไฟฟ้าได้จากแหล่งความร้อนหรือความเย็นที่ผลต่างอุณหภูมิเริ่มต้นต่ำสุดคือ 26°C และสามารถชาร์จแบตเตอรี่ Li-ion 1 ก้อนขนาด 3,000 mAh ในสภาวะเดียวกันเทียบกับผลิตภัณฑ์อื่นๆในตลาดพบว่าใช้เวลาชาร์จให้เต็มน้อยกว่า 15.8-25.4% และให้กำลังไฟฟ้าสูงสุดมากกว่า 30.3-41.4% คิดเป็นกำลังไฟฟ้าสูงสุดต่อพื้นที่ต่ำกว่า 5.7-13.2% จากนั้นได้จัดทำแผนธุรกิจเพื่อออกสู่ตลาดโดยมีกลุ่มเป้าหมายหลักคือนักท่องเที่ยวหรือเจ้าหน้าที่ของรัฐที่ต้องดำรงชีพอยู่ในป่า และกลุ่มเป้าหมายที่ขยายผลคือผู้ใช้อุปกรณ์อิเล็กทรอนิกส์ที่ต้องการพลังงานสำรองยามไม่สะดวกเข้าถึงไฟฟ้า วิเคราะห์ผลตอบแทนการลงทุนให้ผลลัพธ์คือ NPV=19,965,919 บาท, IRR= 274.77% และคืนทุนภายใน 1 ปี

สาขาวิชา ธุรกิจเทคโนโลยีและการจัดการนวัตกรรม ลายมือชื่อนิสิต ....

ปีการศึกษา 2555 .... ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม ....

5087848720 : MAJOR TECHNOPRENEURSHIP AND INNOVATION MANAGEMENT
KEYWORDS : THERMOELECTRIC GENERATOR (TEG) / PORTABLE CONSUMER ELECTRONIC DEVICE (PCED) / POWER SUPPLY

SURAPREE MAOLIKUL : INNOVATIVE PORTABLE ELECTRONIC DEVICES POWERED BY THERMOELECTRIC GENERATORS FROM WASTE HEAT. ADVISOR : ASST. PROF. SOMCHAI KIATGAMOLCHAI, Ph.D., CO-ADVISOR : THIRA CHAVARNAKUL, Ph.D., 246 pp.

This research was aimed at thermoelectric generator's (TEG's) commercialization as a green power supply for portable consumer electronic devices (PCEDs) in the metropolitan market in Thailand. Technical assessment using four commercial 4 cm $\times$ 4 cm TE modules to transfer heat from temperature-controlled water yielded power outputs of 2.1-100.8 mW and voltages of 0.16-1.08V. A business research by a questionnaire with the sample size of 400 at 0.05 level of significance (α) and in-depth qualitative interview found 12 PCEDs and 11 heat / coldness sources with potential for product development. Portable power supply problems were also prioritized. Product qualification criteria with the most importance were deployed into technical requirements for product development techniques with QFD and TRIZ. A prototype comprised 8 components using 3 referred TE modules. It was evaluated for charging characteristics in 5 conditions of uses and produced the maximum power of 4.82 W, with the outstanding feature in the lowest starting temperature differential of 26°C. Fully charging a 3,000 mAh Li-ion battery in comparison with other commercial products, in the same condition, the prototype finished charging process for about 15.8-25.4% faster in duration, with 30.3-41.4% higher maximum power, but with 5.7-13.2% lower maximum power per unit area. Commercialization and business plan was then conducted to focus on the target customers as travelers and government officers with long stay jungle trip. The additional target of people with inconvenience to access electrical power sources for PCEDs was also considered. The business was financially evaluated for satisfactory valuation, i.e. NPV= THB 19,965,919 , IRR= 274.77%, and with 1 year payback period.

Field of Study : Technopreneurship and Innovation Management   Student's Signature ....

Advisor's Signature ....

Academic Year : 2012   Co-advisor's Signature ....

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LIST OF ABBREVIATIONS

English symbols

c_p	Specific Heat Capacity at Constant Pressure (J/(kg.K))
P	Electrical Power (W)
P_{max}	Maximum Electrical Power (W)
$\dot{Q}_{in}$	Input Heat Power for TE Modules (W)
$\dot{Q}_{out}$	Output Heat Power from TE Modules (W)
R	Electrical Resistance (Ω)
T_c	Cold-side Temperature (°C or K)
T_h	Hot-side Temperature (°C or K)
V_{oc}	Open-circuit Voltage (V)
ZT	Dimensionless Figure of Merit for TE Module
V_s	Maximum Regulated Open-Circuited Voltage from TEG Power Supply (V)
V_{TE}	Direct Output Voltage from TE Module (V)
R_L	Adjusted Load Resistance (Ω)
V_L	Voltage Difference between a Load Resistance (V)
I_L	Measured Current Flown in the Circuit (A)
I_{Li}	Theoretical Current Flown in the Circuit (A)
R_s	Source (Internal) Resistance of TEG Power Supply (Ω)
P_{max}	Maximum Power Gain by TEG Power Supply (W)

Greek symbols

ΔT	Temperature Differential (°C or K)
η	Thermal Efficiency (%)
η_{Carnot}	Carnot (Theoretical) Efficiency (%)
η_r	Reduced Efficiency (%)

Abbreviations

DMFC	Direct Methanol Fuel Cell
ICT	Information and Communication Technology
PCED	Portable Consumer Electronic Device
PV	Photovoltaic
TE	Thermoelectric
TEG	Thermoelectric Generator

Chapter I
Introduction

1.1 The Statement of the Problem

Waste heat recovery has been an interesting topic for researchers for a few decades ago due to the economic reason of energy saving. It becomes more attractive as a solution for the global warming concern, which is well known for one of the most severe problems of mankind especially in the latest decade. Various renewable energy sources including the waste heat recovery have been explored and tried for the replacement of traditional fossil energy. This chapter will clarify the reason why it is important and attractive to do this research.

1.1.1 The global warming effect: the world's hottest current environmental issue

Nowadays, the global warming problem or the green house effect has been coming up to be the hottest environmental issue and one of the most important agenda of mankind to encounter. Its consequence increases substantially in many forms of violent disasters around the world e.g. droughts, heat radiations, strong cyclone storms, tsunami, and floods. Evidently, the major cause of the problem stems from the utilization of energy which generates carbon dioxide and methane, the two most influent green house gases leading to the problem [1]. Petroleum as the world's primary energy resource is being consumed substantially and it is, indeed, going to be short in the next few decades. Combustion from petroleum products, furthermore, yields some green house gases, which lead to the global warming. Green house gases are generally carbon dioxide and methane, which together impact the global warming around 70% as shown in the Table 1.1 [1]. Several approaches and solutions have been continuously proposed for contributions especially in the recent decade e.g. alternative fuels, renewable fuels, biofuels or bioenergy, new energy resource explorations, and energy saving practices.

Carbon dioxide plays the principal role for the equilibrium in the ecosystem as shown in the diagram of carbon cycle in the Figure 1.1. Carbon dioxide in the atmosphere is captured via photosynthesis reaction by plants which absorb energy from the sun and then transform carbon dioxide into carbon organic compounds like starch and so on. Carbon organic compounds continue to convert the forms, absorb more energy, and partly accumulate in the form of fossil energy under the ground. Unfortunately, the world's energy utilization skyrockets, while "the green areas" decrease significantly over the world. Consequently, the carbon cycle in the ecosystem is unbalanced and that leads to the inevitable major problem of the global warming due to the accumulation of carbon dioxide and other potential green house gases in the atmosphere.

1.1.2 Global energy crisis

The world's energy crisis is another critical adversity of humankind, which has been weakening the world's energy stability. Mankind is currently dependent on the fossil energy, which is the major but limited energy source. Approximately, oil, natural gas, and coal will be available for the world until around the next 40, 60, and 220 years respectively based on the world's current rate of consumption [2]. Consequently, many scientists and researchers over the world tried hard to substantially explore countermeasures for relieving and reducing the problem and curing the world.

The world's energy can be categorized into 2 types i.e. non-renewable energy and renewable energy. The former is mostly based on fossil fuel as described before and is the primary cause for both the global warming and the energy crisis. On the contrary, the latter is mostly unfamiliar for the world or not currently reliable energy resource for humankind. However, many countries around the world are increasing awareness of its importance as the potential solution for the world's adversity and trying to encourage studies, research, or even utilization of renewable energy to replace the conventional fossil energy resource. There are many forms of the renewable energy e.g. solar energy, wind energy, tide energy, hydrogen energy, biomass energy, etc. though they are at the beginning or "lab scale" progress and the commercializing potential cannot be competitive with the traditional fossil energy. As the result, there have been lots of synthesized technologies in this area in terms of inventions and minor innovations for specific energy markets, but they will increase more potential in the next few decades as the major resources of world's energy and substantially replace the traditional fossil energy.

Table 1.1 Green house gases and their potential affecting global warming [1]

<table>
<tr><th>Greenhouse gases</th><th>Global Warming Potential (time of CO_2)</th><th>Global Warming Effect (%)</th></tr>
<tr><td>1. Carbon dioxide (CO_2)</td><td>1</td><td>57</td></tr>
<tr><td>2. Methane (CH_4)</td><td>21</td><td>12</td></tr>
<tr><td>3. Nitrous oxide (N_2O)</td><td>310</td><td>6</td></tr>
<tr><td>4. Hydrofluorocarbons (HFCs)</td><td>140-11,700</td><td rowspan="3">25</td></tr>
<tr><td>5. Perfluorocarbons (PCFs)</td><td>6,500-9,200</td></tr>
<tr><td>6. Sulfurhexafluoride (SF_6)</td><td>23,900</td></tr>
</table>

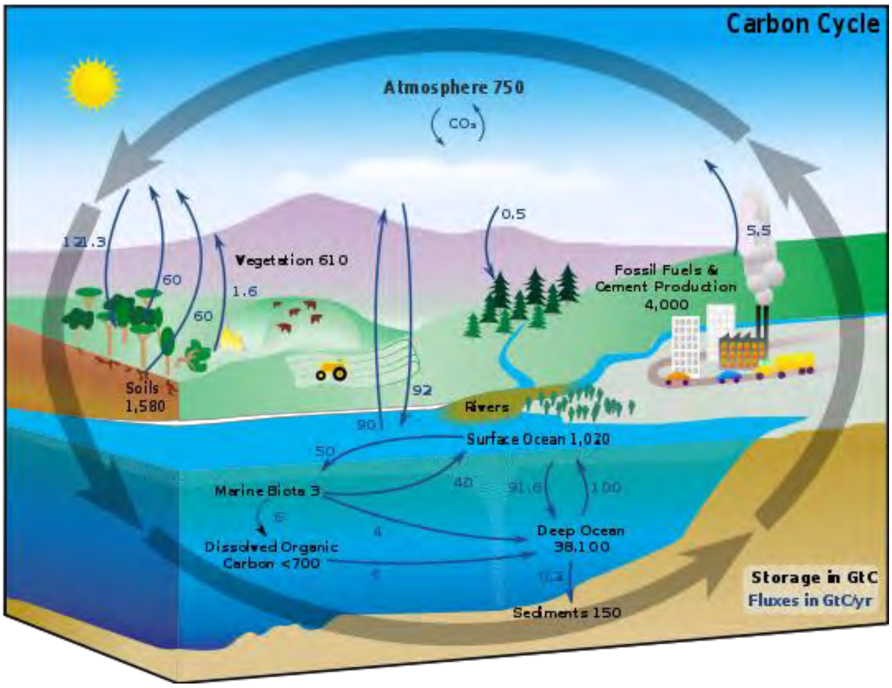


Figure 1.1 The carbon cycle in the ecosystem [3]

Considering each form of renewable energy, the trend of utilization often depends on the availability and specific conditions. For example, solar energy is preferable in tropical areas where there is powerful sunlight and there may be practical problems when using in areas with uncertain sunlight, indoor use, or night-time use. The wind turbine is not practical to invest the expensive technology in low potential areas of wind current. The potential of some renewable energy is rather independent of ambient conditions but relies on the advancement of technology, its commercial potential compared with other technologies, and sufficient and continuous production capability such as hydrogen energy, biomass energy, or even energy from waste heat recovery.

1.1.3 Waste heat recovery: one of the potential renewable energy sources

Various energy scavenging approaches have been introduced in recent years i.e. solar, thermoelectric, electromagnetic, piezoelectric, and capacitive systems [4]. Waste heat recovery is considered to be one of the potential renewable energy sources as it relates to plenty of activities which emit waste heat to the atmosphere. Furthermore, it can be produced with the environmentally-friendly advantage and be one of the potential solution for the global warming problem and energy crisis. Capturing waste heat helps reduce the use of major energy resource especially the fossil fuel, resulting in more efficiency for devices or energy utilization reduction. That means to reduce the emission of carbon dioxide to the atmosphere as the main aspect of the global warming problem.

Regarding general waste heat sources that can be found, they can be divided into 5 sections as follows:

1.) Industrial machinery, especially for heat engines and equipments related to thermal energy e.g. boilers, burners, preheaters, gas and steam turbine, thermal engines, heat pumps, etc. In this section, recovered energy is substantial due to the industrial scale of production.

2.) Vehicle and automobile section, which is currently related to internal combustion engines. This section expands rapidly in the present owing to crowded people especially in large cities using automobiles.

3.) Resident and building section, which is related to some devices incorporated to dissipated heat and temperature difference sources such as air conditioners, refrigerators, hot/cool water suppliers, etc.

4.) Human body and activities, tiny sources of heat compared with other mentioned heat sources which generate heat by humans themselves, or by their daily activities for example: dissipated heat from the skin of human body, breath, exercising activities, having a hot/cold drink in the coffee shop, or even making fire for cooking in camping, and so forth. Although the heat quality from this source is not much attractive to harvest, it is quite stable and reliable because of its necessity for daily life. Furthermore, this can be considered the convenient mobile heat source that will be useful especially for low power consumption electronic devices.

5.) Portable electronic devices, which can be considered, simultaneously, the power consumer and the power generator from their own dissipated heat due to the limitation of their efficiency. Unfortunately, the power recovered from this source is very low owing to the nature of devices that consume little power to operate; however, this recovered power is still useful for other electronic devices or specific applications that consume very low power.

It is reasonable that existing waste heat recovery technologies mostly relates to industrial applications due to the quantity and quality of waste heat source. Industrial factories utilizing substantial heat energy often concerns for unused heat dissipating to the atmosphere. That results in the inefficiency for economic resource utilization and significant environmental impact. Thus, there are significant advantages for energy harvest from those waste heats. Industrial waste heats are mostly recovered via heat transfer process and forward them to other parts which require heats to process their works and so on. For example, the use of waste heat for electricity generation by heat transferring to generate steam to drive a turbine, the use of waste heat from condensate to generate flash steam, or even the use of waste heat from refrigerant compressors to generate hot water. In fact, the industrial waste heat can be categorized into 3 groups as follows [5]:

1.) high-quality waste heat; this type can be explained as the heat from high-temperature source (600-1,600°C) such as flue gases from kilns, which can be recovered for power generation, cogeneration, or contribution in the production processes.

2.) medium-quality waste heat; in other words, medium-temperature source (200-600°C) such as flue gas from boiler heating unit, gas turbine, which can be recovered for medium-pressure steam generation, or contribution in the production processes.

3.) low-quality waste heat; or low-temperature source (35-200°C) such as condensate, cooling water, or cooling air for engines or machines, which can be used in fundamental preheat proposes in a process, or recovery for direct use in a process.

The industrial waste heat recovery and harvesting is attractive because of its various level of heat quality, and also the reason of economic and environmental considerations. Therefore, there are many state-of-the-art approaches and developments currently available in this area. Besides the industrial application, waste heat recovery is not familiar and favorable to apply due to some restrictions with conventional harvest. The vehicle section remains practical for this application due to heat dissipation from internal combustion engine system and related parts generating heat. In fact, the main sources of heat from vehicle can be categorized into 4 parts: engine block, exhaust fumes, coolant fluid, and brake system. One example of heat recovery from automotive engines is turbo-charging which is functioned by conventional thermodynamic cycle of high-temperature exhaust gas to generate more power for engine. Another application relates to enhance efficiency of the linking system within automobile e.g. vapor compression refrigeration (VCR) as Talom and Beyene [6] focused on the application of using waste heat from engine to efficiently run an additional mobile refrigeration system. Mostly, the applications for automobile section emphasizes on reducing loads of engines especially refrigerating load for which let engines to share the load and results in the loss of power to drive. Nonetheless, there is some research contributing to waste heat recovery from automobiles to generate electricity to decrease petrol consumption and reduce carbon dioxide emissions by mainly utilizing the exhaust heat as Rowe [7] claimed that the saving in fuel straightaway reaches 5%. In summary, as the global warming effect and the global energy crisis are significantly critical, there are plenty of research for waste heat recovery from automobile application to generate electricity and reduce fuel consumption for those significant problem solving.

Regarding resident and building section, some potential applications for waste heat recovery include heating or cooling system from some facilities e.g. air conditioners, refrigerators, hot/cold water supply, and others. Although the quality of the heat may not be equivalent to that of industrial section, or even automobile section, it is somewhat interesting that the population especially for developing countries is rapidly growing, and the urbanization is overwhelming in large cities. Consequently, the density of residential energy utilization increases substantially especially for office buildings, department stores, hotels, condominiums, or even entertainment complexes. To analyze, this section grasps the solution for waste heat harvesting by the reason of energy cost saving which is the main propose for owners and social responsibility about energy consumption reduction and unpolluted environment retaining. Some approaches to those objectives may be adjacent to the industrial section's but in the smaller scale of systems. An example currently commercialized is warm water supplier using waste heat recovery from working refrigerant of air conditioners.

Waste heat sources from human body and activities including portable electronic devices are often overlooked for development but have been more interesting especially in the near future. Initially, the human body dissipates heat in 4 forms i.e. (1) respiration, (2) skin convection, (3) sweat, and (4) skin radiation and over two third heat fraction is generated from the skin as shown in the Figure 1.2 [8]. In addition, Yang *et al*. [9] verified the technical feasibility for implantable medical electronic devices by waste heat recovery from human body for power generation and suggested that the skin surface is a potential position to harvest thermal energy from the human body. To support this idea, Luchakov and Nozdrachev [10] stated the heat production from typical adult human of approximately 90W which comprises the most fraction of skin heat transfer from convection, conduction and radiation. In fact, the metabolism in the core of our body is the continuous source of heat generation to control body temperature at the optimal condition for living (37°C). The heat from the body can be dissipated through the skin to retain the optimal temperature condition within the body. Moreover, the heat dissipation depends on human activities e.g. in exercising or playing sports, the heat generation will increase more than a normal condition and these various activities affect the rate of blood circulation which accelerates heat convection to the skin to dissipate out of the body. In addition to skin, our hairs, surprisingly, are the natural efficient heat dissipater and they behave like heat exchangers, which require surface areas for heat dissipation. Thus, our head is an interesting area of temperature-gradient sources from our body. The distributed temperature of our body varies for each organ of the body dissipating heat from the core [8]. The temperature difference results from various factors e.g. skin characteristic, the flow rate of circulating blood, the metabolism rate for each internal organ, and so on.

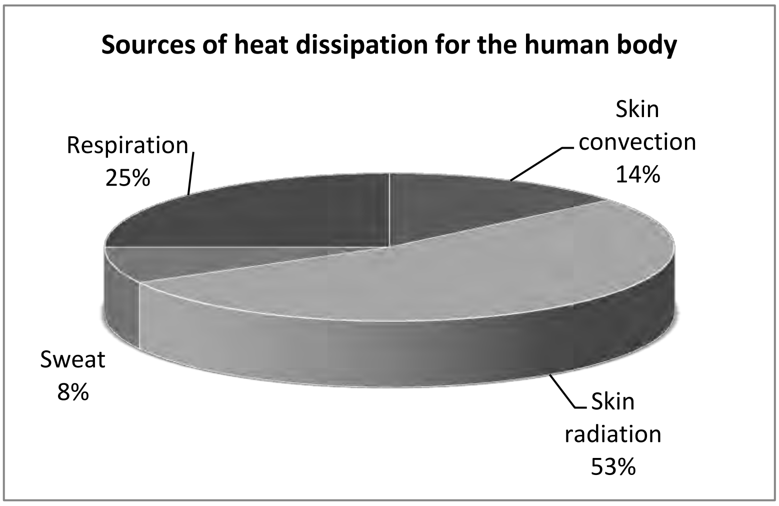


Figure 1.2 sources of heat dissipation from the human body [8]

Moreover, some activities related to daily life encounter the temperature gradient directly and indirectly, for example, having a meal, ice creams, hot/cold beverages, cooking, and so on. In the same way, some handheld electronic devices can generate heat during the use in daily life e.g. laptop computers, LCD projectors, mobile phones, MP3 player, digital cameras, whose heat dissipation depends upon its power consumption rate. The waste heat from human, activities for lives, and portable electronic devices are considered low quality and less potential to harvest into power recovery. Furthermore, conventional harvesting approaches like thermal heat exchangers to transfer waste heat to use in the requiring circumstance seem not practical because of inconvenience, no appropriate applications, and no necessity to use. On the contrary, they, incredibly, have a potential for portable electronic applications consuming tiny power to operate. While there is a limitation of battery power for mobile applications especially in the circumstance that users are inconvenient to charge their batteries, the current trend for urban life becomes using more mobile applications and "stay connected anywhere", which widens opportunities in the near future for waste heat recovery. However, the specification of waste heat harvest for these applications must be considered i.e. convenient to use and to move along with users, reliable to supply sufficient power to the target applications, and, importantly, reasonable and competitive cost, and worth buying. As a result, these applications are interesting and challenging to develop a new product family along with appropriate technology. In addition, the typical energy harvesting technologies can be simply classified in 2 categories as follows: (1) energy harvesting for sensor network for MEMS or micro applications using thin/thick film approach, and (2) energy harvesting for electronic devices using bulk approach [4]. Nevertheless, the former deals with specific target groups e.g. medical gadgets for health care and monitoring, mechanisms to drive artificial organ in our body. It requires technology improvements such as thin film substrates, and TE materials including other supporting and relating technology such as integrated medical gadgets, and heat transfer to fulfill those applications. The latter is commercially designed for general applications of macro-scale with higher temperature difference usage. As a result, this research was aimed to study comprehensively for the latter case only.

1.1.4 Potential market in portable power supply for portable electronic devices

The energy supply of portable electronic devices has been being developed because the density of transistors has been forecasted to double every two years approximately. Thus, small scale size, compact storage density, minimized energy consumption, and shorter processing time for their production become the main criteria for the evolution [11]. For the current use of portable electronic devices, there are, at least, some devices or gadgets to support our daily life in the digital era. Those can be classified in several applications as follows.

1.) Portable consumer electronic devices (PCEDs): these can be utilized as communication tools, data processing tools, and entertainment tools e.g. laptop, mobile phones, smart phones, PDAs, MP3 players, voice recorders, and so on. This category includes field recreational devices for people's recreational activities such as camping, traveling, and trekking. There are various favorable devices to bring along with those people e.g. digital camera, electric torch, and so on. The power consumption varies for each type of devices and running activities required by users. The examples of the power analysis for the tools are shown in Tables 1.2-1.3. Considering the data from the tables, most mobile devices consume power in a few watts down to milliwatts scale and tend to use less power for future designs. There are various forms of applications for users i.e. hand-held form like mobile phones, and wearable form like wrist watches.

2.) Wearable or implantable medical devices: these are attended to use for monitoring metabolic parameters, assisting defective physical function or healing diseases. In addition, Jia and Liu [11] focused on active devices which consume energy with different orders of magnitude ranging from microwatts to several watts. The power supply module often becomes the integrating form attached to those devices for convenient and practical patient's usage. As a result, these devices tend to use small-scale technology (move toward nanoscale) for their operations and mostly require other specific technical support to fulfill their applications.

3.) Field technical measurement devices: this type relates to some specific technical applications which are necessary to use portable measuring tools in field observations or operations, for example, engineering measurement devices, mobile scientific or medical laboratory, mobile quality control equipments, petroleum exploration toolkits, geological surveying equipments, etc. These devices are considered very specific for their characteristics in utilization and require other specific essential technological support. Nevertheless, most devices are used for specific proposes which are not attended for daily life. As a result, there is mostly low necessity for secondary power supplies.

Table 1.2 Average power consumption of common electronic devices [4]

Product	*Average power consumption*
Small portable FM radio	30 mW
Walkman (play mode)	60 mW
TV remote	100 mW
Cell phone (talk/stand-by)	2 W / 35 mW
Electric torch (flashlight)	4 W
Video 8 (no LCD screen)	6 W
Laptop computer	10 W
TV (53/67/wide screen)	50 / 74 / 11 W

Table 1.3 Function based power analysis of various applications [11]

device	email		MP3		browse	notes		messaging		idle
	RCV	reply	speaker	headphone		text	audio	text	audio	
laptop/W	15.16	16.25	18.02	15.99	16.55	14.2	14.65	14.4	15.5	13.975
handheld/W	1.386	1.439	2.091	1.7	1.742	1.276	1.557	1.319	-	1.2584
cellphone/mW	539	472	-	-	-	-	-	392	1147	26
pager/mW	92	72	-	-	-	78	-	-	-	13
high-end MP3/W	-	-	-	2.977	-	-	-	-	-	1.884
low-end MP3/mW	-	-	-	327	-	-	-	-	-	143
voice recorder/mW	-	-	-	-	-	-	166	-	-	17
variance/%	16496	22727	861	4890	950	18252	8825	3673	1351	107500

Commercial substitutions of TEG for the applications with PCEDs can be classified by various form of energy harvesting technology i.e. secondary batteries, solar chargers, fuel cell chargers, and manual chargers.

Regarding traditional batteries for electronic devices, Jia & Liu [11] stated the evaluating benchmarks for the battery performance i.e. the energy density (energy per unit of volume) and the specific energy (energy per unit weight). The comparison for different type of battery was reviewed to compare those benchmarks as shown in the Table 1.4 [11]. Due to the characteristic of electronic devices which varies the power consumption by its activities, the harvesting sources of power can be augmented to batteries; consequently, this leads to increasing their lifetime and reducing the environmental impact by longer battery replacement duration.

Table 1.4 Performance comparisons of different types of battery [11]

Unit	Li-sulfer dioxide	Zinc air	Ni-Cd	Ni-Li	Li-ion
Specific energy/ ($Wh.kg^{-1}$)	125	340	30	50	80
Energy density/ ($Wh.L^{-1}$)	415	550	100	180	200
Cycle life (no. of charges	1	1	1500	500	300-500

Commercial batteries as secondary power supply are classified into internal batteries and external batteries. Internal batteries are the same type of batteries used in specific PCEDs. To use internal secondary batteries means that user need to buy secondary or spared specific-using batteries and charge them to supply only those specific PCEDs (one by one) without switching capability to use with other PCEDs. On the other hand, external batteries are portable power supply comprising secondary batteries to supply electricity for charging various PCEDs by adjusting charging options and changing for an appropriate adapter. Commercial external batteries are potential for the target group of general consumers with various PCEDs usages. The examples of commercialized product are shown in Figure 1.3.

An example of adjacent products for electricity generation for personal portable electronic devices is a photovoltaic solar charger (Figure 1.4) which generate electricity from solar cell to supply laptop computer with maximum power of 10W and suitable for using with notebook or electronic device with less power consumption without conventional electrical power supply. Nevertheless, there are some disadvantages for this technology in the case of reliability for sunlight dependence especially for indoor and night period applications, and the cost for solar cell unit as well.

Moreover, a recent commercialized product of portable generator is "Dinario™" (from Toshiba) – the fuel cell charger for portable electronic devices using the technology of direct methanol fuel cell (DMFC) (Figure 1.5). There was also the prototype for the DMFC charger from Sony demonstrated at the International Hydrogen and Fuel Cell Expo (FC Expo 2009) as shown in Figure 1.6, which emphasize the growing demand of portable chargers and development attempt to reach the market. There are plans for product commercialization with DMFC chargers in the near future from other manufacturers as well. However, this technology needs methanol for the sources of power, so the disadvantage is that methanol is considered as non-renewable technology and needs a supply to drive a power. DMFC energy transformation yields carbon dioxide as a potential green house gas shown in the equation (1.1).

$$2\ CH_3OH + 3\ O_2 \rightarrow 2\ CO_2 + 4\ H_2O \qquad (1.1)$$

A manual charger is an alternative for secondary power supply using hand power to generate electricity via dynamo principle. A recently commercial product from Sony Corporation is an example as shown in Figure 1.7. The product is aimed for the target group of general consumer especially in the country with frequent natural disaster, so the manual charger can provide emergency power for their PCEDs to communicate as necessary. The performance of manual charger is revealed by its OEM that in order to obtain sufficient power for 1-minute phone call, users shall rotate the dynamo for 3 minutes approximately. Obviously, this product is designed for emergency use only, and does not applicable for normal usage condition.

Figure 1.3 Product example: “External batteries”

Figure 1.4 Product example: “Solar laptop charger”

Figure 1.5 “Dinario” – Toshiba’s first commercial fuel cell charger (DMFC)

Figure 1.6 Sony’s fuel cell charger (DMFC) prototype

Figure 1.7 Sony's commercial manual charger product

1.1.5 Potential technologies in waste heat recovery for PCEDs

Current waste heat recovery technologies comprise many types mentioned before i.e. direct use of hot/cold substance, and heat transfer from waste heat sources to heat-required substance in the process through heat exchangers. In addition, there are 2 technologies that have been developed for decades but their applications of power generation is mostly stated as lab-scale prototypes or inventions but scarcely successfully commercialized in the area of portable generator i.e. thermoelectric generators (TEGs) and thermoacoustic electric generators (TAEGs). Naturally, they are both heat engines but use different working fluid to generate works from heat.

TAEGs utilize inert gas i.e. helium or argon to generate sound and it consequently needs secondary energy conversion devices such as alternator or piezoelectric for electricity generation afterwards. In other words, there are two energy conversion processes i.e. thermal-to-acoustic conversion and acoustic-to-electric conversion. Mostly, it is applied to develop the large-scale thermoacoustic engine or thermoacoustic refrigeration instead of mobile applications. Anyway, miniaturized TAEG have been developed in laboratories in order to improve such limitations as a big size, a reduced efficiency for thermal-acoustic-electric energy conversion, noise pollution, a minimum threshold temperature gradient, a working gas, reliability, inconvenience for portable applications, and so on [12]. In short, the technology needs to head through maturity in lab scale before processing into commercialization phase in the future.

On the other hand, TEG technology allows direct energy conversion from thermal to electric energy using electrons and holes to behave like working fluids. It is advantageous to use for portable applications owing to its qualification of its small size, light weight, reliability, durability (no moving parts). There are some applications contributed by TEG technologies mostly in research and development step e.g. TEG from exhaust gas out of automobiles, TEG in military applications to generate electricity in the field of battle, whereas the obvious commercialized product example was the wristwatch “SEIKO Thermic” which was proposed for some niches as shown in Figure 1.8. The performance of TEG relates to the capability of thermoelectric material e.g. alloys based on bismuth in combination with antimony, tellurium, and selenium, etc. and the efficiency of energy conversion mainly depends upon the advancements of thermoelectric materials and their form.

Recently, there was a commercialization of a product with TEG to supply power for PCED. This product was called “The Power Pot” ™ as shown in Figure 1.9 and was aimed to serve secondary power when users are living off the grid, or spending time in the outdoors. The source of energy for this product comes from fire in any situations. Actually, TEG-based power supply is superior to other renewable technologies e.g. solar, and wind in the aspect of more reliable power. The product needs any fire to heat it and water to fill in for building temperature difference. This is a robust and light-weight generator that can produce maximum power of 5 watts for a USB output with the voltage of 5 volts and the maximum current of 1 ampere. However, the concept for this product principally aimed for deliberate heat source, but not waste heat source. In other words, there might be an intensity to light up the fire in order to charge a battery via The Power Pot. Therefore, this is a consideration for the product development to respond the purpose of transferring renewable energy into ready-for-use power next.

In short, TEGs are currently probable to use for PCEDs as described because of its nature of convenience to move along, appropriate power supply for small-size electronic devices, and its reasonable cost for applications. In fact, utilizing TEG for applications of PCEDs can be various and more attractive in the present and future e.g. small laptop computers or “notebooks”, PDAs, GPS, smart phones, Bluetooth handsets, MP3 players, digital cameras, portable TV, etc. or maybe the applications for personal medical and health devices e.g. hearing assistants, health indicators for exercising practice, medical sensors etc. However, each application in the product range has different attractiveness, features of overall system, and technology compatibility and appropriateness which are necessary to make a decision for the best configuration to develop further.

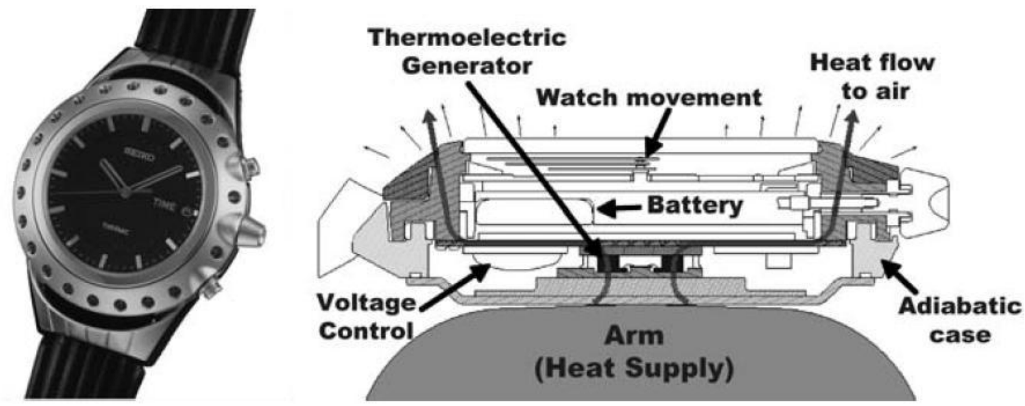


Figure 1.8 Thermoelectric wristwatch “SEIKO Thermic”, powered by heat from user’s skin (left) its feature, (right) cross-sectional diagram. [13,14] Copyright by Seiko Instrument Inc.

Figure 1.9 commercial TEG-based power supply product: “The Power Pot”™

1.1.6 Innovations from the technological applications and the management for successful diffusion

A practical definition of innovation is proposed as "a successful exploitation of a new idea" [15]. Regarding the primary assumption for this research, the innovation relates directly to business opportunities; therefore, the successful commercialization will be the scope of the research to synthesize the complete innovation. To conclude, the innovation according to the research is composed of 2 components: (1) the new application of waste heat recovery technologies (new technologies with some forms of inventions); and (2) the approach to develop products for target market with competitive advantages and sustainable growth to do business (successful commercialization for derivative products of the proposed technologies.) This innovation, obviously, is classified in the form of product innovation using energy harvesting technology. In addition, the mentioned technologies have been developed for a few decades but they were not feasible for such a market of mobile digital devices as expanding a lot in the present. There are other commercial products existing in markets using those technologies but in the other application and serving some niches in commercialization. For example, commercial thermoelectric (TE) modules tend to use in the refrigeration propose using reverse principle of TEG. The innovation from this research, accordingly, is synthesized using the combination of the core technology – TEG and other complement technologies to develop and establish new configurations of portable generators for the new vastly-potential market. In short, "the architectural innovation" is proposed to synthesize for expanding the new market in the form of product innovation.

To make a successful commercialization, the innovation process might be considered for the suitable way. The Rothwell's coupling process [16] seems practical for the current technologies status and the severe market competitive conditions being the fundamental innovation process to go on. In other words, to consider real current competitive conditions where technologies has been developed to lead the way, there must be the trend of individualization and alternative for market and thus high competition to survive. Therefore, both technical aspect and marketing aspect are unavoidable issue to conduct in the research and have to be considered corresponding to financial attractiveness to make a decision for the most potential option for commercialization. To encourage successful diffusion of innovation, the business plan has to be established to conduct the successful commercialization for the product after the prototype is generated.

1.1.7 Summary of rationale for the research

The intention for the research is derived from the two vastly-critical problems of the world's ecology and environment in the present i.e. the global warming effect, and the world's energy crisis. Both problems have a significant increase of violence and impact in various disasters often appearing in the latest decade. Thus, the world community is trying to figure out the way to practically solve those severe problems, and renewable energy consumption instead of "fossil fuel" is one of the effective solutions for the world's crises. Unfortunately, most renewable technologies has been worldwide developed but only a few are commercially competitive compared with the traditional fossil fuel according to the initial developing state in "the technology S-curve" [17]. Waste heat recovery technology, in the same way, is not the exception, but is one potential approach for the problem solving which is considered in the area of energy scavenging.

The exploitation for waste heat recovery approaches can be classified in several applications. However, the most interesting area is focused on PCEDs, which is rapidly increasing as an era of real-time and wireless community, and the principal problem, indeed, is the availability and reliability of mobile power source to supply those less-power-consumption digital devices. There is a potential opportunity to harvest the heat from daily-life temperature gradient to generate small power for those devices. The thermoelectric technology is potentially selected to exploit in the mentioned condition with plenty of intrinsic advantages but still some limitations which are necessary to analyze in the new product design process to verify the most appropriate approach to harvest maximum waste heat energy.

Accordingly, this research aims to synthesize the product innovation which can be classified as "the architectural innovation" in thermal energy harvesting to supply the rapidly-growing PCED market. In addition, it is essential to outline the approach for the innovation management to drive the invention successful to the target market which is the fulfillment of the innovation process and has a potential for diffusion in other market or other corresponding product family later in the future.

1.2 The Research Objectives

The research objectives are defined as follows:

- To evaluate the potentials and limitations including other existing applications of thermoelectric generator (TEG) technology for the specific application

- To explore and validate the market attractiveness in Thailand for each potential application

- To analyze and validate financial feasibility for the specific potential application

- To analyze the attractiveness of the application options for new product design and to select the most optimal option for development in one case of product innovation (optional if more than one feasible option available)

- To conduct new product design and building a prototype for the selected case

- To conduct business plan for the potentially successful commercialization of the innovation

1.3 The Research Scope

The research scope is defined as follows:

- To evaluate the focused technology for waste heat recovery generators i.e. thermoelectric generator (TEG) which are basically appropriate for the defined application and its technical feasibility to extend from the lab scale to industrial or commercial scale including other supplementary technologies (optional if necessary or appropriate) to fulfill design objectives or to enhance functions e.g. heat transfer and heat exchanger technology, battery technology, piezoelectric generator technology, and others.

- To explore and evaluate the market feasibility in Thailand of developing generators via the technologies mentioned for the only application for PCEDs i.e. communication tools, processing tools, entertainment tools, and field recreational tools using bulk approach (excluding for sensor network using MEMS/thick/thin film approach)

- To evaluate the financial feasibility by determining financial attractiveness and making financial scenario for investments and expected beneficial returns for the only options with technical and market feasibility proof

- To select the entire feasible options to conduct systematic decision making with some appropriate methodology to choose the only most feasible option to develop further (optional if more than one feasible option available)

- To conduct new product design using appropriate tools for aesthetic design and engineering design and introducing the potential industrial product design based on industrial scale
- To build the prototype of which the type can express thorough specification and detail, then test and verify the innovative products / services for their function, reliability, and business aspect.
- To conduct business plan, in particular, directly relating to the product commercialization e.g. marketing plan, operation plan, financial plan, product and service development plan, intellectual property management plan (if available)

1.4 Primary Agreements

There are some agreements to clarify before conducting the research as follows:

- TEG is the focused technology to study for primary developing the electric generator from suitable thermal supplies. However, if the selected application is necessary to combine other energy harvesting technologies, this issue is to be considered for additional exploitation to complete the design objective.
- Although the research is trying to harvest energy from waste heat, thermal energy intensity from waste heat may be limited and insufficient for some application. The product design specification may be more flexible in some ways. For example, deliberate heat sources (not considered as wasted) generated by users like firing, boiling water, may attend to use occasionally which is matching the daily-life activities, and so on to complete the design objective.

- The approaches primarily proposed to use in the research methodology is the main approaches which are likely to use in the research. Nevertheless, those approaches may be partly utilized, replaced, reduced, or other approaches will be added or enhanced as appropriate concerns during the research progress to bring up the best outcomes and to achieve the research objectives.

- Some essential supplementary data and variables about the start-up business may be assumed arbitrarily but reasonably corresponding with the real context at the present time of the research.

- The intellectual property protection will be done in accordance with the most appropriate way to create the highest advantages for the business that is assumed to be existing at that time, but not always to finalize with some kind of intellectual property protection forms e.g. patenting

1.5 Limitations of the research

The research can be completed with some limitations as follows:

- The product design in the research has a limitation of the thermal-to-electric capacity; hence, it may be exploited either to supply entire electricity to some portable electronic devices or to supply partial power to enhance their battery powering period. Perhaps, the secondary battery is needed for some more power consumption applications to allow continuous charging and to compensate for the power fluctuation.

- A prototype from the design is fundamentally expected to be identical to the real product innovation. However, if there are troubles in some production aspect, the set of prototypes may be produced composed of many parts of complementary prototype e.g. “looks-like” prototype, “works-like” prototype, mock-up model, rapid prototype, paper prototype, or even behavioral prototype, etc. which are sufficient and appropriate to express functions, emotions, using behavior, other related aspects obviously and descriptively.

- The successful innovation cannot be verified directly from the real market or real condition. However, the real options theory or the technology acceptance model (TAM) may be selectively adapted and applied to fulfill this limitation.

1.6 Contributions from the research

The completed research will become advantageous and contribute values for each aspect as follows: educational aspect, business aspect, customer aspect, as well as social and environmental aspect.

1.6.1 Educational aspect

- Clarifying the review of pros and cons, appropriateness of applications by the waste heat recovery technology applied for portable electronic devices

- Applying the real option analysis for the innovation project valuation as a case study

- Determining the limitations and developments for up scaling from research scale to industrial scale

- Combining the complementary and supplementary technologies to help product improve their function, value, and performance

1.6.2 Business aspect

- Encouraging successful exploitation of the new technology to drive the innovation

- Acquiring approaches to develop devices or module to save more energy from waste heat recovery in the related business or other business

- Involving the reduction of carbon dioxide from fossil fuel combustions leading to “carbon credit selling business”

1.6.3 Customers aspect

- Obtaining convenience to use their portable electronic devices referred from customer needs especially wherever they cannot reach conventional electrical power sources during their trips

- Supporting the future trend of communication as “stay connected anywhere and anytime” and reliable electrical supplies is needed

- Adding more choice for supplying emergency electrical power wherever and whenever there are requirement by collecting heat from environments

- Increasing the efficiency for electrical consuming devices

1.6.4 Social and Environmental aspect

- Reducing global warming effect by waste heat harvesting that reflects to decrease the use of mainstream energy such as fossil fuel

- Considered as one of renewable energy for the replacement of fossil fuel and helping the world decrease consumptions of the mainstream energy

- Becoming the source of clean energy with the encouragement of contributing the highest value from the world’s energy

- Regarded as environmentally friendly energy source which reducing the pollution from the consumption of energy

1.7 The Research Methodology Outline

The research content is entirely composed of 3 phases i.e. feasibility study, new product design, and commercialization. Research methodology is overviewed corresponding to the research scope as follows.

1.7.1 Feasibility study phase (Phase I)

1.) Technology evaluation, and technical feasibility study

2.) Market potential and market feasibility study

3.) Investment assessment and financial feasibility study

4.) Decision making for the most optimal option for further innovation synthesis (optional if more than one feasible option available)

1.7.2 New product development phase (Phase II)

5.) Product design

6.) Engineering and industrial design

7.) Prototyping and testing

1.7.3 Commercialization phase (Phase III)

8.) Conducting business plan for the successful commercialization

9.) Validity verification for the business and the successful innovation

10.) Discussing and concluding the overall achievement including further suggestions

1.8 The research plan and schedule

Table 1.5 The research plan and schedule

No.	Research Progress	Mar'11	Apr'11	May'11	Jun'11	Jul'11	Aug'11	Sep'11	Oct'11	Nov'11	Dec'11	Jan'12	Feb'12	Mar'12	Apr'12	May'12	Jun'12	Jul'12	Aug'12	Sep'12	Oct'12	Nov'12	Dec'12
1	Technology evaluation and feasibility study	■	■	■	■																		
2	Market feasibility study				■	■	■																
3	Financial feasibility study						■	■															
4	Decision making for the winning option					■	■	■	■														
5	Product Design/ New Product Developtment									■	■	■											
6	Engineering and Industrial Design											■	■	■									
7	Prototyping and Testing													■	■	■	■						
8	Conducting business plan for commercialization															■	■	■	■				
9	Validity verification for the business and the successful innovation																	■	■	■	■		
10	Discussion, conclusion, and completing dissertation report																	■	■	■	■	■	■

Chapter II
Literature Review

2.1 TEG Potential for Commercialization

2.1.1 Thermoelectric Generators (TEG) Theory

TEGs are solid-state devices with no moving parts involving "the Seebeck effect", the basis of thermoelectric power generation. Electric flows occur by two dissimilar metals or n-type and p-type semiconductors of thermoelectric materials subject to the temperature gradient along their length [18] as shown in Figure 2.1. The power output appears in the form of a voltage, directly varies with a temperature differential between the hot side and the cold side ($V = \alpha \Delta T$), and an electrical current, resulting from a heat flow. The figure of merit of thermoelectric materials (ZT) relies on the Seebeck coefficient (α), electrical resistivity (ρ), and thermal conductivity (κ), and absolute temperature (T) of the material as shown for the relationship in Equation (2.1).

$$ZT = \frac{\alpha^2 T}{\rho} \qquad (2.1)$$

The maximum experimental thermal-to-electric efficiencies were calculated by considering the ratio of P_{max} to $\dot{Q}_{in}$ in Equation (2.2).

$$P = \; . \dot{Q}_{in} \qquad (2.2)$$

Carnot or ideal efficiencies were also determined by Equation (2.3) for comparison.

$$_{Carnot} = \frac{\Delta T}{T_h} \qquad (2.3)$$

State-of-the-art efficiencies were predicted in linear efficiency ratio of good typical Bi_2Te_3 devices of 0.04% /K of temperature differential as shown in Figure 2.2 [13], and then the predicted maximum power was calculated backward from the known $\dot{Q}_{\text{in}}$ and $_{\text{max}}$ using Equation (2.2). Effective or experimental figure of merit (ZT) for TE module needed to consider all the passive losses that degrade the TEG performance from ideal TEG e.g. the impact of electrical contact resistance, interconnect resistance, exterior ceramic conduction losses, and substrate-to-substrate conduction losses in the gaps that separate TE elements [19]. The figure of merit was related to 3 parameters: , T_h, and T_c and was calculated by using Equation (2.4).

$$= \frac{\Delta T}{T_h} \cdot \quad {}_r = \frac{\Delta T}{T_h} \cdot \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_c}{T_h}} \tag{2.4}$$

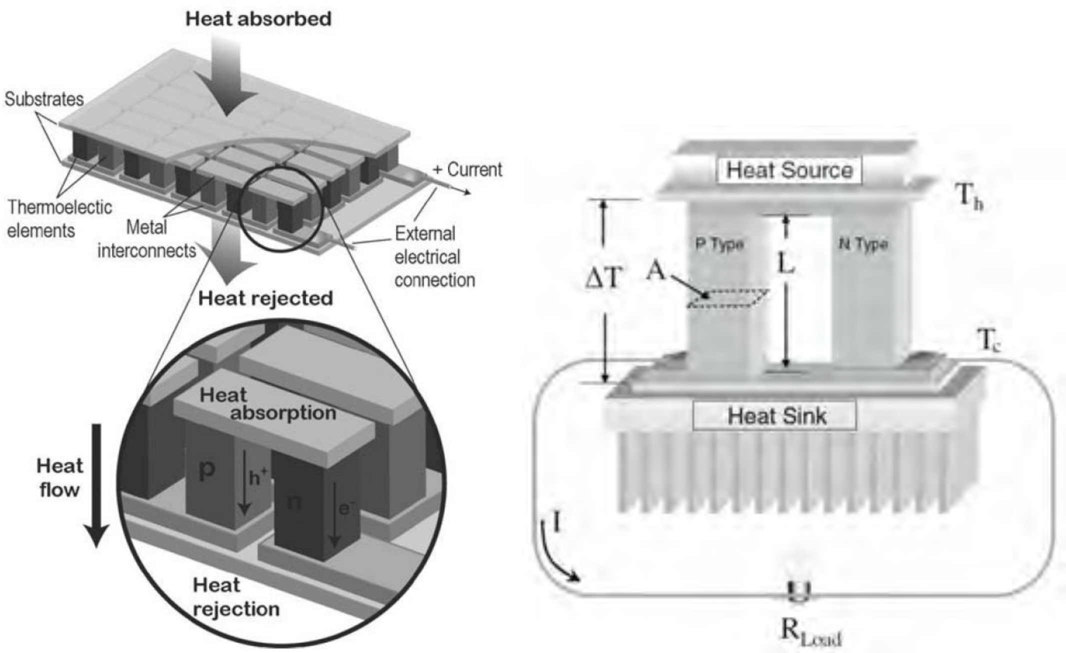


Figure 2.1 Thermoelectric generator module diagram [13, 20]

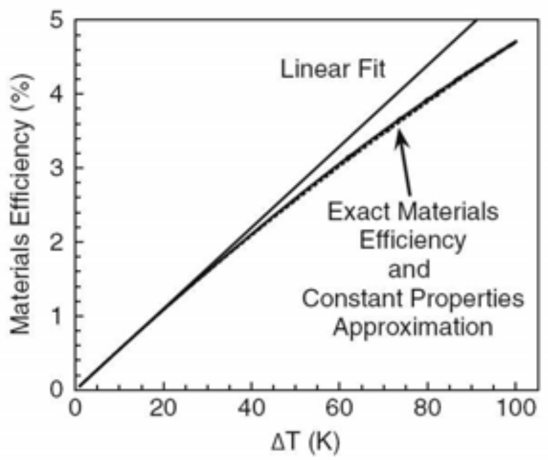


Figure 2.2 Efficiency of a bismuth telluride-based thermoelectric module (cold side temperature at 300 K, assuming no additional losses) [13]

2.1.2 Thermoelectric Generator Applications in the Past

In the past, some thermoelectric generators (TEGs) have been researched for various applications. For example, Killander and Bass [21] developed a stove-top generator for household utilization with net electrical output for battery of 1-5 W. As a mobile application, Rahman and Shuttleworth [22] developed a power supply powered by butane-gas-heating TEG with the maximum power output of 13.5 W approximately. Some researches combined TEG with other renewable energy or even to improve energy efficiency by TEG [23]. Roth *et al*. [24] developed photovoltaic/ thermoelectric (PV/TE) hybrid system as a 50-W power supply for a mobile telephone repeater. Still, successfully-commercialized applications of TEG are nowadays doubtful. Such well-known commercialized TEG applications as thermocouple sensors, TE wristwatches [14], and TEG for biosensors merely served niches due to the disadvantage of inherently low electrical power output from a TE module.

2.1.3 Rising Issue of Requirements for Portable Consumer Electronic Devices

The energy supply of portable consumer electronic devices (PCEDs) has become recently more interesting to develop further because the number of transistors in a given area of silicon, the basis of digital devices, has been forecasted to double every two years approximately; thus, small scale size, compact storage density, minimized energy consumption, and shorter processing time become the main criteria for the evolution and will raise more potential in the near future [11]. Considering the global market trend of power supply for PCEDs, there were many studies revealing attractiveness for PCED market as follows. Atkinson [25] stated for the market demand and the "run-time gap" that there has been an increase of portable device power demand which was three times faster than the rate of battery improvement and reached four times by 2010. This can be depicted by the market extension for such devices as smart phones, tablet PC, PDAs, laptops, MP3 players, and so on, and those were actually available with contemporary battery technology. Daim and Jordan [26] have studied the forecast of technological change for laptop batteries. Their research revealed the significantly reducing figures of battery patents especially in a few years ago. In addition, they proposed an issue of the maturity of battery technology and the beginning of the challenger technologies, especially for portable fuel cell technology. Nonetheless, the prime obstacles of portable fuel cell commercialization, able to adapt for TEG's consideration, was also proposed in 4 reasons: (1) the substantial heat dissipation, (2) more excess heat energy production, (3) the efficiency that needs to be improved, and (4) the need for rechargeable. To emphasize the market potential corresponding to TEG, Agnolucci [27] reviewed comprehensively for economics and market prospects of portable fuel cell. The figures for the global market of portable fuel cell for portable electronic devices and its market occupation were shown in Table 2.1 to 2.2. This research implied comprehensive global market trend for portable power sources. In addition, there has been significant momentum from other correspondent studies of the portable power source demand, and portable fuel cell potential was mostly raised to compare with that of traditional battery as revealed by Ramirez-Salgado and Dominguez-Aguila [28], Kamarudin *et al*. [29], and Flipsen [30], for examples. Moreover, there was a recent study from Wee and Choi [31] involving the carbon dioxide emission (one of the potential green house gas) from mobile applications, in particular. This research implied upcoming momentum in using renewable energy to avoid global warming encouragement. Regarding the related researches of the potential market for portable power sources, they all implied the opportunity and the gap to improve in this field. Although portable fuel cell seems to be the most potential challenging technology, especially for direct methanol fuel cell (DMFC), they need much more improvements to mature for successful commercialization and take many years to reach a dominant design in the market. Hence, there is still a gap for other renewable energy technologies to take this advantage from the rapidly-growing market, and the practical thermal energy harvesting is not exceptional.

Table 2.1 Worldwide total available market for microfuel cells in millions of unit :estimated sales using the 2002-2007 annual growth rate (AGR) [27]

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	AGR
Camcorders	10	11	13	15	18	20	23	27	31	36	15.2
Digital cameras	7	9	12	15	19	25	33	42	54	70	28.9
Mobiles	305	322	344	371	408	447	483	522	563	608	8
Laptops	34	37	41	47	54	62	71	80	90	102	13.1
PDAs	13	17	20	24	29	36	44	53	65	79	21.9

Table 2.2 Percentage of total available market occupied by microfuel cells [27]

	2006	2007	2008	2009	2010	2011
Camcorders and digital cameras		2	2	2	2	2
Mobiles	2	3	5	5	5	5
Notebook computers	9	16	30	30	30	30
PDAs	20	31	50	50	51	51

2.2 Innovation Management and New Product Development

Innovations, generally, can be defined as various meanings and definitions. One of the overwhelming and respected meaning states that "the innovation is the successful exploitation of new ideas" [15]. The exploitation can be separated into either the public use for social benefits or the successful commercialization for private business profits. The innovation process, basically, can be driven by the generic model as shown in the figure 2.3

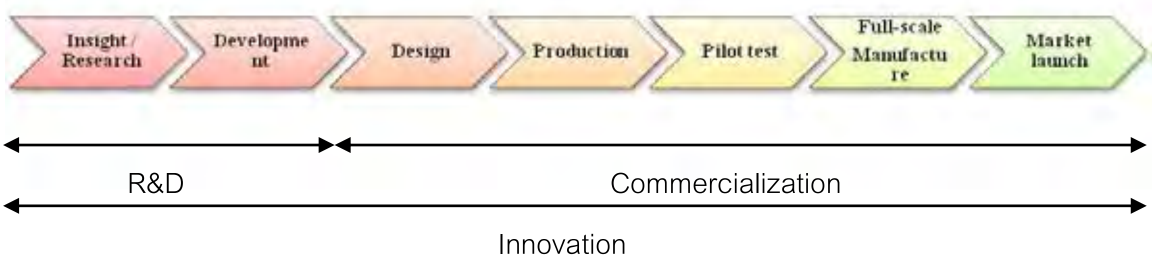


Figure 2.3 A generic model of the innovation process [17]

In addition, the generic model can reflect a fundamental for the firm of which the innovation is a vital part. The basic approach for the firm starting to be innovative is composed of 2 processes i.e. technology-push process and demand-pull process which is the first and second generation of Rothwell's simple linear models [16] as illustrated in the figure 2.4 and 2.5.

Figure 2.4 Technology-push process [16]

Figure 2.5 Demand-pull process [16]

In the third generation, there was a saturation of the global market with inflation and stagflation from the mid 1970's to the mid 1980's. The awareness of technological advancement was recovered to obtain some breakthroughs in order to escape from saturated marketplace. Therefore, a successful innovation model should consider influence of both market needs and technological breakthroughs to drive both incremental innovations and radical innovations as well. That leads to the "coupling model" process [16] as shown in Figure 2.6 which is emphasizing in the balance impact between market consideration and R&D activities.

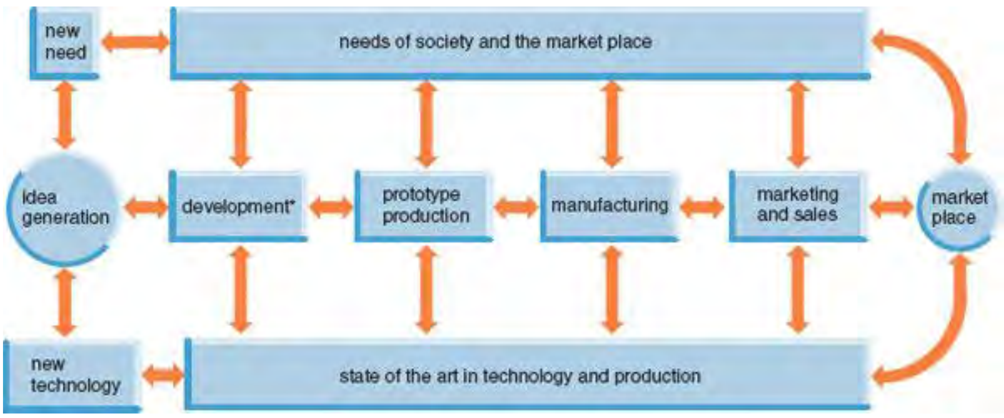


Figure 2.6 Coupling model process [16]

Next, the fourth generation of innovation process model was developed from the early 1980's to the mid 1990's due to shorter lead time and more competitive market conditions. "Total concepts" paradigm was developed to integrate product development process into parallel platform. The linkage to customers and suppliers was closer, stronger, and more interactive to encounter more violent competitions in marketplace. The Rothwell's "integrated model" process [16] is exemplified in Figure 2.7.

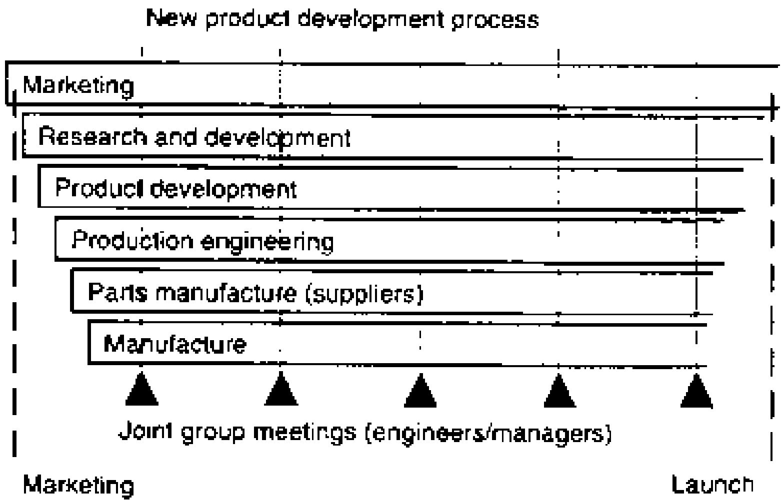


Figure 2.7 Integrated model process [16]

The fifth generation of innovation process model was developed due to the resource constraints from the 1990's onwards. There were some concerns for the speed of change in business conditions and business players should be more robust and flexible. Some trends has been introduced in the business to leverage competitive capabilities e.g. advanced enterprise resource planning, manufacturing information systems. More constraints arose in marketplace, so it was necessary to add value into product with unique quality to build brand awareness and to increase the value of products or services. Open innovation concept became more attractive as it involved collaboration of strategic partnerships to ensure satisfactory outputs in high quality, less cost, quicker delivery, and unexpected special services. Therefore, the Rothwell's "Network Model" process [16] was developed in the last generation to respond the robust conditions of market place.

Regarding new product development (NPD) model, the generic product development process of Ulrich and Eppinger [32] which generally can be divided into six major phases (as illustrated in Figure 2.8): (1) planning, (2) concept development, (3) system-level design, (4) detail design, (5) testing and refinement, and (6) production ramp-up. The framework outline corresponds to the Stage-Gate ® process from Cooper [33] (figure 2.9), which mostly recommended to use with incremental innovation developments, is the classic template to start with. Unfortunately, regarding platform and breakthrough innovation, it may not be suitable to start the NPD process with the Stage-Gate ®. Instead, the strategic vision for in-depth market understanding or even in-depth technology insights shall be completed before applying the Stage-Gate ® approach, which is known as fuzzy front end (FFE) process. By the way, each phase of the process is decomposed into a great number of design activities, creating a huge, complicated, and unstructured network. The design activities have various objectives and constraints, and numerous interactions and information transfers. Hence, opposite to manufacturing process or business process, the NPD process has such typical characteristics as creative, dynamic, interdisciplinary, strongly interrelated, iterative, uncertain, and risky [34].

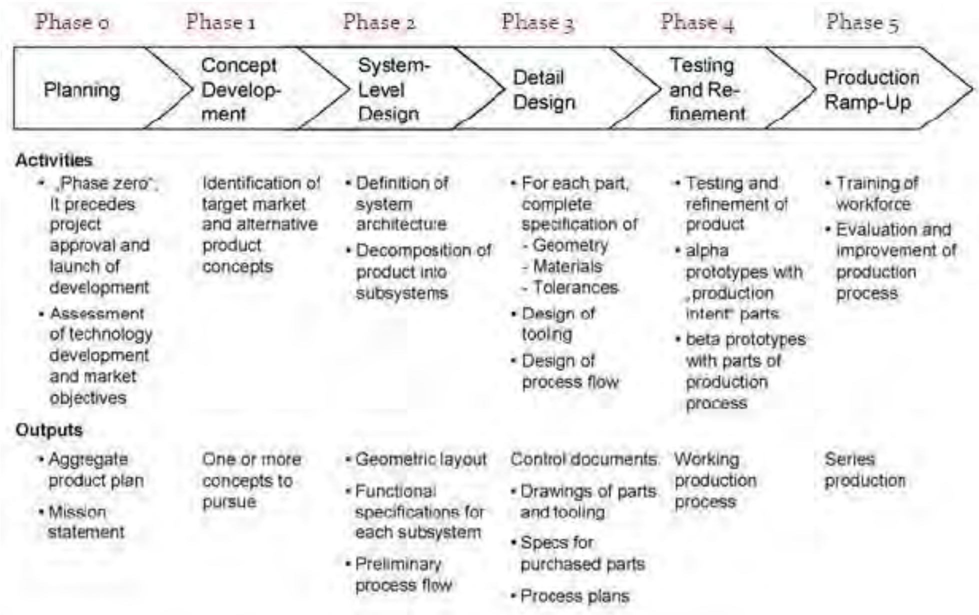


Figure 2.8 The six-phase generic product development process [32]

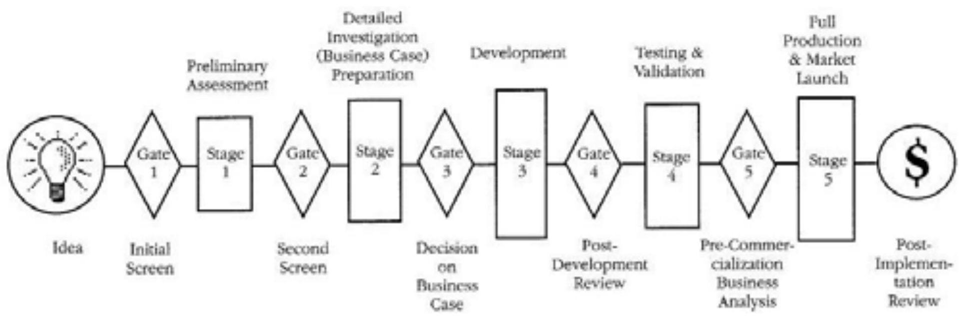


Figure 2.9 The Stage-Gate ® process [33]

2.3 DC-to-DC Step-up (Boost) Converter Circuit

DC to DC step-up converter circuit or boost converter is the circuit that convert direct current to direct current and increase output voltage higher than input voltage. From Figure 2.10, the average voltage between inductance (V_L) is zero, and the current (I_L) relies on the condition of the switch as follows.

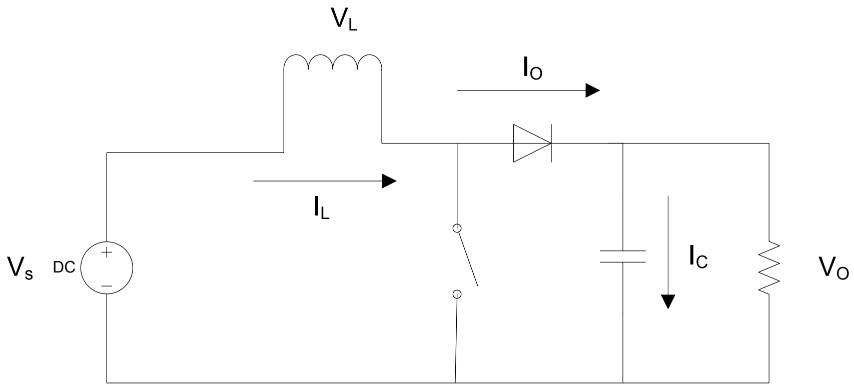


Figure 2.10 DC-to-DC step-up (boost) converter circuit

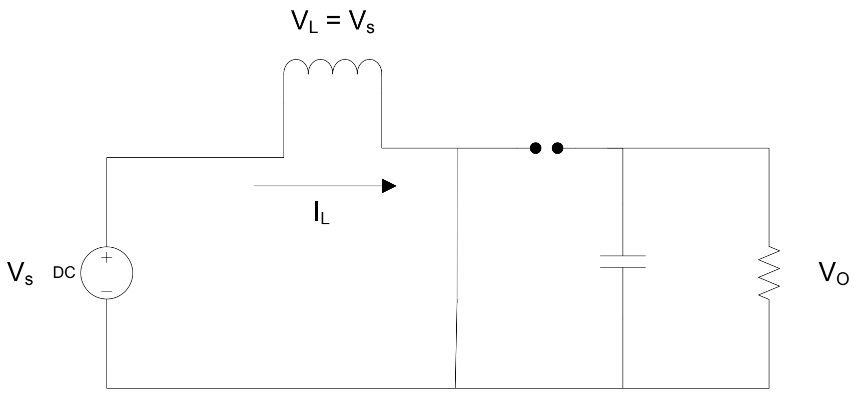


Figure 2.11 Equivalent circuit of DC-to-DC step-up (boost) converter circuit when switching on [35]

(1) When the switch is on (as shown in Figure 2.11), the current will flow through the inductance and passing the switch. The diode will be backward biased, so the current will not flow though.

From Kirchhoff's law,

$$-V_s + V_L = 0$$

$$V_L = V_S = L\frac{dI_L}{dt}$$

$$\frac{dI_L}{dt} = \frac{V_S}{L} \qquad (2.5)$$

Assuming constant change rate of current (linear increase of current) and dt = DT if the switch is on,

$$\frac{\Delta I_L}{\Delta t} = \frac{\Delta I_L}{DT} = \frac{V_S}{L}$$

$$\Delta I_L = \frac{V_S DT}{L} \qquad (2.6)$$

When ΔI_L is the change of current through inductance at switching-on status

V_S is the input voltage

I_L is the average current through inductance

D is duty ratio or duty cycle

(2) When the switch is off (as shown in Figure 2.12), the current still flows through the inductance. The diode will be forward biased, so the current will flow though the diode.

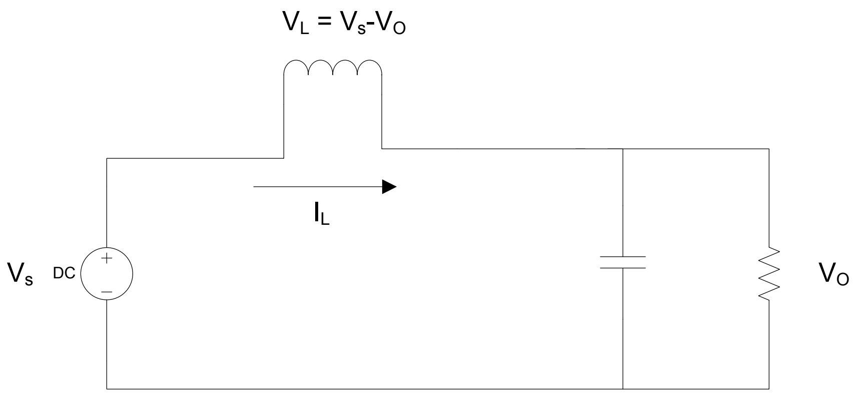


Figure 2.12 Equivalent circuit of DC-to-DC step-up (boost) converter circuit when switching off [35]

From Kirchhoff's law, assuming the output voltage is constant

$$-V_s + V_L + V_O = 0$$

$$V_L = V_s - V_O$$

$$V_L = L\frac{dI_L}{dt}$$

$$\frac{dI_L}{dt} = \frac{V_S - V_O}{L} \qquad (2.7)$$

Assuming constant change rate of current (linear decrease of current) and dt = (1-D)T if the switch is off,

$$\varDelta I_L = \frac{V_S - V_L}{L}(1 - D)T \qquad (2.8)$$

In the steady state, the change of current through inductance equals zero ($\varDelta I_{L,on} + \varDelta I_{L,off} = 0$) , so the ratio of output voltage to input voltage, which is called voltage expansion rate, is described as the equation (2.9)

$$V_0 = \frac{1}{1-D}V_S \qquad (2.9)$$

A boost converter circuit is driven by pulse width modulation (PMW) signal which is processed by the mechanism of integrated circuit to turn on/ off the switch, so increasing output voltage higher than input voltage as described beforehand.

2.4 Maximum Power Transfer of a Power Source

2.4.1 Maximum Power Transfer Theorem

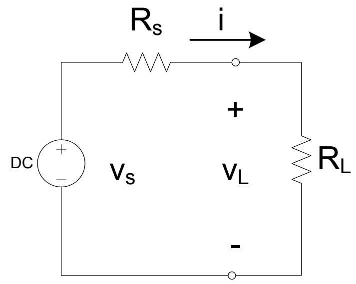


Figure 2.13 Basic equivalent circuit diagram of power source characteristic [36]

The current in the circuit in Figure 2.13 is determined using Ohm's Law:

$$i = \frac{v_S}{R_S + R_L} \qquad (2.10)$$

The voltage across the load resistor, v_L, is found using the voltage divider rule:

$$v_L = v_S \cdot \frac{R_L}{R_S + R_L} \qquad (2.11)$$

The power dissipated in the load, P_L can be determined as follows:

$$P_L = v_L \cdot i = \frac{R_L v_S^2}{(R_S + R_L)^2} \qquad (2.12)$$

Then, rewrite this to get rid of the R_L on the top:

$$P_L = \frac{v_S^2}{(\frac{R_S}{\sqrt{R_L}} + \sqrt{R_L})^2} = \frac{v_S^2}{R_S(\frac{\sqrt{R_S}}{\sqrt{R_L}} + \frac{\sqrt{R_L}}{\sqrt{R_S}})^2} \qquad (2.13)$$

Assuming the source resistance is not changeable; thus, the maximum power is obtained by minimizing the bracketed part of the denominator in the above equation. It is an elementary mathematical result that $x + x^{-1}$ is at a minimum when x=1. In this case, it is equal to 2. Therefore, the above expression is minimum under the following condition:

$$\frac{\sqrt{R_S}}{\sqrt{R_L}} = 1 \qquad (2.14)$$

This leads to the condition that:

$$R_L = R_s \qquad (2.15)$$

The maximum power out of the source is obtained if the load resistance is identical to the internal source resistance.

2.4.2 Internal Resistance Calculation via DC Load Test

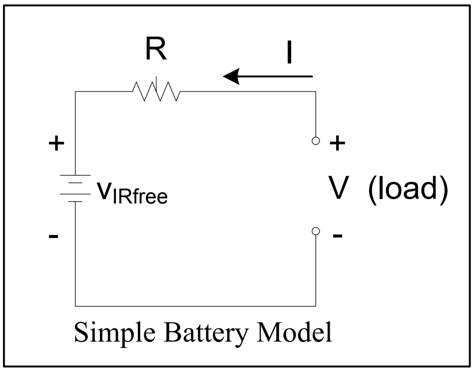
Equation (2.15) implied that to charge a battery with maximum power transfer needed for R_s (internal resistance of thermoelectric power source) to equal R_L (adjusted internal resistance of a battery).

Depth of discharge (DOD) is another approach to indicate a state of charge (SOC) of a battery. The DOD is the inverse of SOC: as one increases, the other decreases. While the SOC units are percent points (0% = empty; 100% = full), the units for DOD can be Ah (e.g.: 0 = full, 50 Ah = empty) or percent points (100% = empty; 0% = full). As a battery may actually have higher capacity than its nominal rating, it is possible for the DOD value to exceed the full value (e.g.: 52 Ah or 110%), something that is not possible when using SOC.

For purposes of estimating peak (discharge) power capability at a given depth of discharge, a dynamic resistance is determined based on a measurement of $\Delta V/\Delta I$ between a base current and a high current step. In case of the calculation for typical batteries, the changes in voltage and current are measured from a point in time just before the beginning of a 30 second current pulse to a point near the end of the 30 second pulse, as shown in Figure 2.14. It described an example of the DC load test when various conditions of loads or resistance were applied for experiments i.e. no load ($R=0\Omega$), load no.1 ($R= R_1$), and load no.2 ($R=R_2$). The characteristic of voltage reduction during load application was plotted with time. The internal resistance value is calculated as:

$$R_s = \Delta V / \Delta I = (V_1 - V_2) / (I_1 - I_2) \qquad (2.16)$$

The numeric value of R is always positive because the value of I (by convention) is negative [37,38].



$$R_s(\Omega) = \frac{V_1 - V_2}{I_1 - I_2}$$

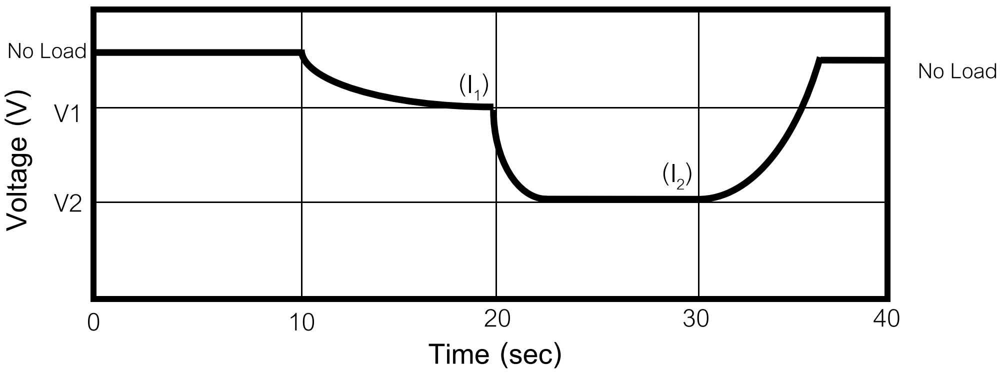


Figure 2.14 The diagram of internal resistance calculation via DC load test [37,38]

Chapter III

Research Methodology

Comprehensive research methodology is defined for the guideline to conduct the research progress. As stated in the chapter 1, the three-phase research methodology outline is brought up for reviewing and specifying the essential detail to grasp overall related approaches as follows.

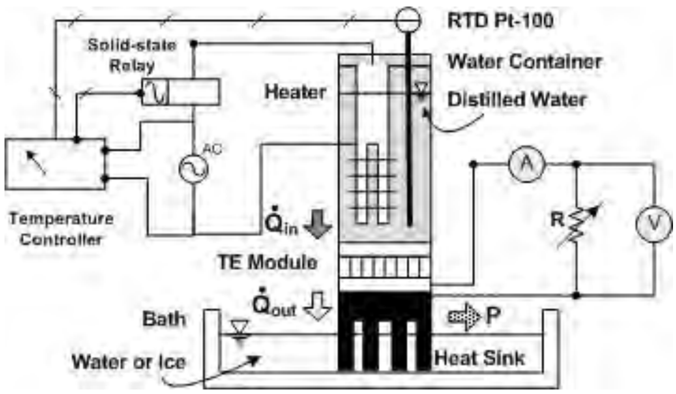
3.1 Feasibility study phase (phase I)

3.1.1 Technology evaluation, and technical feasibility study

Technology evaluation is conducted to assess the core technology defined in the scope of the research and reviewing complementary and supplementary technologies for commercialization from researches, patents, and other commercial products. The essential factors directly attributed to product specification is taken into consideration e.g. size, weight, efficiency, range of use (temperature and its gradient), strength, durability, reliability, corrosion, stability, additional technologies, and so on.

Experiments were conducted to simulate typical conditions for actual situations of users. Four bismuth–telluride (Bi_2Te_3) bulk TE modules were used as TEG mode encountering temperature differentials of T_h and T_c. TE modules from Ferrotech Corporation were used in this research. The specification of the modules, mainly defined for cooling applications, is described as follows: (1) single-stage TE module no.9500/127/085, (2) TE materials of n-type and p-type bulk Bi_2Te_3 (Bismuth Telluride), (3) maximum input current of 8.5 A, (4) maximum DC input voltage at I_{max} and ΔT = 30°C of 17.5V, (5) dimension in width × length × height of 39.70 mm × 39.70 mm × 3.94 mm, and (6) TE elements in a module of 127 couples. The temperature range for experiments was set for the most probable situation in daily lives of PCED users. T_h range is defined for 37-100 °C, found from such sources as equipment heat sinks, hot matter, and also our skin, whereas the T_c range was set at 0-30°C, typically found as ice, cold water, and ambient air.

The configuration of experimental set is shown in Figure 3.1 as to simulate temperature differentials. The hot side of the TE modules was attached with an 8.0 cm × 8.0 cm × 20.0 cm stainless-steel water container with a 1,000-W heater installed inside. Some 1.2-litre distilled water was filled in the container to collect heat from the heater which was temperature-regulated by controller module with RTD Pt-100 sensor. On the other hand, the cold side of the TE modules was attached with the heat sink dipping in a bath, and heat dissipated through water or ice filled in the bath. The input heat was set by increasing water temperature in the container to the set-value T_h of 37, 55, 75, and 95 °C, while the cold side temperature, T_c , was maintained by water at 25-30°C (ambient), and 0 °C (ice filled). The framework of technical feasibility study was illustrated in Figure 3.2.



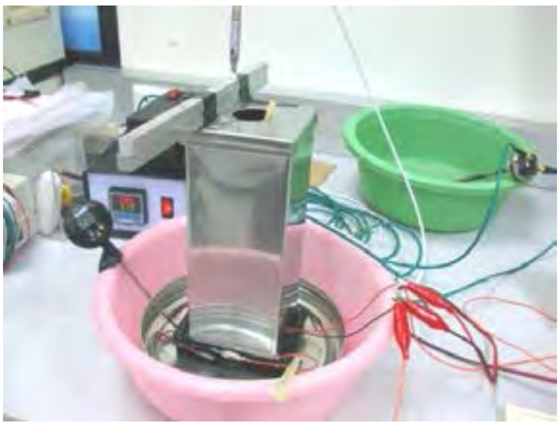


Figure 3.1 The configuration of experimental set for technical feasibility study

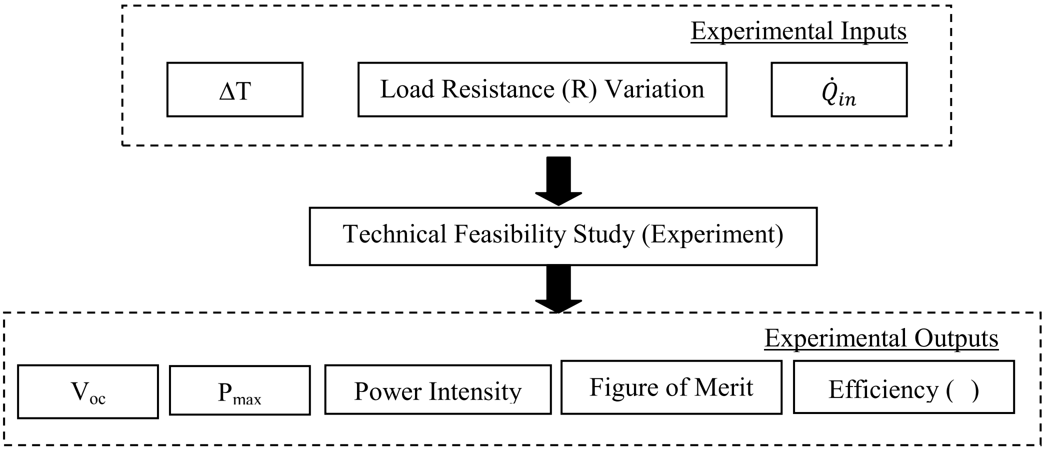


Figure 3.2 The framework for technical feasibility study

The TE modules supplied electrical power to a variable resistance set. The current through the resistance and the voltage across it were measured by handheld multimeters. A plot between I and V yielded an open-circuit voltage (V_{oc}), close-circuit currents (I_{cc}), and maximum power. Then, the thermal-to-electric efficiency and effective figure of merit could be calculated.

The input heat power was determined by measuring temperature's decreasing rate of the water container due to heat transfer from the water through the bottom of container. The average input heat power was calculated at the set-value T_h conditions with an error of +/-0.5°C. Heat power loss from the other sides of container was determined by insulating the bottom and conducting experiments in the same way. The power loss subtracted overall heat transfer values to yield the net input heat power ($\dot{Q}_{in}$) through the TE modules. The input heat power calculation was conducted by Equation (3.1).

$$\dot{Q}_{in} = \frac{dQ}{dt} = (mc_p.\frac{dT}{dt})_{gross} - (mc_p.\frac{dT}{dt})_{lost} \qquad (3.1)$$

The maximum experimental thermal-to-electric efficiencies were calculated by considering the ratio of P_{max} to $\dot{Q}_{in}$ in Equation (3.2).

$$P = \ .\dot{Q}_{in} \qquad (3.2)$$

Carnot or ideal efficiencies were also determined by Equation (3.3) for comparison.

$$_{Carnot} = \frac{\Delta T}{T_h} \qquad (3.3)$$

State-of-the-art efficiencies were predicted in linear efficiency ratio of good typical Bi_2Te_3 devices of 0.04% per 1 Kelvin of temperature differential [13], and then the predicted maximum power was calculated backward from the known $\dot{Q}_{in}$ and $_{max}$ using Equation (3.2). Effective or experimental figure of merit (ZT) for TE module needed to consider all the passive losses that degrade the TEG performance from ideal TEG e.g. the impact of electrical contact resistance, interconnect resistance, exterior ceramic conduction losses, and substrate-to-substrate conduction losses in the gaps that separate TE elements [19]. The figure of merit was related to 3 parameters: , Th, and Tc and was calculated by using Equation (3.4).

$$= \frac{\Delta T}{T_h} \cdot \quad _{r} = \frac{\Delta T}{T_h} \cdot \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_c}{T_h}} \qquad (3.4)$$

3.1.2 Market potential and market feasibility study

The target market is grasped and segmented into the proposed scope, the consumer portable electronic devices market. Also, the unmet customer needs and the strength of competitors has to be determined. Business research is introduced to classify the market need in sectors and determine the potential market size. Main activity relates to the secondary data analysis via literature search and/or expert interview. In addition, if there are still a lack of some essential insights for this part of study, qualitative research methodology such as individual depth interviews, or even group interviews are considered to select for qualitative data collection of "how and why" concepts for more deeply understanding of the market. Purposive sampling, by choosing participants arbitrarily for their characteristics or their experiences, attitudes, or perceptions [39], is possibly selected for the study if there is additional qualitative research.

The business research was conducted to analyze consumer behaviour for their PCED utilization patterns, power supply lacking problems, and encountering practical heat sources or sinks in 3 modes: daily life, work, and leisure hobbies. The population was people living in Bangkok, one of typical metropolitan area. Based on the secondary data analysis from literature and National Statistical Office of Thailand, quantitative analysis via questionnaires was applied using the cluster probability sampling methodology with the sample size of 400, statistically, at 0.05 level of significance using calculation method suggested by Yamane [40]. Qualitative analysis was also conducted to emphasize the rationale of consumer's behaviour using in-depth qualitative interview. The data analysis yielded descriptive statistics, and assumption verification for the correlations between independent variables i.e. sex, age, income, occupation, and hobby and dependent variables i.e. PCED consumption, PCED power supply problem, related heat source or sink, and purchase decision.

The framework of business research for market attractiveness was shown in Figure 3.3.

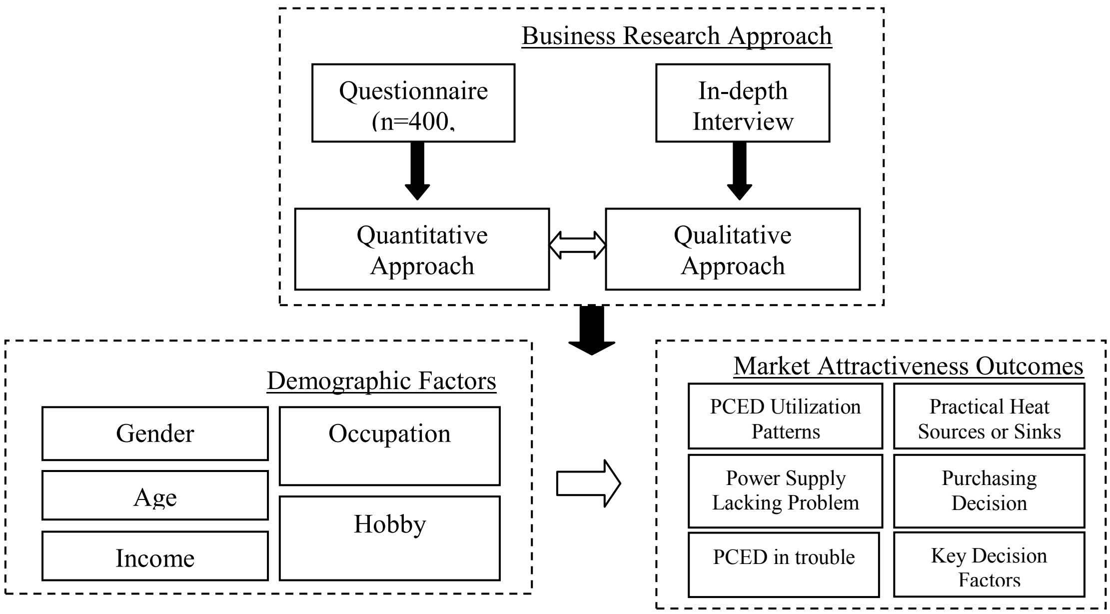


Figure 3.3 The comprehensive framework of the business research for market attractiveness

3.1.3 Fundamental investment assessment and financial feasibility study

The financial feasibility for the potential options examined in the early stages is analyzed to determine financial attractiveness for the investment of each innovation case, calculating principal parameters e.g. NPV, payback period, IRR, B/C ratio and so on which is relating to the comprehensive financial analysis using the estimated data from typical sources. This section was done by needing some information of potential target market, manufacturing and operational cost. Therefore, the financial feasibility would not be finalized until the thorough business plan section was finished.

3.2 New product development phase (phase II)

3.2.1 Product design

An innovative product is planned to synthesize and new product design is conducted mainly referring the stage-gate approach [33] (Figure 3.4) by matching target market to related technologies using additional essential techniques for examples.

- Quality Function Deployment (QFD) mainly in the first phase: analyzing and converting the market needs to technical requirements
- Theory of Inventive Problem Solving (TRIZ): solving the contradiction problem corresponding to QFD analysis.

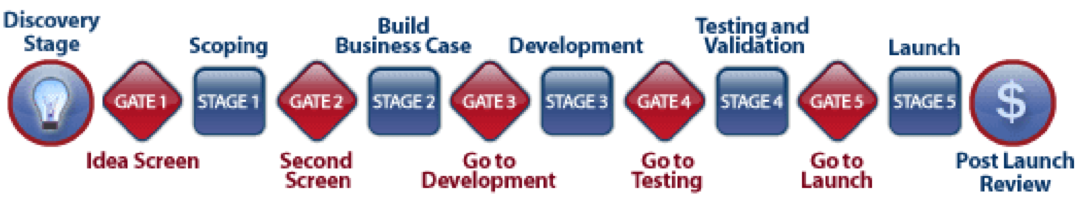


Figure 3.4 Stage-Gate ® framework for new product development

3.2.2 Engineering and industrial design

The most appropriate design in the concentrated aspects (mainly from the market considerations) is determined and optimal design solution is generated using the approach of "Design for Manufacture and Assembly" (DFMA).

3.2.3 Prototyping and testing

A demonstrating prototype or a set of comprehensive prototypes which is sufficient to describe product characteristics, usage lifestyle, features and functions is developed. The set of appropriate prototypes will be selected for examples: "works-like" prototype, "looks-like" prototype, behavioral prototype, paper prototype, mock-up model, rapid prototype.

3.3 Commercialization phase (phase III)

3.3.1 Conducting business plan for the successful commercialization

Business plan is developed in order to manage the innovation into successful commercialization. The business plan involves directly for the commercialization of new product e.g. marketing plan, operation plan, financial plan, product and service development plan, intellectual property management plan (if available)

3.3.2 Validity verification for the business and the successful innovation

The overall business and the successful innovation are verified for its validity via technology acceptance model (TAM). This model appears to be the most widely accepted among information systems researchers in order to verify new applications or software introduced to users [41]. It involves the consideration for 2 principal factors i.e. perceived usefulness and perceived ease of use, a major determinant of user's intention and a significant secondary determinant of his/her intention respectively, as shown the model component Figure 3.5 [41]. The two factors, thus, are of primary relevance for user acceptance behavior. The model is widely applied mostly in the area of information and communication technology, and, indeed, able to apply for other technological product development also.

Technology acceptance model (TAM), referred from Figure 3.5, was brought to evaluate customers' attitude for the product invention, and sample customers would justify whether the product invention is worth for them to buy it and accept for practical utilizations. That implies the successful exploitations and leads to the complete innovation.

Each element of TAM was analyzed for its rationale and all elements were required to combine sample customers' attitude and lead to a conclusion of customer acceptance. Qualitative in-depth interview was used to find out supporting rational and root cause for each attitude with the product covering all potential opportunities of exploitations. Moreover, qualitative research could lead to suggestions or opportunities for improvements in the aspect of both product improvements and appropriate contexts of use.

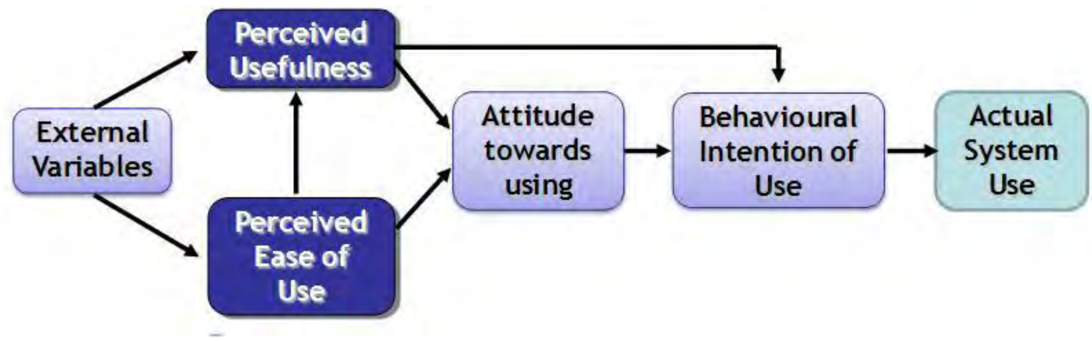


Figure 3.5 Technology Acceptance Model (TAM) [42]

3.3.3 <u>Discussing and concluding the overall achievement including fur suggestions</u>

The overall achievement including further suggestions is discussed and concluded.

Chapter IV
Results and Discussion

4.1 Technical Feasibility

The results of the power output from various conditions were plotted in charts to reveal the relationship of I-V and P-V, as shown for all conditions of T_c = 0°C and 27°C in Figure 4.1. Maximum power outputs, maximum voltages, and maximum thermal-to-electric efficiencies were calculated as shown in Table 4.1. In addition, the trend for those key figures were plotted for considering the relationship versus temperature differentials (ΔT) as shown in Figures 4.2 to 4.4.

Open circuit output voltages (V_{oc}), which were composed of accumulating voltages from TE elements, were determined as the TE module characteristics for generating highest voltages while temperature differentials (ΔT) existed. The relations between V_{oc} and ΔT were directly linear with an approximate rate of 23 mV/°C (for T_c= 0°C) and 24 mV/°C (for T_c= 27°C) as shown in Figure 4.2. The Seebeck coefficient (α) was calculated considering the number of all 508 couples of TE elements in 4 TE modules, to be 46 ±1 μV/°C for each couple.

The maximum power outputs (P_{max}) from 0°C and 27 °C cold-side condition ranged from 20.3 mW to 100.8 mW and from 2.1 mW to 46.3 mW, respectively as shown in Figure 4.3, whereas the voltages corresponding to the maximum outputs for the mentioned conditions ranged from 0.39V to 1.08 V and from 0.16 V to 0.86 V, respectively, depending on temperature differentials and heat transfer ability. This implied ranges of potential outputs to consider further in product design criteria. Moreover, the trends from Figure 4.3 showed non-linear power outputs and the trend lines for both conditions of T_c were separate from each other. This pattern resulted from the distinctive heat transfer characteristic of input heat power ($\dot{Q}_{in}$) at different operating temperatures of both T_h and T_c, and increasing efficiency trends shown in Figure 4.4. These voltages at the optimally operating conditions needed step-up converting and output stabilizing to effectively supply electricity. The more temperature differential applying to the module would cause the peak of P_{max} to shift upward and to occur at rising voltage as well. This can be explained by assuming I-V linear trends with approximately equivalent slope for every T_c condition from Figure 4.1. A general linear equation for the I-V relationship was determined to solve a value of V for the maximum power as shown in Figure 4.5 and Equations (4.1) to (4.3).

Table 4.1 The experimental results for TEG characteristic

Condition	T_c (°C)	T_h (°C)	ΔT (°C)	$\dot{Q}_{in}$ (W)	P_{max} (mW)		Power Intensity (μW/cm²/°C)		V_{oc} (V)
					Experimental	Predicted[1]	Experimental	Predicted[1]	
1	27.0	37.0	10.0	1.3	2.1	5.2	3.3	8.1	0.3
2		55.0	28.0	1.8	9.4	19.7	5.3	11.0	0.6
3		75.0	48.0	1.9	23.1	37.4	7.5	12.2	1.1
4		95.0	68.0	2.7	46.3	73.9	10.6	17.0	1.7
5	0.0	37.0	37.0	2.3	20.3	34.2	8.6	14.4	0.8
6		55.0	55.0	3.2	49.6	70.1	14.1	19.9	1.3
7		75.0	75.0	3.8	80.7	113.8	16.8	23.7	1.6
8		95.0	95.0	3.9	100.8	147.6	16.6	24.3	2.2

Condition	T_c (°C)	T_h (°C)	ΔT (°C)	η_{max} (%)			Figure of Merit (ZT)	
				Experimental	Predicted[1]	Carnot	Experimental	Predicted[1]
1	27.0	37.0	10.0	0.16	0.40	3.2	0.22	0.64
2		55.0	28.0	0.54	1.12	8.5	0.27	0.66
3		75.0	48.0	1.19	1.92	13.8	0.38	0.69
4		95.0	68.0	1.71	2.72	18.5	0.40	0.73
5	0.0	37.0	37.0	0.88	1.48	11.9	0.32	0.60
6		55.0	55.0	1.56	2.20	16.8	0.41	0.63
7		75.0	75.0	2.13	3.00	21.6	0.43	0.66
8		95.0	95.0	2.59	3.80	25.8	0.43	0.69

[1.] The values derived or calculated from the predicted linear efficiency ratio suggested by Bierschenk and Miner (2007)

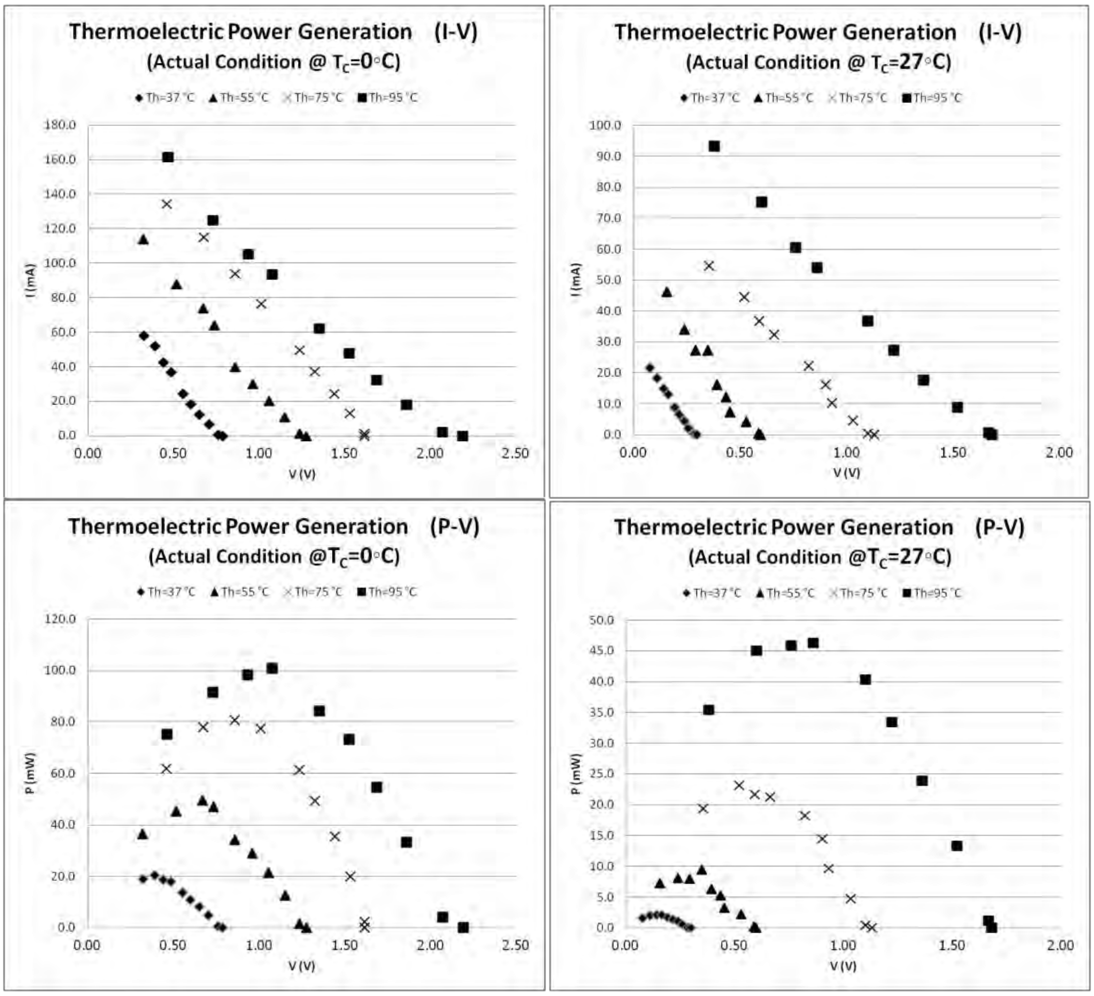


Figure 4.1 I-V and P-V relationship for all conditions of T_c = 0°C and T_c = 27°C

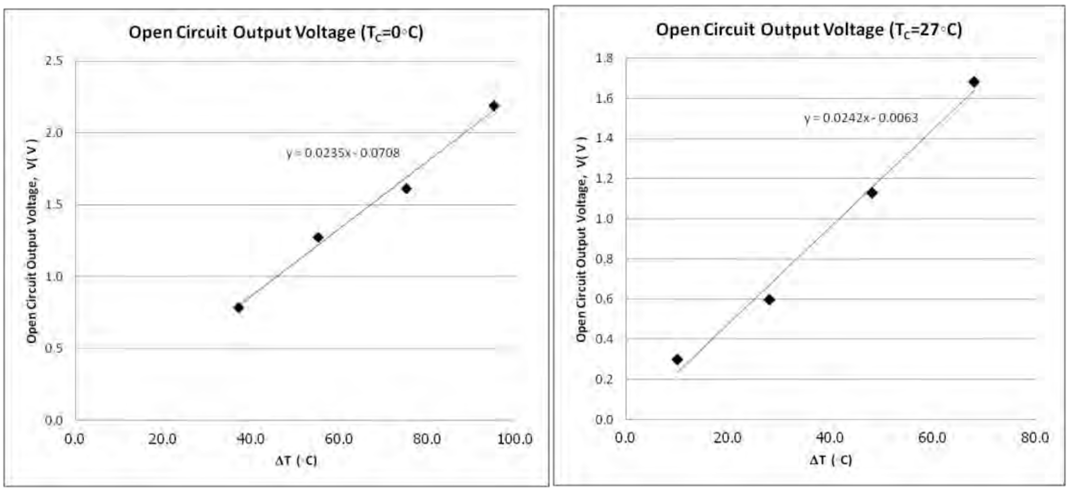


Figure 4.2 The relationship of open circuit output voltages versus temperature differentials

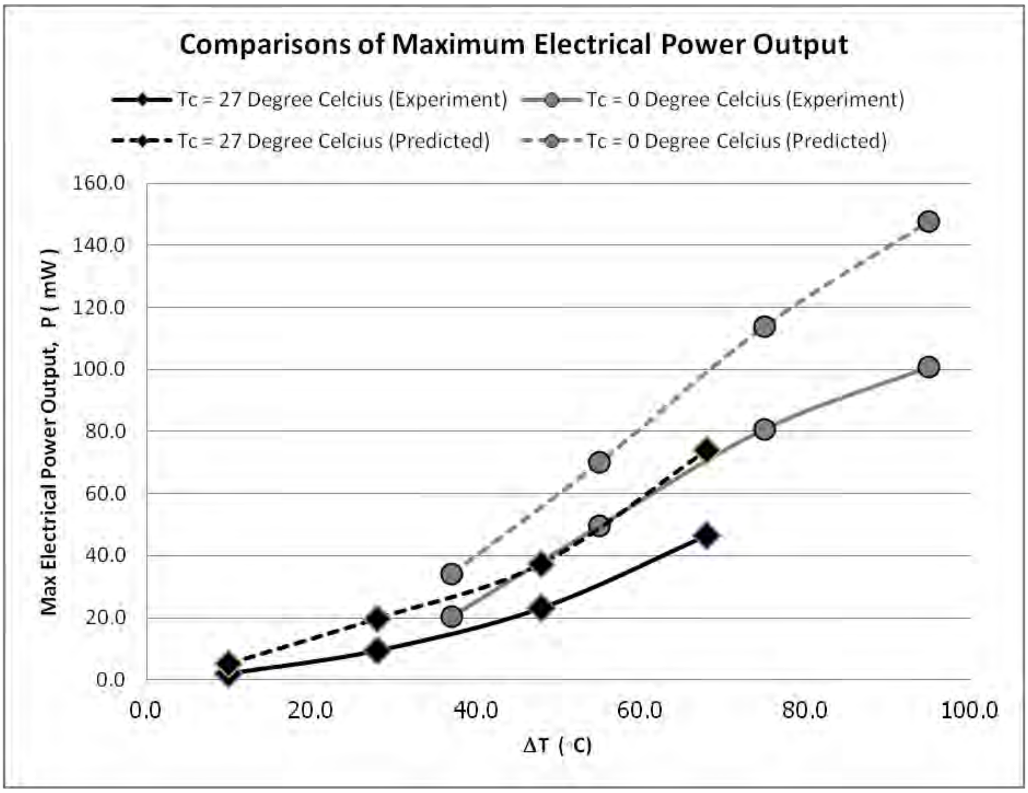


Figure 4.3 The relationship of TEG maximum electrical power outputs versus temperature differentials for all conditions of the experiments compared with those outputs calculated from the predicted state-of-the-art efficiencies

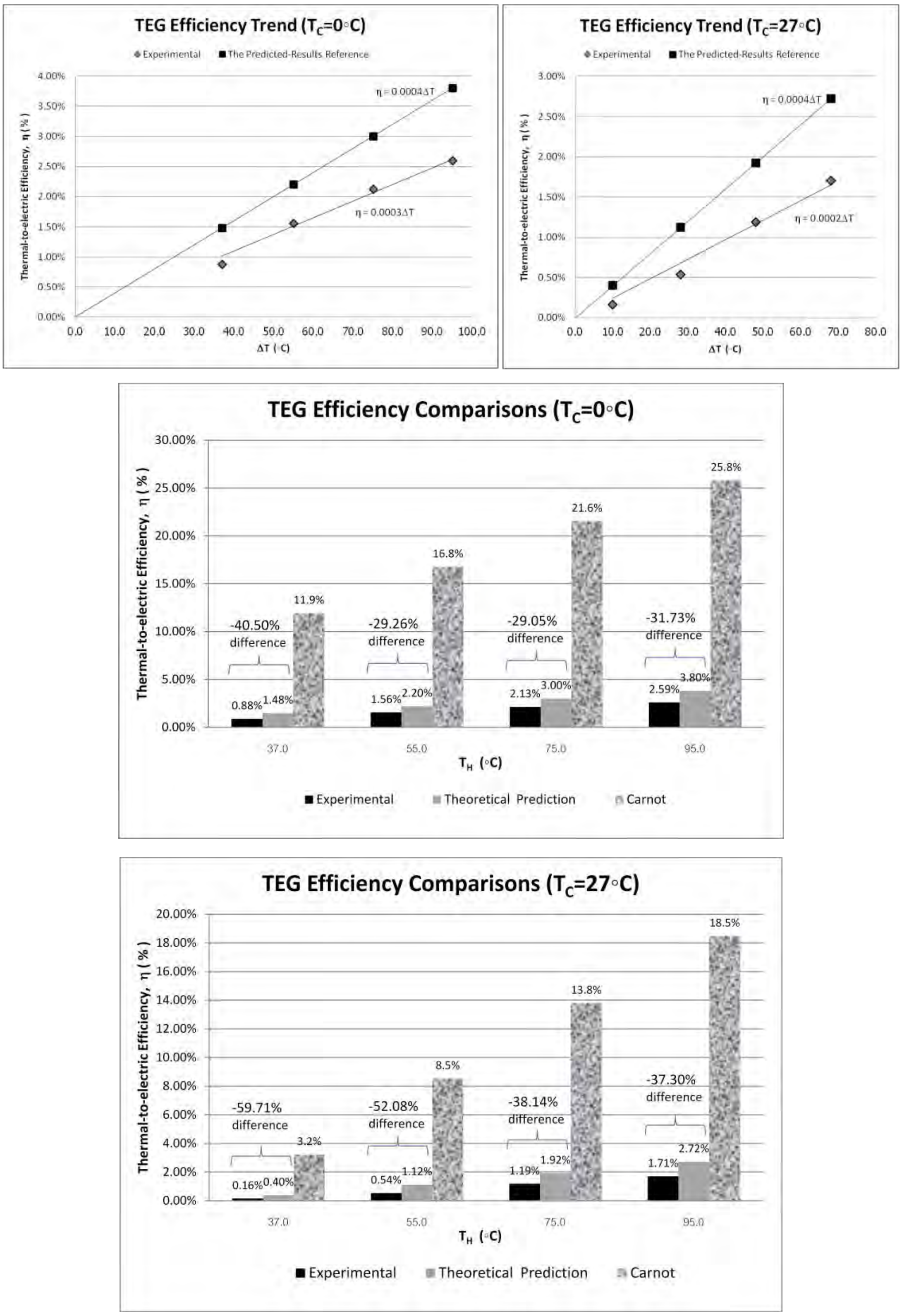


Figure 4.4 The relationship of TEG maximum thermal-to-electric efficiencies versus temperature differentials and TEG efficiencies comparisons

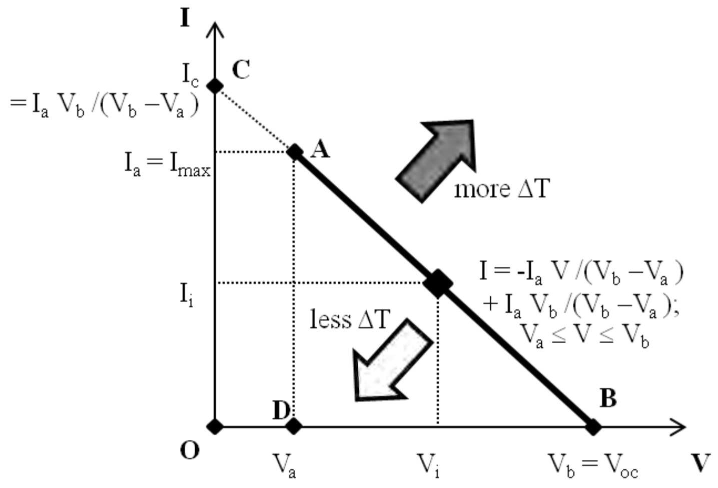


Figure 4.5 A general linear equation for I-V relationship approximated from the characteristic of experimental results

From Figure 4.5, determining the approximated general linear trend equation;

$$OBC \sim \Delta DBA;\ I_c = \frac{I_a.V_b}{V_b - V_a};\ \ I = -\frac{I_a.V}{V_b - V_a} + \frac{I_a.V_b}{V_b - V_a}\ for\ V_a \leq V \leq V_b \quad (4.1)$$

From Equation (4.1), determining P in terms of V;

$$P = IV = \left(-\frac{I_a.V}{V_b - V_a} + \frac{I_a.V_b}{V_b - V_a}\right).V = -\frac{I_a.V^2}{V_b - V_a} + \frac{I_a.V_b.V}{V_b - V_a}\ \ for\ V_a \leq V \leq V_b \quad (4.2)$$

From Equation (4.2), determining V for P_{max} by solving

$\frac{dP}{dV} = 0 = -\frac{2I_a.V}{V_b - V_a} + \frac{I_a.V_b}{V_b - V_a}$, when $V_a \quad V_b = V_{oc}$;

$$\text{for } P_{max},\ V = \frac{V_b}{2} = \frac{V_{oc}}{2} \quad (4.3)$$

The result revealed that the maximum power occurred when adjusting a voltage to the value of $V_{oc}/2$ approximately, and the optimal voltage would change depending on the condition of ΔT, which is directly proportional to V_{oc} as shown in Figure 4.2. Therefore, a commercial application of TE module is required to maintain a maximum power output by adjusting an optimal voltage corresponding to changeable conditions of use as a significant consideration of product development.

To analyze the relationship between maximum electrical power outputs (P) and temperature differentials (ΔT) from Figure 4.3, the general linear equation in Figure 4.5 were analyzed to verify the trend of them as follows.

From the principle of Seebeck ($V = \alpha \Delta T$) and Equation 4.2;

$$P = IV = f(\Delta T) = -\frac{I_a.\propto^2 \Delta T^2}{V_b - V_a} + \frac{I_a.V_b.\propto,\Delta T}{V_b - V_a} \; for\; V_a \leq V \leq V_b \tag{4.4}$$

The relationship pattern between P and ΔT, consequently, is described as a parabolic curve with the start point at origin point (0,0) and the curve goes up in the first quadrant to reach maximum P while ΔT increases.

The maximum thermal-to-electric efficiencies (η_{max}) from the experiments were compared with the predicted values suggested by Snyder [13] and Carnot efficiencies and shown in Figure 4.4. The predicted linear trends of maximum efficiencies were illustrated for a guideline, and the actual trends of those were direct-variation and have linear trends as shown in Figure 4.4. Approximately, the TE modules yielded η_{max} from the experiments in the rate of 0.03%/°C and 0.02%/°C with cold-side temperature of 0 and 27 ◦C, respectively, as illustrated in Figure 4.4. The average effective figure of merit of 0.40 and 0.32 of TE module with cold-side temperature of 0 and 27 ◦C, respectively, are still significantly lower than the predicted value of around 0.66. The drops of efficiencies and figures of merit revealed some additional experimental pitfalls. As analyzed, the actual temperature differentials across TE modules from the experiments were considered lower than the set point because of the position of the temperature sensor apart from TE module contact point, and non-uniform temperature distribution in the water container and the bath. As a result, compared with the predicted maximum efficiencies of good typical devices, the experimental maximum efficiencies reduced substantially from usual characteristics. To narrow the gaps between experimental and predicted results, the difference between actual temperature differentials of TE modules and those from the measured records should be as few as possible. Each inherent practical TE module characteristic as described in Equation (2.1) i.e. Seebeck coefficient (α), electrical resistivity (ρ), and thermal conductivity (κ) also yielded reduced ZT value from the predicted value of good bismuth telluride devices as shown in Table 4.1.

To summarize, as the guideline for technical characteristics references in consumers‟‟ exploiting conditions and also a baseline for up scaling to higher power input or higher temperature differences, the useful and applicable technical information is summarized as follows.

1) The experimental power inputs ranged from 1.3 W to 3.9 W. As a result, the maximum power outputs (P_{max}) from 0°C and 27 °C cold-side condition ranged from 20.3 mW to 100.8 mW and from 2.1 mW to 46.3 mW respectively. Practically, power inputs depend on heat sources and sinks from selected applications. Due to the objective of this research in harvesting waste heat from surroundings of PCED consumers, one potential application of waste heat harvest from a hot water container was selected to exemplify TEG characteristics.

2) The voltages corresponding to the maximum power outputs for the mentioned conditions, depending on ΔT, ranged from 0.39V to 1.08 V and from 0.16 V to 0.86 V respectively. This implied the range of performance in typical conditions for 4-TEG module application in the temperature differential range of not more than 100°C and the cold-side temperature of 0°C to ambient temperature.

3) The Seebeck coefficient (α) was calculated for the number of all 508 couples of TE elements in 4 TE modules, to be 46 ±1 μV/°C for each couple.

4) The maximum power occurred when adjusting a resistance load to obtain output voltage in the value of $V_{oc}/2$ approximately.

5) Linear-trend efficiencies from Figure 4.4 could be used to predict approximate efficiencies, which were proportional to ΔT. However, if ΔT exceeds 100°C as shown in Figure 2.2, the linear fits will not practical for approximation and the highest practical efficiencies of TEG is around 5% [13].

6) The average effective figure of merit of 0.40 and 0.32 of TE module with cold-side temperature of 0 and 27 ◦C respectively are still significantly lower than the predicted value of around 0.66. To narrow the gaps between experimental and predicted results, the difference between actual temperature differentials of TE modules and those from the measured records should be as few as possible. This would be taken in considerations in product design phase.

4.2 Market Attractiveness

The results from the business research were revealed to analyze PCED consumer behaviour for their PCED utilization pattern, power supply lack problems, and encountering heat sources/sinks. Quantitative analysis results were analyzed, statistically, with the sample size of 400 at 0.05 level of significance. In addition, the qualitative analysis outcome from in-depth qualitative interview could suggest the rationale of consumer's behaviour as shown in this section. The questionnaire form for quantitative research was revealed in Appendix A.

The objectives for the market attractiveness study were to filter target PCEDs and target heat sources/ sinks including conditions for potential niche. In addition, voice of customers and important problems for power supply lack of PCEDs were examined for the product and production design in the next step.

4.2.1 Quantitative Approach

The questionnaires were verified for validity with experts and for reliability with satisfactory Cronbach"s alpha of more than 0.808 (good level of reliability) [43, 44] as shown for the printout data in Appendix B. Descriptive statistics and correlations of factors were determined. In case of correlation analysis of two qualitative variables i.e. the type of nominal and ordinal scale, including the case of dependent interval-scale variables with non-normal distribution of those skewed data, Pearson"s χ^2 method could be used to verify the correlation of the pair of variables [44]. Referred from the questionnaire in Appendix A, all variables related to the study were defined in Table 4.2.

4.2.1.1 Variable characteristics

Independent variables were the characteristics of samples for the questionnaire survey i.e. gender, age, income, occupation, and hobby, whereas dependent variables corresponded to the statement of problem for this research to find out the most appropriate condition for an innovative product design in the next step. The data from the questionnaire depicted the sample characteristics as shown in Tables 4.3-4.7.

Table 4.2 List and characteristics of business research variables in the study

No.	Variable	Scale type	Description
1. Independent variables			
1.1	Gender	Nominal	Genders of the samples: male or female
1.2	Age	Ordinal	Range of ages for the samples
1.3	Income	Ordinal	Range of income or salary for the samples
1.4	Occupation	Nominal	Jobs or career for the samples
1.5	Hobby	Ordinal	Rank of the most favourite hobbies for the samples in descending order
2. Dependent variables			
2.1	PCED ownership	Ordinal	Rank of the most frequent usage of PCEDs for the samples in descending order
2.2	Problem for PCED power supply	Interval (1 to 5)	Likert scale (1to 5) for power supply lacking problems of PCEDs for the samples
2.3	PCED in trouble	Ordinal	Rank of PCEDs with the most frequent encounter of power supply lacking problem for the samples in descending order
2.4	Heat or cool source	Interval (0 to 4)	Likert scale for encounter frequency of heat or cool sources for the samples
2.5	Decision making for a purchase	Nominal	Responses of whether or not the samples decided to buy an innovative power supply product for solving power supply problems
2.6	Key factor for a purchase	Interval (1 to 4)	Likert scale for importance of purchasing decision factors for the samples

1.) Gender

Table 4.3 Amount and percentage of the samples classified by genders

Gender	Amount	Percentage
Male	222	50.6
Female	217	49.4
Total	439	100.0

2.) Age

Table 4.4 Amount and percentage of the samples classified by ages

Age (years)	Amount	Percentage
Less than 20	20	4.6
20-39	360	82.0
40-59	57	13.0
60 and above	2	0.5
Total	439	100.0

3.) Income

Table 4.5 Amount and percentage of the samples classified by incomes

Income (Baht/month)	Amount	Percentage
No income	29	6.6
1-5,000	10	2.3
5,001-10,000	47	10.7
10,001-30,000	189	43.1
30,001-50,000	91	20.7
50,001-100,000	53	12.1
More than 100,000	20	4.6
Total	439	100.0

4.) Occupation

Table 4.6 Amount and percentage of the samples classified by occupations

Income (Baht/month)	Amount	Percentage
Student	63	14.4
Mass Media	3	0.7
Aviation Officer	1	0.2
Retired Person	2	0.5
Manager	8	1.8
Employee	135	30.8
Merchant	10	2.3
Artist	4	0.9
Entrepreneur	32	7.3
Police / Soldier	4	0.9
Freelance	24	5.5
Governmental Officer	78	17.8
Teacher	8	1.8
Lecturer / Professor	26	5.9
Medical Officer	6	1.4
Engineer / Architect	18	4.1
Project Operator	1	0.2
Industrial Worker	6	1.4

5.) Hobby

Table 4.7 Amount and percentage of the samples classified by hobbies

Rank of selected favorites	Selected favorite hobbies									
	Sports		Traveling		Camping		Photographing		Eating	
	No.	%	No.	%	No.	%	No.	%	No.	%
1	54	25.1	52	18.6	2	2.0	9	5.3	25	10.7
2	24	11.2	58	20.8	5	5.1	23	13.6	35	15.0
3	15	7.0	38	13.6	9	9.1	28	16.6	31	13.2
4	29	13.5	27	9.7	9	9.1	22	13.0	37	15.8
5	23	10.7	45	16.1	10	10.1	18	10.7	29	12.4
6	12	5.6	24	8.6	10	10.1	8	4.7	25	10.7
7	18	8.4	17	6.1	4	4.0	13	7.7	18	7.7
8	6	2.8	4	1.4	4	4.0	12	7.1	13	5.6
9	7	3.3	5	1.8	7	7.1	9	5.3	5	2.1
10	7	3.3	1	0.4	6	6.1	8	4.7	9	3.8
11	6	2.8	3	1.1	5	5.1	3	1.8	3	1.3
12	2	0.9	3	1.1	6	6.1	7	4.1	1	0.4
13	5	2.3	1	0.4	6	6.1	6	3.6	1	0.4
14	2	0.9	1	0.4	4	4.0	0	0.0	1	0.4
15	4	1.9	0	0.0	7	7.1	2	1.2	1	0.4
16	1	0.5	0	0.0	5	5.1	1	0.6	0	0.0
17	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	215	100.0	279	100.0	99	100.0	169	100.0	234	100.0
Percent of total chosen items	49.0 %		63.6 %		22.6 %		38.5 %		53.3 %	

Table 4.7 (continued) Amount and percentage of the samples classified by hobbies

Rank of Favorites	Selected favorite hobbies									
	Cooking		Going to temple		Party		Shopping		Internet/ Social Network	
	No.	%	No.	%	No.	%	No.	%	No.	%
1	9	7.1	12	9.7	13	7.0	20	10.6	119	32.7
2	13	10.2	6	4.8	14	7.5	25	13.3	86	23.6
3	14	11.0	11	8.9	31	16.7	28	14.9	46	12.6
4	7	5.5	17	13.7	26	14.0	24	12.8	42	11.5
5	17	13.4	10	8.1	19	10.2	20	10.6	20	5.5
6	13	10.2	10	8.1	17	9.1	16	8.5	21	5.8
7	7	5.5	4	3.2	16	8.6	12	6.4	15	4.1
8	5	3.9	10	8.1	6	3.2	12	6.4	4	1.1
9	8	6.3	5	4.0	10	5.4	7	3.7	1	0.3
10	5	3.9	4	3.2	10	5.4	7	3.7	0	0.0
11	6	4.7	10	8.1	6	3.2	4	2.1	4	1.1
12	6	4.7	7	5.6	8	4.3	3	1.6	3	0.8
13	3	2.4	1	0.8	5	2.7	3	1.6	1	0.3
14	7	5.5	6	4.8	2	1.1	4	2.1	1	0.3
15	3	2.4	6	4.8	1	0.5	2	1.1	1	0.3
16	4	3.1	5	4.0	2	1.1	1	0.5	0	0.0
17	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	127	100.0	124	100.0	186	100.0	188	100.0	364	100.0
Percent of total chosen items	28.9 %		28.2 %		42.4 %		42.8 %		82.9 %	

Table 4.7 (continued) Amount and percentage of the samples classified by hobbies

Rank of Favorites	Selected favorite hobbies									
	Playing Game		Movie / Music		Singing / Playing Music		Plant / Animal Feeding		Reading	
	No.	%	No.	%	No.	%	No.	%	No.	%
1	14	7.9	34	12.2	17	11.3	5	3.7	49	17.4
2	34	19.2	40	14.4	14	9.3	14	10.4	44	15.6
3	32	18.1	44	15.8	17	11.3	19	14.1	45	16.0
4	20	11.3	46	16.5	12	7.9	13	9.6	47	16.7
5	18	10.2	30	10.8	26	17.2	11	8.1	33	11.7
6	9	5.1	21	7.6	12	7.9	13	9.6	17	6.0
7	7	4.0	14	5.0	11	7.3	10	7.4	16	5.7
8	7	4.0	17	6.1	7	4.6	6	4.4	8	2.8
9	6	3.4	10	3.6	9	6.0	2	1.5	8	2.8
10	5	2.8	2	0.7	4	2.6	10	7.4	8	2.8
11	0	0.0	7	2.5	2	1.3	5	3.7	2	0.7
12	4	2.3	0	0.0	3	2.0	4	3.0	3	1.1
13	5	2.8	3	1.1	7	4.6	3	2.2	0	0.0
14	1	0.6	9	3.2	7	4.6	10	7.4	0	0.0
15	6	3.4	0	0.0	2	1.3	8	5.9	1	0.4
16	8	4.5	1	0.4	1	0.7	2	1.5	1	0.4
17	1	0.6	0	0.0	0	0.0	0	0.0	0	0.0
Total	177	100.0	278	100.0	151	100.0	135	100.0	282	100.0
Percent of total chosen items	40.3 %		63.3 %		34.4 %		30.8 %		64.2 %	

Table 4.7 (continued) Amount and percentage of the samples classified by hobbies

Rank of Favorites	Selected favorite hobbies			
	Massaging / Spa		Others	
	No.	%	No.	%
1	2	1.9	3	23.1
2	2	1.9	0	0.0
3	16	15.1	0	0.0
4	7	6.6	1	7.7
5	11	10.4	0	0.0
6	10	9.4	2	15.4
7	2	1.9	0	0.0
8	6	5.7	0	0.0
9	7	6.6	1	7.7
10	5	4.7	0	0.0
11	3	2.8	0	0.0
12	1	0.9	0	0.0
13	6	5.7	1	7.7
14	1	0.9	0	0.0
15	10	9.4	0	0.0
16	17	16.0	1	7.7
17	0	0.0	4	30.8
Total	106	100.0	13	100.0
Percent of total chosen items	24.1 %		3.0 %	

For hobby selection by the samples, a person could select his/her favorite hobbies by defining the rank of his/her favorite in descending order, i.e. the rank no.1 means the most favorite for him/her, rank no.2 means the second favorite, and so on. The percent of total chosen items indicated the amount of samples that chose an item as one of their hobbies.

4.2.1.2 Problem identification and analysis

The results in Table 4.8 revealed amount of samples with PCED trouble of power supply insufficiency in number and percentage of all samples and average rank of impact level prioritized by the samples that were significantly impacted by the power supply lacking problem. The problem was related to power sources for each PCED that consumers felt the adversity of insufficient electrical power for their favourite PCEDs so that they could not use them further as they desired or felt frustrated with them. The samples were asked in the questionnaire to prioritize impacts of power supply problem from each PCED. The rank chosen in the questionnaire (from no.1,2,3, and so on) was arranged in descending order from the most impact level or the most important from PCED‟s power supply lacking problem.

Table 4.8 Descriptive statistics of PCEDs in trouble in consumers‟ opinions

No.	PCED	Amount of people owning PCED		Amount of People with power supply problem		Mean of rank of problem impact level
		No.	% by samples	No.	% by owners	
1	Laptop computer	342	77.9%	330	96.5%	1.86
2	Mobile phone	258	58.8%	242	93.8%	2.29
3	Smart phone	240	54.7%	231	96.3%	1.81
4	Digital compact camera	210	47.8%	186	88.6%	3.08
5	D-SLR camera	103	23.5%	92	89.3%	3.72
6	Tablet PC	75	17.1%	70	93.3%	3.40
7	CD/ MP3/ IPOD player	91	20.7%	68	74.7%	4.66
8	PDA/ Pocket PC	57	13.0%	57	100.0%	3.92
9	Video / DVD / MP4 player	83	18.9%	56	67.5%	4.48
10	Portable flashlight	82	18.7%	51	62.2%	4.96
11	Camcorder	44	10.0%	44	100.0%	4.45
12	Portable GPS	48	10.9%	40	83.3%	4.38
13	Bluetooth headset	44	10.0%	40	90.9%	5.33
14	Portable electronic game	39	8.9%	32	82.1%	4.53
15	Voice recorder	30	6.8%	24	80.0%	5.21

The target PCEDs were assumed to be selected in the design process for items with amount of people with power supply problems not less than 80% found by owners. This filtration leaded to niche in application range information with potential to use innovative power supply product. As a result, target applications comprised (1) a laptop computer, (2) a mobile phone, (3) a smart phone, (4) a digital compact camera, (5) a D-SLR camera, (6) a tablet PC, (7) a PDA/ pocket PC, (8) a camcorder, (9) a portable GPS, (10) a Bluetooth headset, (11) a portable electronic game, and (12) a voice recorder.

In addition, the survey examined 5-level relationship in ascending order Likert scale between practical heat sources or sinks and the sample users i.e. (1) “never”, (2) “seldom”, (3) “sometimes”, (4) “often”, and (5) “always” for average level in a range of (1) 0.00 to 0.80, (2) 0.81 to 1.60, (3) 1.61 to 2.40, (4) 2.41 to 3.20, and (5) 3.21 to 4.00 respectively. The practical heat sources or sinks were recommended for some items with inherent heat transfer e.g. laptop computers, mobile phones, air conditioners, refrigerators, and heat from direct sunlight which “always related” to samples“ daily lives, whereas some items e.g. automobiles, hot/cold beverage containers, PCs, food packages, and cooking devices “often related” to them as shown in Table 4.9. However, heat sources or sinks with low encounter level (excluding “never encounter”) were still considered potential for harvesting but with more study for exploring niche that significantly related to them. In addition, due to the limitation for TEG technology and the cost of production compared with other power supply technology of direct charging from electricity source e.g. external or secondary battery or power supply, some heat or cool sources in adjacent area of minimum electrical sources e.g. at household, buildings, offices, would be uninteresting in harvesting heat for electrical charging. As a result, the 11 heat or cool sources from No.2, 4, 5, 9-15, and 17 in Table 4.9 were included after the filtrations, and were taken in considerations in the next step.

Table 4.9 Comparison of average frequency levels of user‟s encounter for some potential heat sources or sinks in daily life with the Likert scale

No.	Heat or cool source	Mean for encounter level	Interpretation	Minimum electricity sources in adjacent area
1	Refrigerator	3.55	always encounter	Electrical plug
2	Mobile phone	3.33	always encounter	N/A
3	Air conditioner	3.32	always encounter	Electrical plug
4	Laptop computer	3.28	always encounter	N/A
5	Direct sunlight	3.18	often encounter	N/A
6	Automobile	2.84	often encounter	12VDC Battery
7	Hot/cold water supply	2.81	often encounter	Electrical plug
8	Personal computer	2.73	often encounter	Electrical plug
9	Cold beverage cup	2.69	often encounter	N/A
10	Hot beverage cup	2.43	often encounter	N/A
11	Food bag	2.32	sometimes encounter	N/A
12	Cooking Device	2.06	sometimes encounter	N/A
13	Instant food box	1.81	sometimes encounter	N/A
14	Cold dessert bowl	1.67	sometimes encounter	N/A
15	Hot pot	1.43	rarely encounter	N/A
16	LCD projector	1.29	rarely encounter	Electrical plug
17	Candle/ joss stick	1.21	rarely encounter	N/A
18	Lighter	0.54	never encounter	N/A
19	Portable saucer	0.51	never encounter	Electrical plug
20	Others	0.47	never encounter	Electrical plug
21	Cigarrette	0.44	never encounter	N/A
22	Hot-water bag	0.40	never encounter	N/A

Correlations between demographic factors and PCEDs with the trouble of power supply, and those between demographic factors and user‟s encounter of heat sources or sinks in daily life were validated by χ^2 test at 0.05 level of significance as shown in Tables 4.10 and 4.13. The results from Table 4.10 suggested some factors with more specific targets to consider when a product design is focused at some PCEDs with the problem of sufficient power supply. For example, the design criteria of TEG power supply for smart phones to solve power problem are to consider specific group of people with some age range i.e. youngster workers, and teenagers, preference for playing sports, enjoy eating, party, and playing game applications, whereas those for D-SLR cameras are to consider people with favourite activities related to outdoor photography including travelling, camping, and planting or animal feeding as well. In the same way, the results from Table 4.13 suggested factors that significantly generate relationship between PCED users and some daily heat sources or sinks. In conclusion, two correlating factors implied to find out some categories that were favourable or the most related ones to focus in a product design, whereas those without correlation expressed no differences in all categories.

Table 4.10 Correlations between demographic factors and PCEDs with the trouble of power supply, validated by χ^2 test at 0.05 level of significance (Sign "+" indicates that the pairing factors significantly correlate with each other with the p-value < 0.05.)

No.	PCED in trouble	Sex	Age	Income	Occupation	Hobby																
						Sports	Traveling	Camping	Photographing	Eating	Cooking	Praying	Party	Shoping	Internet	Game	Movie/Music	Singing/ Playing Music	Planting / Feeding	Reading	Massaging	Others
1	Laptop Computer			+						+												
2	Mobile Phone					+				+	+		+	+	+							
3	Smart Phone		+			+				+			+			+						
4	Digital Compact Camera		+				+		+	+	+			+	+	+	+	+		+		
5	D-SLR Camera								+										+			
6	Tablet PC									+	+						+					
7	PDA/ Pocket PC																					
8	Camcorder																					
9	Portable GPS				+																	
10	Bluetooth headset																					
11	Portable electronic game																					
12	Voice recorder				+																	

To analyze the correlation between demographic factors and PCEDs with power supply problems, contingency and gamma coefficient of significantly correlating variables were determined to describe how much the two variables correlated each other and how much the two variables formed a trend and relating direction respectively [45]. Table 4.11 revealed the results of contingency and gamma coefficient analyzed by SPSS software version 17.0. Some pairs of correlated variables with contingency coefficient $\geq$ 0.800 were selected to consider crosstab detail of the pair of variables.

Table 4.11 Correlation level and direction between demographic factors and PCED with the trouble of power supply, (Gamma and Contingency coefficient)

No.	PCED in trouble	Age		Income		Occupation	Sports		Traveling		Camping	
		Gamma	Contingency	Gamma	Contingency	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency
1	Laptop Computer			0.001	0.463						-0.055	0.799
2	Mobile Phone						0.049	0.772				
3	Smart Phone	0.059	0.604				0.127	0.808				
4	Digital Compact Camera	-0.361	0.457						0.102	0.702		
5	D-SLR Camera											
6	Tablet PC											
7	PDA/ Pocket PC											
8	Camcorder											
9	Portable GPS					0.896						
10	Bluetooth headset											
11	Portable electronic game											
12	Voice recorder					0.882						

No.	PCED in trouble	Photographing		Eating		Cooking		Praying		Party		Shopping	
		Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency
1	Laptop Computer			0.054	0.747								
2	Mobile Phone			0.054	0.818	0	0.883			0.263	0.799	0.181	0.855
3	Smart Phone			0.009	0.842					0.063	0.81		
4	Digital Compact Camera	0.09	0.856	-0.075	0.789	0.226	0.875					0.247	0.822
5	D-SLR Camera	0.299	0.879										
6	Tablet PC			0.285	0.869	0.327	0.9						
7	PDA/ Pocket PC												
8	Camcorder												
9	Portable GPS												
10	Bluetooth headset												
11	Portable electronic game												
12	Voice recorder												

No.	PCED in trouble	Internet		Game		Movie/Music		Singing/ Playing Music		Planting / Feeding		Reading	
		Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency
1	Laptop Computer												
2	Mobile Phone	0.066	0.671										
3	Smart Phone			0.143	0.772								
4	Digital Compact Camera	0.156	0.728	0.085	0.825	0.197	0.734	0.125	0.825			0.214	0.726
5	D-SLR Camera									-0.11	0.874		
6	Tablet PC					0.014	0.86						
7	PDA/ Pocket PC												
8	Camcorder												
9	Portable GPS												
10	Bluetooth headset												
11	Portable electronic game												
12	Voice recorder												

From the crosstab analyses between demographic factors and the ranks of PCEDs with power supply problems as shown in Appendix C, the outcome and focal point were described in Table 4.12.

Table 4.12 The outcome and description for crosstab analysis of pair variables between demographic factor and PCED in trouble

No.	Demographic factor		PCED in trouble	
	Considered item	The highest portion	Considered item	The highest portion
1	Occupation	(1) Employees, (2) Government officer	Portable GPS	Rank No. 2,3,4
2	Occupation	(1) Employee, (2) Business owner / Government officer/ Professor or instructor	Voice recorder	Rank No.4 (with the most frequency for those who find problems)
3	Hobby-Sports	Rank no.1	Smart phone	Rank No.1
4	Hobby-Photographing	Rank no.2	Digital compact camera	Rank No.2
5	Hobby-Photographing	Rank no.2 and 3	D-SLR camera	Rank no.3
6	Hobby-Eating	Rank no.4	Mobile phone	Rank no.1
7	Hobby-Eating	Rank no.2	Smart phone	Rank no.1
8	Hobby-Eating	Rank no. 4 and 5	Tablet PC	Rank no.3
9	Hobby-Cooking	Rank no.3	Mobile phone	Rank no.1
10	Hobby-Cooking	Rank no.3	Digital compact camera	Rank no.3
11	Hobby-Cooking	Rank no.2 and 5	Tablet PC	Rank no.2
12	Hobby-Game	Rank no. 2 and 3	Smart phone	Rank no.1
13	Hobby-Game	Rank no. 2 and 3	Digital compact camera	Rank no.3
14	Hobby-Movie /music	Rank no.3	Tablet PC	Rank no.3
15	Hobby-Singing / playing music	Rank no.1	Digital compact camera	Rank no.2

From Table 4.12, special target groups were interpreted for examples as follows.

(1) Occupation of employee was the highest portion to encounter the power supply problems of portable GPS and voice recorder, and the samples indicated the power supply problems of portable GPS and voice recorder at the 2nd to 4th rank and the 4th rank in the highest portion respectively.

(2) The samples with the power supply problems of smart phone chose a hobby of playing sports at the first rank in the highest portion , and those with a hobby of playing sports indicated the power supply problems of smart phone at the first rank in the highest portion.

(3) The samples with the power supply problems of digital compact camera chose a hobby of photographing at the second rank in the highest portion, and those with a hobby of photographing indicated the power supply problems of digital compact camera at the second rank in the highest portion.

(4) The samples with the power supply problems of D-SLR camera chose a hobby of photographing at the second and third rank in the highest portion, and those with a hobby of photographing indicated the power supply problems of digital compact camera at the third rank in the highest portion.

(5) Like (2) to (4), the item no.6 to 15 in Table 4.12 could be interpreted in the same approach as described.

In summary, the trouble of power supply for PCED was existed without any significant differences among ranges in all demographic factors for laptop computers, PDAs/ pocket PCs, camcorders, Bluetooth headsets, and portable electronic games. Consequently, all target customer groups should be considered in the product design without preferences. On the other hand, special considerations were needed for some ranges in each demographic factor to reach the preferred customer targets effectively. The considerations with interesting points of applications (the 1^{st} , 2^{nd} , and 3^{rd} rank for PCED in trouble) were as follows.

(1) Smart phones and mobile phones were selected for the 1^{st} rank of PCED in trouble in the highest portion of some specific groups. The trouble in smart phones was found the most with the users who selected sports as a hobby for the 1^{st} rank, or selected eating as a hobby for the 2^{nd} rank, or selected playing games as a hobby for the 2^{nd} and 3^{rd} rank. The trouble in mobile phones was found the most with the users who selected cooking as a hobby for the 3^{rd} rank, or selected eating as a hobby for the 4^{th} rank.

(2) Digital compact cameras, tablet PCs, and portable GPS were selected for the 2^{nd} rank of PCED in trouble in the highest portion of some specific groups. The trouble in digital compact cameras was found the most with the users who selected photographing as a hobby for the 2^{nd} rank, or selected singing / playing music as a hobby for the 1^{st} rank. The trouble in tablet PCs was found the most with the users who selected cooking as a hobby for the 2^{nd} and 5^{th} rank. The trouble in portable GPS (including the 3^{rd} and 4^{th} selected rank) was found the most with the users who were employees and government officers.

(3) D-SLR cameras, tablet PCs, and digital cameras were selected for the 3^{rd} rank of PCED in trouble in the highest portion of some specific groups. The trouble in D-SLR cameras was found the most with the users who selected photographing as a hobby for the 2^{nd} and 3^{rd} rank. The trouble in tablet PCs was found the most with the users who selected watching movies/ listening to music as a hobby for the 3^{rd} rank. The trouble in digital compact cameras was found the most with the users who selected playing games as a hobby for the 2^{nd} and 3^{rd} rank, or selected cooking as a hobby for the 3^{rd} rank.

Table 4.13 Correlations between demographic factors and user‟s encounter of heat or cool sources in daily life, validated by χ^2 test at 0.05 level of significance (Sign "+" indicates that the pairing factors significantly correlate with each other with the p-value < 0.05.)

No.	Heat or cool source	Sex	Age	Income	Occupation	Hobby																
						Sports	Traveling	Camping	Photographing	Eating	Cooking	Praying	Party	Shoping	Internet	Game	Movie/Music	Singing/ Playing Music	Planting / Feeding	Reading	Massaging	Others
1	Mobile Phone		+											+				+				
2	Laptop Computer		+		+				+													
3	Direct Sunlight																		+			
4	Cold-Beverage Cup	+	+									+					+					
5	Hot-Beverage Cup												+				+		+			
6	Food Package	+				+						+										
7	Cooking Device	+								+			+							+		
8	Instant food box		+	+																		
9	Cold dessert bowl																					
10	Hot pot																					
11	Candle/ joss stick																					

Table 4.14 revealed the results of contingency and gamma coefficient analyzed by SPSS software version 17.0. Some pairs of correlated variables with contingency coefficient ≥ 0.500 was selected to consider crosstab detail of the pair of variables.

From the crosstab analyses between demographic factors and the ranks of PCEDs with power supply problems as shown in Appendix C, the outcome and focal point were described in Table 4.15.

Table 4.14 Correlation level and direction between demographic factors and user‟s encounter of heat or cool sources in daily life, (Gamma and Contingency coefficient)

No.	Heat sources & sinks	Sex	Age		Income		Occupation	Sports		Photographing		Eating	
		Contingency	Gamma	Contingency	Gamma	Contingency	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency
1	Mobile Phone		0.001	0.276									
2	Laptop Computer		-0.192	0.268			0.424			0.014	0.563		
3	Direct Sunlight												
4	Cold-Beverage Cup	0.155	-0.202	0.309									
5	Hot-Beverage Cup												
6	Food Package	0.22						0.194	0.524				
7	Cooking Device	0.192										-0.007	0.505
8	Instant food box		-0.313	0.229	-0.223	0.297							
9	Cold dessert bowl												
10	Hot pot												
11	Candle/ joss stick												

No.	Heat sources & sinks	Praying		Party		Shopping		Movie/Music		Singing/ Playing Music		Planting / Feeding		Reading	
		Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency	Gamma	Contingency
1	Mobile Phone					-0.008	0.551			-0.03	0.586				
2	Laptop Computer														
3	Direct Sunlight											-0.182	0.624		
4	Cold-Beverage Cup	0.117	0.653					0.02	0.481						
5	Hot-Beverage Cup			0.057	0.571			0.011	0.454			-0.013	0.612		
6	Food Package	0.06	0.625												
7	Cooking Device			0.084	0.547									-0.002	0.468
8	Instant food box														
9	Cold dessert bowl														
10	Hot pot														
11	Candle/ joss stick														

Table 4.15 The outcome and description for crosstab analysis of pair variables between demographic factor and encounter level of heat or cool source

No.	Demographic factor	Encounter level of heat or cool source	
		Considered item	The highest portion
1	Hobby-Sport	Food package	Encounter level 4 (often encounter)
2	Hobby-Photographing	Laptop computer	Encounter level 5 (always encounter)
3	Hobby-Eating	Cooking device	Encounter level 3 (sometimes encounter)
4	Hobby-Praying	Cold-beverage cup	Encounter level 4 (often encounter)
5	Hobby-Praying	Food package	Encounter level 3 (sometimes encounter)
6	Hobby-Party	Hot-beverage cup	Encounter level 5 (always encounter)
7	Hobby-Party	Cooking device	Encounter level 3 (sometimes encounter)
8	Hobby-Shopping	Mobile phone	Encounter level 5 (always encounter)
9	Hobby-Singing /playing music	Heat from mobile phone	Encounter level 5 (always encounter)
10	Hobby-Planting/ animal feeding	Direct sunlight	Encounter level 5 (always encounter)
11	Hobby-Planting/ animal feeding	Hot beverage container	Encounter level 5 (always encounter)

In summary, the encounter level of heat or cool sources was selected without any significant differences among ranges in all demographic factors for instant food boxes, cold dessert bowls, hot pots, and candles/ joss sticks. Consequently, all target customer groups should be considered in the product design without preferences. On the other hand, special considerations were needed for some ranges in each demographic factor to reach the preferred customer targets effectively. The considerations with interesting frequencies of encounter (the level 3-5 for frequencies of encounter) were as follows.

From Table 4.15, special target groups were interpreted as follows.

(1) The samples which chose a favourite hobby of playing sports mostly encountered a heat source of food package in the level 4 (often encountering).

(2) The samples which chose a favourite hobby of photographing mostly encountered a heat source of laptop computer in the level 5 (always encountering).

(3) The samples which chose a favourite hobby of eating mostly encountered a heat source of cooking devices in the level 3 (sometimes encountering).

(4) The samples which chose a favourite hobby of praying mostly encountered a cool source of cold beverage cup in the level 4 (often encountering).

(5) The samples which chose a favourite hobby of praying mostly encountered a heat source of food package in the level 3 (sometimes encountering).

(6) The samples which chose a favourite hobby of partying mostly encountered a heat source of hot-beverage cup in the level 5 (always encountering).

(7) The samples which chose a favourite hobby of partying mostly encountered a heat source of cooking device in the level 3 (sometimes encountering).

(8) The samples which chose a favourite hobby of shopping mostly encountered a heat source of mobile phone in the level 5 (always encountering).

(9) The samples which chose a favourite hobby of singing or playing music mostly encountered a heat source of heat from mobile phone in the level 5 (always encountering).

(10) The samples which chose a favourite hobby of planting or animal feeding encountered a heat source of direct sunlight and hot beverage container in the level 5 (always encountering).

To analyze and combine with experimental conditions in the technical assessment work, most of conditions for using TEG power supply were at cold-side temperature of ambient (T_c = ambient), and the hot-side temperature varies depending on related heat sources. Direct sunlight was practical for common PCED users to use as heat source for TEG. Cold-beverage cup, on the contrary, was a practical item using as a heat sink for TEG but with some conditions for specific groups of people to focus. However, in the case of T_c is lower than ambient temperature, T_h side is scarcely more than ambient temperature or human body‟s temperature (37°C) relating to daily usual human activities referred from the survey.

As the survey explored problems of power supply for PCEDs, 8 problems were categorized and verified in levels of impact to the sample users as follows.

Inflexibility for power management

(1) Inconvenience to pick up various chargers while travelling: This requirement implied to improve a universal battery with capability to charge more than one PCED‟s battery.

(2) Preparation of adapters to charge PCED when going abroad: There was a problem to consider about preparing adapter to transform voltage and compatible plug-socket pattern.

(3) Incapability to anticipate remaining time for battery: Due to the uncertain load and power utilization pattern for users, they needed an indicator or a display to monitor the power level in order to save power effectively.

Inconvenience to access a power source

(4) Adversity to find an electrical plug to recharge: When going outside to some places, users might not be convenient to find a wall socket and to stay there for a while until the battery was fully charged.

(5) Inconvenience to find electrical wire plug to recharge: In some situations, a wall socket was located in an inconvenient position within personal reaches e.g. in the meeting room, class room, etc.

(6) A Worry for power saving for PCED in case of travelling: During a trip with limited power supply or inconvenient situation to find power source, there would be a need to save power to prolong the use of PCED until the battery power was empty.

Deterioration of equipments

(7) Problems with AC charging adapters (break down): Adapters might be deteriorated and resulted in inability of charging electricity into a battery and it would not be fully charged in normal time.

(8) Deteriorated or breaking-down batteries: For deteriorated batteries, their spare parts sold individually were mostly expensive to replace the old one, and it was worthier buying a new set of PCED instead. Therefore, if the batteries lasted longer, it helped users save a cost in equipment replacement effectively.

The results were measured in ascending order by Likert scale from level 1 (the least) to level 5 (the most). The results of average level of each problem for the sample users were described and sorted in descending order from the most important as shown in Table 4.16. To conclude, inconvenience to find a power source to recharge PCEDs, inflexibility to prepare various chargers while travelling, to manage power for gadgets, deterioration of a battery, and inconvenience to wire a plug „often‟ impact on users statistically in descending order and needed to be served to satisfy those PCEDs‟ users by a novel universal power supply. Those 5 items with impact level of "often impact" would be taken for consideration for product conceptual design next.

Table 4.16 Quantitative data for problems of power supply for PCEDs

Rank	Problems of power supply for PCEDs	Average level of its impact (Likert scale)	Classification for impact level
1	Adversity to find an electrical plug to recharge	3.81	"Often impact" (3.41-4.20)
2	Inconvenience to pick up various chargers while travelling	3.71	"Often impact" (3.41-4.20)
3	A Worry for power saving for PCED in case of travelling	3.69	"Often impact" (3.41-4.20)
4	Deteriorated or breaking-down batteries	3.62	"Often impact" (3.41-4.20)
5	Inconvenience to find electrical wire plug to recharge	3.57	"Often impact" (3.41-4.20)
6	Incapability to anticipate remaining time for battery	3.38	"Sometimes impact" (2.61-3.40)
7	Problems with chargers (break down)	3.31	"Sometimes impact" (2.61-3.40)
8	Preparation of adapters to charge PCED when going abroad	3.15	"Sometimes impact" (2.61-3.40)

In this section, the target gadgets and condition of thermal harvesting were primarily determined. Twelve PCEDs and 11 heat or cool sources as described before were included after the filtration process to scope the target point for product development phase. Variable correlation study and crosstab results were needed to verify some specific conditions or niches that were more potential to commercialize than general condition.

4.2.1.3 Purchasing decision and key decision factor

In this section, responses to buy innovative power supply product were determined in the questionnaire. The amount of potential buyers was revealed in Table 4.17 and implied the demand to purchase in the context of metropolitan area in Thailand for 86.3% but with conditions for decision making consideration.

The purchasing decision factors were also estimated by the subsequent part of the questionnaire to fulfil the condition for product development as shown in Table 4.18. Due to the limitation of the research time frame, the factors with "the most important" level from the result (the rank no. 1 to 10) were selected to be considered in the next step.

Table 4.17 Purchasing decision statistics for the samples

Purchasing Decision	Frequency	Percent	Cumulative Percent
Buy with conditions	379	86.3	86.3
Do not buy / not interested	60	13.7	100.0
Total	439	100.0	

Table 4.18 Purchasing decision criteria for the samples

Rank	Purchasing decision criteria	Importance level (Likert scale)	Interpretation of factor‟s importance
1	Safety to users and gadgets	3.87	"the most important" (3.26-4.00)
2	Sufficient power supply capacity	3.78	"the most important" (3.26-4.00)
3	Light weight	3.73	"the most important" (3.26-4.00)
4	Ease of use	3.73	"the most important" (3.26-4.00)
5	Reasonable price	3.63	"the most important" (3.26-4.00)
6	Durability	3.62	"the most important" (3.26-4.00)
7	Warranty and after-sales service	3.62	"the most important" (3.26-4.00)
8	Flexibility to use with various gadgets	3.56	"the most important" (3.26-4.00)
9	Reliability for brand and OEM	3.47	"the most important" (3.26-4.00)
10	Environmentally-friendly battery disposal	3.44	"the most important" (3.26-4.00)
11	Green and energy-saving product	3.21	"substantially important" (2.51-3.25)
12	Aesthetic/ attractive design	2.94	"substantially important" (2.51-3.25)
13	Creative features and new experience	2.79	"substantially important" (2.51-3.25)
14	Additional feature e.g. flashlight	2.35	"slightly important" (1.76-2.50)

There was, nevertheless, some consideration relating to current and inherent limitations to develop the product referred from other substituting products of secondary power supply and the performance of TEG technology. There were some obstacles from the result in Table 4.18 to develop the product complying users‟ criteria i.e. (1) sufficient power supply capacity, (2) reasonable price, and (3) environmentally-friendly battery disposal.

For the first two referred criteria, the limitation of TEG module as referred to technical feasibility study part has confirmed that the maximum efficiency to transform heat into electricity was not more than 5%. The cost of TE module production is high compared with other technology. To obtain sufficient power supply capacity for users‟ electronic gadgets other than raising temperature difference by more potential heat sources, more TE modules are necessary to be added into the product and raise its cost to uncompetitive status compared with other referred products. The solution, thus, was to emphasize the application of use to focus at situations without electricity sources or scarce to find power sources for their gadgets. The situations included as follows.

(1) Outdoor activities for a long trip (more than 2-3 day) without electrical power supply from on-grid network, generators, batteries, automobile‟s batteries
(2) Applications referred to the criteria of flexibility to use with various gadgets with an adversity of more than one type of battery to take with for outdoor activities in a long trip e.g. D-SLR camera, smart phone, compact camera, portable GPS, wireless communication equipments, and so on.
(3) Rural off-grid areas which have limitation for the electrical power generation and need more power transformation for electronic gadget
(4) Emergency case which cause primary electrical power source to be shut down, so that it will be useful for secondary power supply to maintain electricity for electronic communication gadgets e.g. flood, earth quake, tsunami, solar storm, and so on

In addition, for the third referred criteria, environmentally-friendly battery disposal was related to battery technology which is supplementary to this research. However, this scope was not the main objective of the research and due to the limitation of the research time line. This criteria, hence, was neglected for consideration and would be proposed for the future work.

4.2.2 Qualitative Approach

4.2.2.1 PCED's Power Supply Problem Analysis:

To explore the motivation and rationale of some interesting PCED"s power supply problems and further insights, in-depth qualitative interviews were conducted for various groups of PCED users. The problems of PCED"s power supply could be categorized by their rationales as follows:

Inflexibility for power management

1. Power management: Sometimes, PCED"s users could not estimate remaining duration for battery use due to various conditions of power consumption. For example, if a user need their smart phone to connect the internet via 3G connection protocol, to turn on music out of loudspeaker, to record voices, to play games, and so on, those activities will accelerate power consumption in different rates and the battery will run out of power quickly.

2. The need for reliable response for portable energy: Using many PCEDs while traveling, users would desire a secondary energy source with small size, light weight, reasonable price compared with other products, and acceptable charging time with sufficient power capacity. Thus, users implied the requirement about convenience for portable applications with effective power supply and reasonable price as well.

Inconvenience to access a power source

3. Adversity to find an electrical plug to recharge: Sometimes, dynamic situations brought out inconvenience to find an electrical wall socket to recharge batteries, or the power source junction did not correspond to PCEDs" adapters when going abroad.

Deterioration of equipments

4. Problems with AC charging adapters: In this case, some deteriorated electrical adapters might be incapable to recharge and cannot transfer power input for batteries. Besides, PCED‟s users might forget their charging adapters because there were more than one PCED.

5. Deteriorated or breaking-down batteries: Some batteries for laptop computers or mobile phones tended to deteriorate quickly and were not rechargeable owing to impropriate charging conditions, low-quality types of batteries, and expiring batteries due to exceeding the amount of charging cycles in their specifications. Merely replacing batteries was mostly unfavorable due to expensive individual batteries; moreover, the condition of in-use gadget was too good to be replaced with a new set of it.

Other comments

6. Safety for battery charging: Mostly, they preferred original equipment manufacturer (OEM)‟s chargers and batteries to ensure safety during charging.

4.2.2.2 PCEDs with Longer Power Supply Desire

In this section, some needs for specific desire of longer available power for using PCED were determined. These expressions implied the focus for new product development to respond them later on.

1. Smart phone users with frequent usage in various applications and activities needed to save power to use longer or some secondary power supply.

2. Secondary power supplies would be favourable for supplying duration not less than a few hours basically, being convenient to bring out, low weight, and abilities to indicate remaining power during usages, charging status and power level.

3. For TEG-based power supply, some additional recommended heat sources or sinks in daily lives for idea generation were listed as follows: (a) heat sources e.g. light bulbs, internet routers, microwave ovens, motorcycles, irons, hair dryers, TVs (especially plasma TV), mosquito repellents (lighting and smoke), items

for our body (especially on the seat when sitting or footwear), overhead/ LCD projectors, transformers, parked cars in the sunlight, heat from under the roof of house, heat from machines, hot water bag for ladies; (b) heat sinks e.g. fans, and cool water supply.

4.3 Product and Production Design

4.3.1 Quality function deployment (QFD) and Theory of inventive solving problem (TRIZ)

Quality function deployment (QFD) or "house of quality" (HOQ) technique at the first phase for product planning and TRIZ technique were applied to explore specifications of the product in order to ensure that the product would be launched to serve customer needs exactly at the first time. Voices of customers were transferred from preferable criteria of a good product in the questionnaire into technical requirements, and this information was used for parts and production planning further.

The first phase of QFD technique needs transferring ideas from customers or "voices of customers" into technical requirements that are brought to process for the design concept and respond customer desires. Voices of customers for the desire of TEG-based power bank, obtained from the business research results of the quantitative and qualitative questionnaire as described in the previous section, can be categorized into 3 groups as follows;

1.) Basic requirements for the product: i.e. safety to users and gadgets, and sufficient power supply capacity.
2.) Convenience for users and practical functions: i.e. light weight, convenient for portable applications, easy to use, durable for usages, and reliable for various situations of usages.
3.) Design and attractions: i.e. environmentally friendly, enable to indicate charging status and energy level, and reasonable price.

All 11 voices of customers were needed to be deployed into technical requirements. Each item of voice can be analyzed to related technical function, which can comprised more than one technical function. In contrast, some technical function from different voices of customers may be the same function as well. An analysis diagram was shown in Figure 4.6 and 12 technical functions were concluded for QFD process

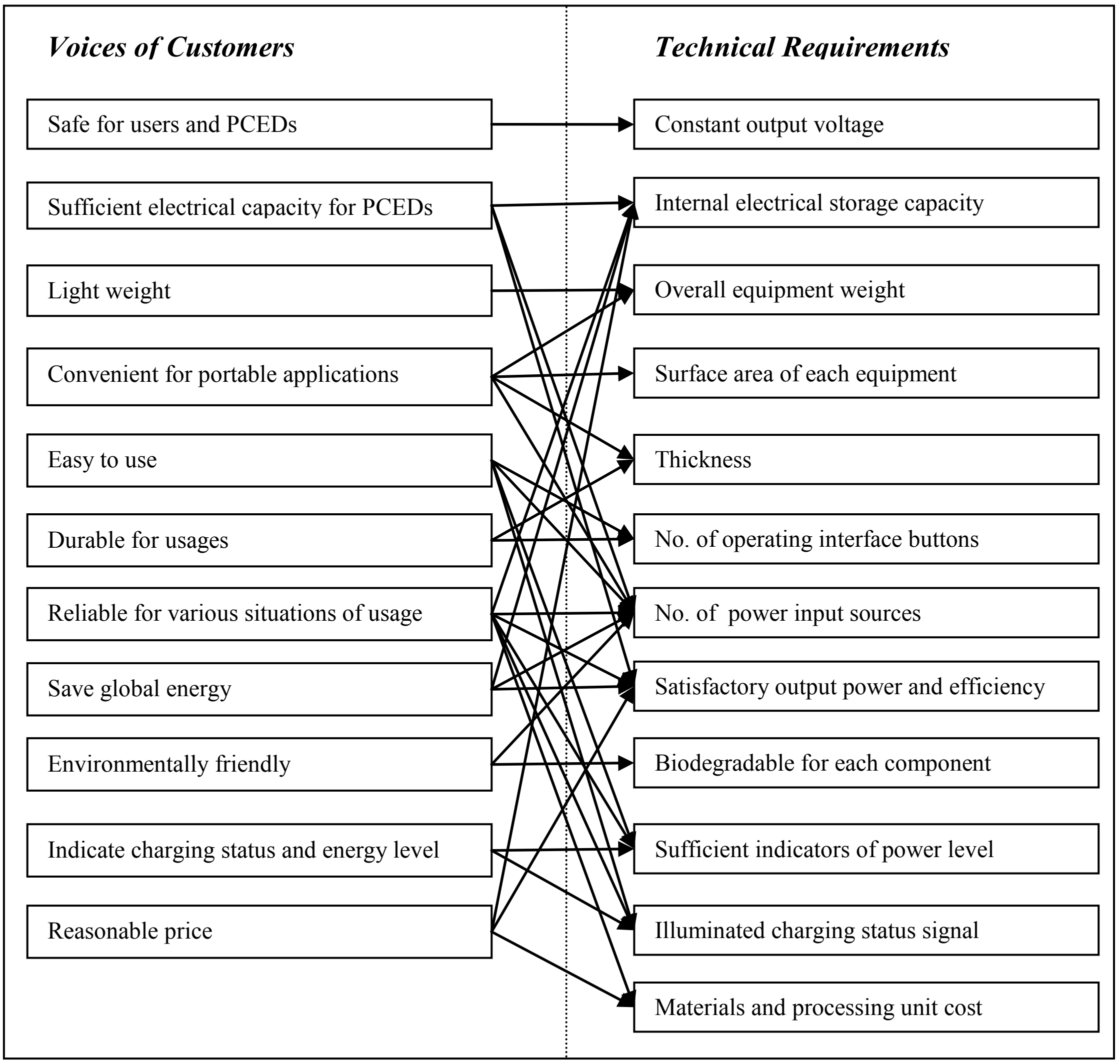


Figure 4.6 Deploying process from voices of customers to technical requirements with strong and moderate relationship

From the relation matrix in Figure 4.7, the scores of importance for technical requirement in the design resulted from a summation of each multiplication of an importance weight and relationship level for a customer requirement. The total scores of technical requirement significance were ranked to be considered for a product design as revealed for the first-half rank next. Six technical requirements with ascending-order rank of importance derived from QFD process were listed as follows.

1. The number of power input sources
2. Satisfactory power output and efficiency
3. Internal electrical storage capacity
4. Illuminated charging status signal
5. Sufficient indicator of power level
6. Equipment weight

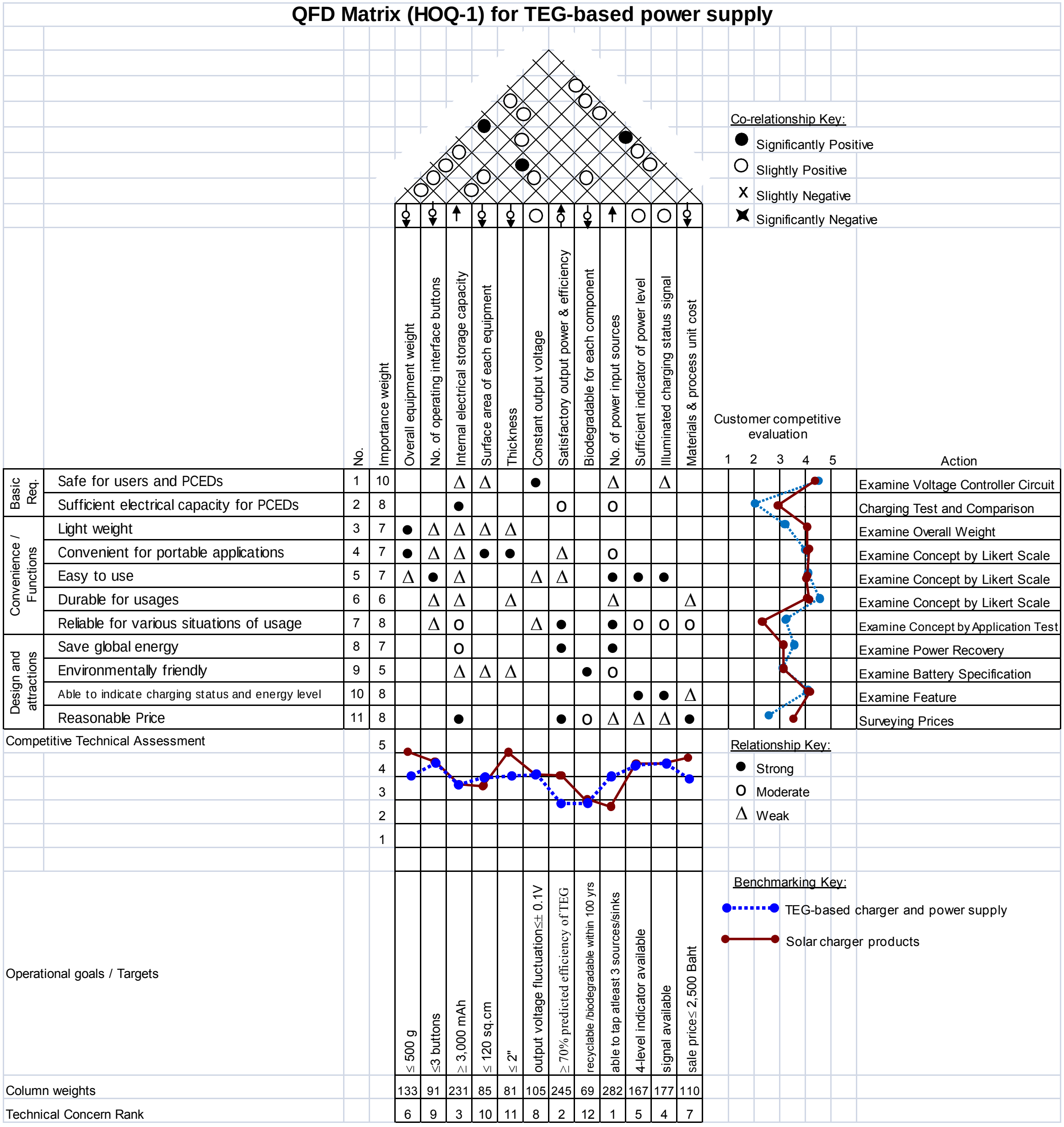


Figure 4.7 Quality function deployment (QFD) HOQ-1 matrix for the product design

The outcome of QFD process was taken in consideration to the next process of product design and design for manufacturing and assembly. The recommendation from QFD was stated as shown in Table 4.19.

Table 4.19 Product design criteria and consideration derived from QFD process

Rank No.	Technical Requirements	Goal /Target	Consideration
1	The number of power input sources	At least 3 input sources	Needed to be available for both deliberate heat sources and waste heat sources/ sinks: heat from stove / cooking devices, sunlight, and food containers
2	Satisfactory power output and efficiency	5Volt / ≥70% predicted efficiency by TEG	Users need a constant voltage supply of 5V for generic USB and need the highest efficiency, which is limited for adherent characteristic of TEG and is reduced by all passive losses and heat transfer capability.
3	Internal electrical storage capacity	3,000 mAh	Typically, power banks in the market was designed to recharge smart phones at least twice in time, and smart phone battery‟s capacity is about 1,500 mAh.
4	Illuminated charging status signal	Light signal available	Users need to ensure the charging process initiation despite a low temperature difference.
5	Sufficient indicator of power level	4 level	Users need to manage their personal power by power indicator with adequate scale resolution compared with general power indicators of their PCED.
6	Equipment weight	≤ 500g	Needed for a design with lightest weight but limited by necessary components for TEG technology, so benchmarked with the lightest product in TEG technology.

Before all technical requirements were brought to develop a new product, problems of contradiction for those criteria were considered for solutions by applying TRIZ principle. As the QFD matrix revealed relationships for technical requirement items, there were 4 factors with significant relationship for one another i.e. equipment weight, surface area, satisfactory output power & efficiency, and materials & process unit cost. A physical contradiction occurred with the qualification of surface area which related to the number of TE module in a product. In other words, a qualification of surface area was simultaneously desired both to increase to help rising power output and efficiency and to decrease a size for convenient portable manner and for cost saving. Principle of separation with 4 classifications was used to propose the solution for the physical contradiction as shown in Table 4.20.

4.3.2 Design for Manufacture and Assembly (DFMA)

Gap Finding from Substituted Products

From the results of technical requirements, the conceptual design was proposed for the product design. Initially, other commercialized substituting products were brought to compare for their strengths and weakness. Photovoltaic solar chargers, electric external batteries, which have been already introduced to PCED"s market, were the 2 primary substituting products for TEG-based power supply. This analysis to find the gaps of improvements was very useful for a new product development of TEG-based power supply to be successfully commercialized in the market. The comparison for those products was shown in Table 4.21.

Regarding the results from the business research, there were some practical applications for TEG utilization. In order to diversity the market need from that of the other alternative products i.e. PV solar chargers, electric external batteries, manual chargers, and fuel cell chargers, their weakness should be considered for improving TEG product. The research has pointed out some applications which are suitable to supply power with TEG module. Input temperature difference was, thus, classified into 2 groups i.e. (1) waste heat/ coldness recovery; and (2) deliberate heat / coldness generation as shown in Table 4.22.

Table 4.20 An application of the principle of separation from theory of inventive problem solving (TRIZ) to solve physical contradiction problems

Classification of Separation Principle	Considerations	Application for the research
Area Separation	A qualification of TE module surface area should increase in some places, but reduce in others.	TE module surface area should be adjusted, and users could decide the surface area they need to use in the different place.
Time Separation	A qualification of TE module surface area should increase in some time, but reduce in others.	TE module surface area should be adjusted, and users could decide the surface area they need to use in the different time.
“Parts and the Whole” Separation	A qualification of TE module surface area should be in a value for the whole system, but in the other or the opposite when considered as parts.	TE modules should be separated to support the need of light weight, but if more power is needed, overall module or more modules should be included.
Conditional Separation	A qualification of TE module surface area should increase in some conditions, but reduce in others.	TE module surface area should be adjusted, and users could decide the surface area they need to use in the different circumstance.

Table 4.21 Comparison of power supply products for their advantages and disadvantages

Product	Advantages	Disadvantages
PV Solar Chargers	1. No operational cost to obtain the solar energy 2. No noise and pollutions 3. Higher power conversion efficiency more than 5-10 times compared with TEG	1. Much battery capacity to store electricity 2. Sunlight is available in daytime and not raining time. 3. Non-steady sunlight intensity 4. High cost of investment
Electric external batteries	1. Convenient and reliable power supply for "plug-and-charge" characteristic 2. Compact design and easy for portable application	1. Non-renewable energy 2. Electrical energy is needed for power consumption. (cost aspect) 3. Impractical in case of a lack of electricity
Manual chargers	1. No operational cost to obtain human energy by hand 2. Less conditional with human power 3. No pollutions	1. Limited with weariness of users 2. Low power generation 3. Just suitable for emergency case with occasional power supply
Fuel Cell Chargers	1. Convenient and reliable power supply 2. Silent, no pollution	1. Expensive operational cost due to refilled methanol as energy carrier 2. Dependent on availability of methanol supply
TEG-based Power Supply	1. Silent, no pollution 2. No moving part, thus little wear and low maintenance cost 3. More various input power sources	1. High cost of investment 2. Low thermal –to-electric efficiency (not more than 5%) 3. A little bit bigger size compared with PV module due to the addition of Heat receiver and heat sink

Table 4.22 Potential input temperature difference and target power-consuming PCEDs for the product design concept

Target PCEDs	Input Temperature Difference Approach	
	Waste heat / coldness recovery	Deliberate heat / coldness generation
1. Laptop computer 2. Mobile phones 3. Smart phones 4. Digital compact camera 5. D-SLR cameras 6. Tablet PC 7. PDA / pocket PC 8. Camcorder 9. Portable GPS 10. Bluetooth headset 11. Portable electronic game 12. Voice recorder	1. Mobile phone / Smart phone (hot) 2. Laptop computer (hot) 3. Direct sunlight (hot) 4. Cold beverage containers (cold) 5. Hot beverage containers (hot) 6. Food container / Package (hot/ cold) 7. Cooking device: Stove / Oven / Pan / Pot when cooking (hot) 8. Instant food box (hot) 9. Cold dessert / ice cream bowl (cold) 10. Hot pot / suki yaki / shabu (hot) 11. Soil / water resource (cold)	1. Hot pack cloth (hot) 2. LPG burner (supplied from LPG cylinder, LPG can) (hot) 3. Candles / joss stick (hot) 4. Source of flame (hot) 5. Lighter (hot) 6. Fresheners (cold)

Conceptual Product Design

As the information from the business research and technical requirement analysis revealed, the product concept can be summarized as follows.

1) Due to the efficiency limit of TEG, it, sometimes, cannot be solely charged by TEG but to serve the need for inconvenience in power supply by principally charged from electrical wall socket also.
2) The product will be used as "personal power bank" to serve individual PCEDs as for usual situations and emergency case.
3) The product will urge consumers to be aware of ecology consideration by tagging equipments for harvesting waste heat anytime, anywhere they could.
4) The product emphasize on energy harvesting from direct sunlight and to adapt it as saucers to tag heat or coldness from beverage containers. In this case, there must be an option that the user would like to keep the container warm or cool, or it is not necessary at that time. Therefore, the product will have to provide an option to bring out output power for electricity generation or not.
5) Deliberate heat or coldness sources are considered the strengths of TEG-based product whenever there are serious needs for electric power supply for PCEDs without sufficient traditional electrical power sources.
6) Due to the disadvantages of lower efficiency and higher cost, the product should be added for its value in flexibility to enhance the consumer experience to use and make it interesting story-telling.

Target Condition of Uses

In addition to the 4 main situations of usage described in Section 4.2.1.3, some more urban situations of usages for practical TEG products were assessed, and those are opportunities to serve missing customer needs as follows:

1) Travelling or trekking in some situations, it is quite inconvenient to find an electrical source to charge a battery e.g. on bus, train, plain, cars as a passengers (not an owner). Especially for the trip that takes a long time to go, It may be not practical every time, but anytime that there are chances to harvest waste heat or coldness to drive a temperature difference. And the generated electricity will be contained in the battery.
2) Somewhere that consumer can barely fine an electrical wall socket, or off-grid rural areas in which people need spare power supply for personal gadgets ,or inconvenient places for people to wire a plug in some situations e.g. in a meeting, in a library, in a public place. Spare power bank with accumulative electrical pre-charge could be on standby and ready for use anywhere and anytime.
3) Accumulate the electrical charge but not aim to be fully charged. Main charges are from household to fully charge but TEG need to fulfil the charge as possible that there are available temperature difference sources
4) In some situations with adversity for energy supply e.g. when users go camping, field trip, or in emergency situations, users need to generate electricity for their PCEDs and deliberate heat sources or coldness such as hot pack cloth, candles, lighters, fresheners will be brought for supplying temperature difference to generate electricity.
5) If there is a potential heat / coldness sources that they are always intended to use for a daily life e.g. candles, and stove, waste heat recovery may be treated as a potential by-product to improve person energy utilization pattern.

A product design was then proposed for commercialization, and the design was analyzed for investment feasibility in the next step. The TEG-based commercialized power supply was revealed next.

Product Components and Functional Details

This product was intended to be able to harvest heat from both daily waste heat and deliberate heat sources. It comprises 8 components to respond the product concept and functions as follows.

1) TEG component
    - 3 pieces of single-stage TE modules with series interconnection
    - TE materials of n-type and p-type bulk Bi_2Te_3 (Bismuth Telluride) with TE elements in a module of 127 couples approximately
    - dimension in width × length × height of 40.0 mm × 40.0 mm × 4.0 mm
    - Top and bottom - covered with aluminium plate 0.3-mm thickness with guidance for connecting with other accessories
    - Enhancing heat transfer capability with silicone heat transfer compound
2) Solar thermal power trap / "Green house" module
    - Additional function to obtain solar thermal energy for TEG
    - Enhancing heat absorption with heat absorber-coated aluminum sheet of 0.3 mm (more than 90% heat absorption)
    - Trapping the sunlight by transparent Acrylic (PMMA) plastic frame 5.0-mm thickness
    - Sealing the "green house" with butyl O-Ring

3) Waste-heat trap module
    - Additional function to obtain thermal conduction for TEG
    - Clipping application and a silicone strap with aluminium joints using with some hot container e.g. hot pots, portable boilers for camping to fasten the module with a container
    - A handle made of polycarbonate plastic for good thermal insulation and preventing users from touching hot parts
    - Easily connect to TE module
4) Heat sinks and stand module
    - The body is made of aluminum with 8.0 cm × 12.0× 8.0 cm.
    - Used for enhancing heat dissipation by filling water or transferring heat through water via its fin.
    - Water container available for enhancing heat dissipation capability by filled water
5) Charge Controller Circuit
    - DC-to-DC step-up (boost) converter
    - Low Voltage Disconnect (LVD)
    - Maximum Power Point Tracking (MPPT)
    - Battery Temperature Compensate (BTC)
    - Overcharge protection
    - LED status demonstration interface
6) Battery Module
    - Li-ion type 3.7V×1 at least 3000 mAh
7) Adapters
    - USB wiring reel
    - Various USB charger adapters
8) Packaging
    - Screened paper based with transparent polyethylene plastic

The manufacturing process for those of all parts were considered and concluded in Table 4.23.

Table 4.23 Potential manufacturing process for the parts of a TEG-based thermal-to-electric power supply product

No.	Components	Parts	Quantity	Materials	Sources	Assigned Manu Process
1	TEG	TE modules	3 Pcs.	n-type and p-type bulk Bi_2Te_3 (Bismuth Telluride)	Supplier / OEM	N/A
		Top & Bottom - covering Plate	1 Set	Aluminum sheet	Supplier	Sheet-metal cutting/ Punch and die
2	Solar thermal power input	Heat absorber plate	1 Pc.	Heat absorber-coated Aluminum sheet	Supplier	Sheet-metal cutting/ Punch and die
		Heat collector body	1 Pc.	Aluminum (Casting grade)	Outsourcing	Aluminum casting
		Sunlight trapping lid	1 Pc.	Acrylic (PMMA)	Outsourcing	Injection molding
		Insulation	1 Set	Insulating Material	Supplier	N/A
		Sealant ring	1 Pc.	Butyl Rubber	Supplier	N/A
3	Waste-heat trap module	Body	1 Pc.	Polycarbonate Plastic	Outsourcing	Injection molding
		Belt	1 Pc.	Silicone Strap with Stainless Steel Buckle	Outsourcing	N/A
		Fastener set	1 Set	Stainless Steel	Supplier	N/A
4	Heat sink module	Body	1 Pc.	Aluminum (Casting grade)	Outsourcing	Aluminum casting
		Lid and wire fin	1 Pc.	Aluminum (Casting grade)	Outsourcing	Aluminum casting

Table 4.23 (continued) Potential manufacturing process for the parts of a TEG-based thermal-to-electric power supply product

No.	Components	Parts	Quantity	Materials	Sources	Assigned Manu Process
5	Charge controller circuit	Ultra-low-voltage boost controller	1 Pc.	Electronic elements	Outsourcing	N/A
		Output regulating circuit	1 Pc.	Electronic elements	Outsourcing	N/A
		LED indicator circuit	1 Pc	Electronic elements	Supplier	N/A
		USB socket	2 Pcs.	General specification	Supplier	N/A
		Micro USB socket	1 Pc.	General specification	Supplier	N/A
		DC input power socket	1 Pc	General specification	Supplier	N/A
		Case	1 Pc	Polypropylene	Outsourcing	Injection molding
6	Battery module	Li-ion Battery	1 Pc	Li-ion battery type 3.7V×1 at least 3,000 mAh	Supplier	N/A
7	Adapter Set	USB wiring reel	1 Pc	General specification with heavy-duty, flame-resistant cable	Outsourcing	N/A
		USB charger adapters	1 Set	General specification	Supplier	N/A
		AC adapter	1 Set	General specification	Supplier	N/A
8	Packaging	Package	1 Pc	Label screened paper, Plastic racks	Outsourcing	N/A

To support the charging concept of the product design, the battery management module was designed for the configuration as shown in Figure 4.8.

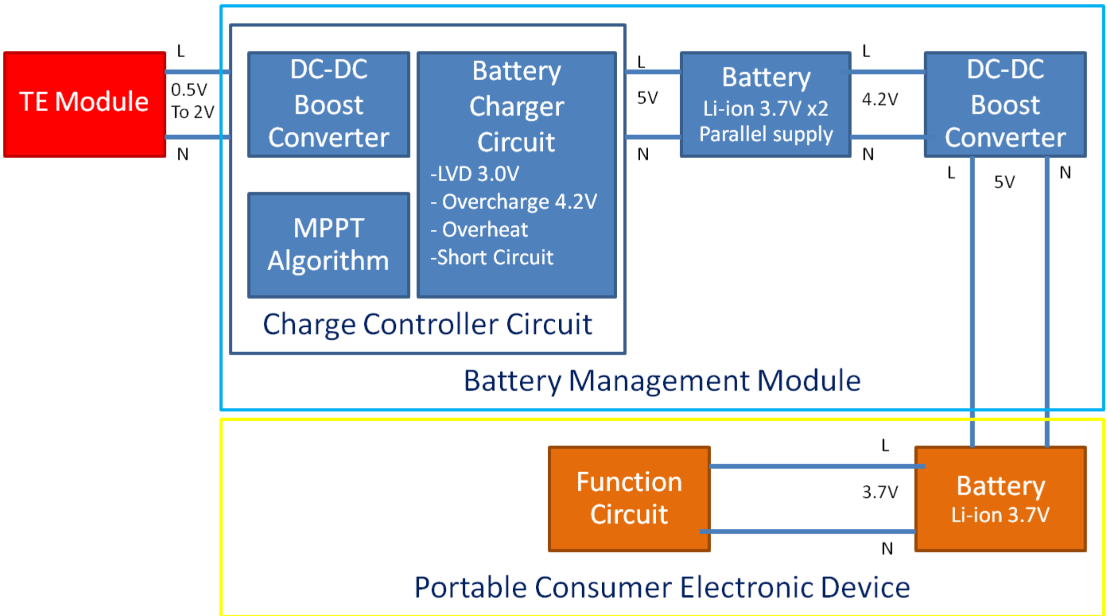


Figure 4.8 The configuration of battery management module to acquire power input from TE module and supply power output to PCEDs

The charge controller module was designed and invented using the concept of the boost converter circuit in Section 2.3: DC-to-DC Step-up (Boost) Converter Circuit. The chipset from Texus Instrument Inc. (TI) No. bq25504 for battery management functions and was adapted for the appropriate condition for TEG application with set-up constant voltage output of 4.2VDC. The condition diagram for electrical configuration was suggested by TI as shown in Figure 4.9, and the figure of printed circuit board (PCB) was illustrated in Figure 4.10. The PCB was tested for power input and output function by using simulated DC regulator to supply DC voltage in the range of 0.0-4.0 VDC to input section and measuring voltage outputs.

The result from the experiment was revealed the cold-start voltage of 332 mV with continuous harvesting from low input source at the minimum operating voltage input of 79 mV and the output was maintained at 4.11 V as shown in Figure 4.11. Equipments and PCB prototype testing in various conditions were illustrated in Figures 4.12-4.16.

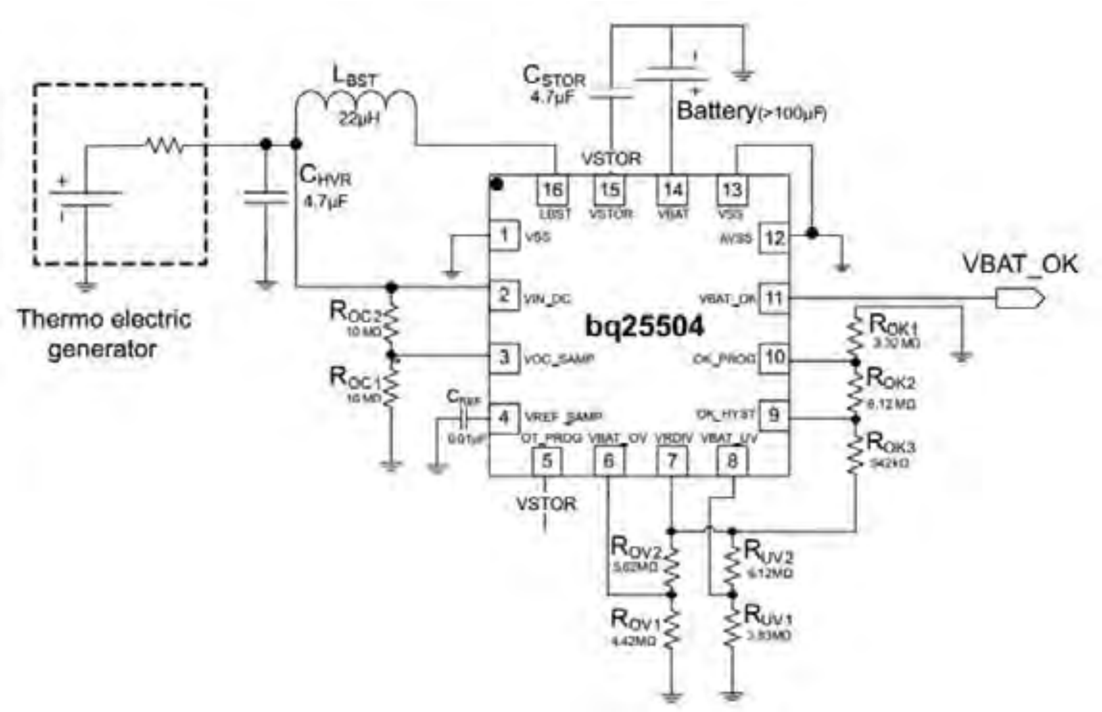


Figure 4.9 Condition diagram of electrical component of the chipset no. bq25504 for TEG application suggested by TI [46]

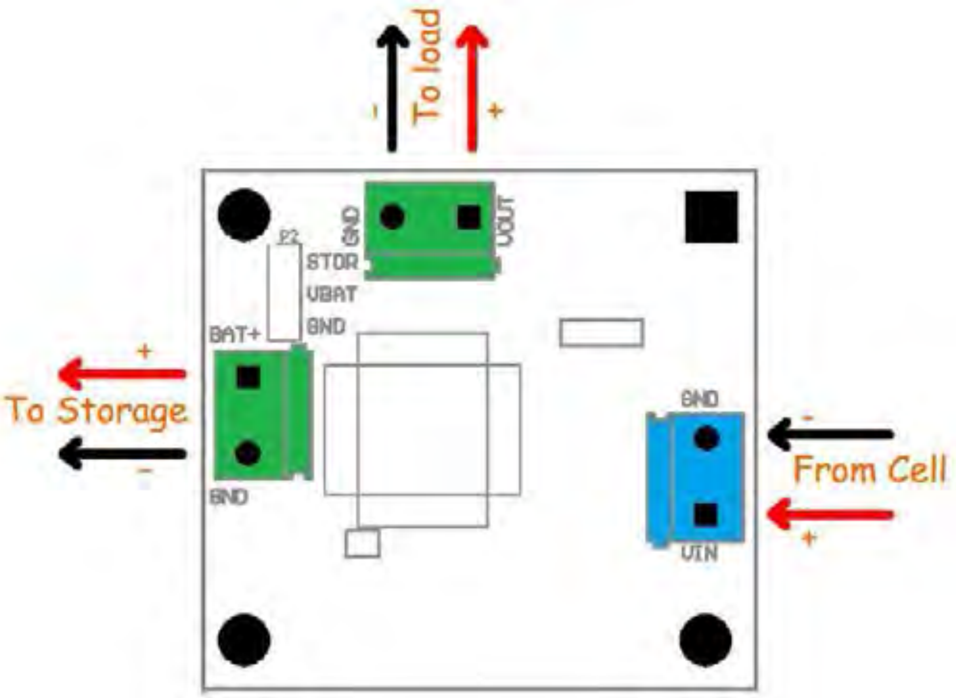


Figure 4.10 Illustration for printed circuit board applying the bq25504 chipset from TI

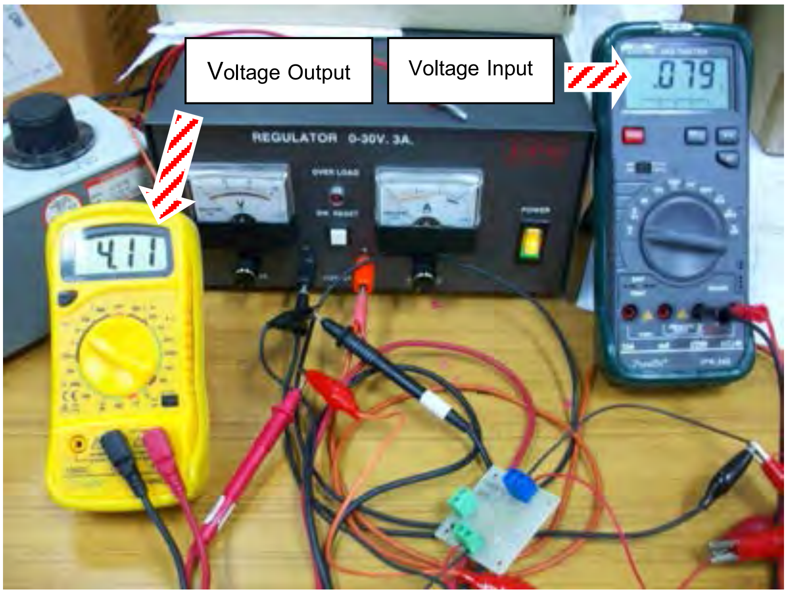


Figure 4.11 The PCB test for power supply function

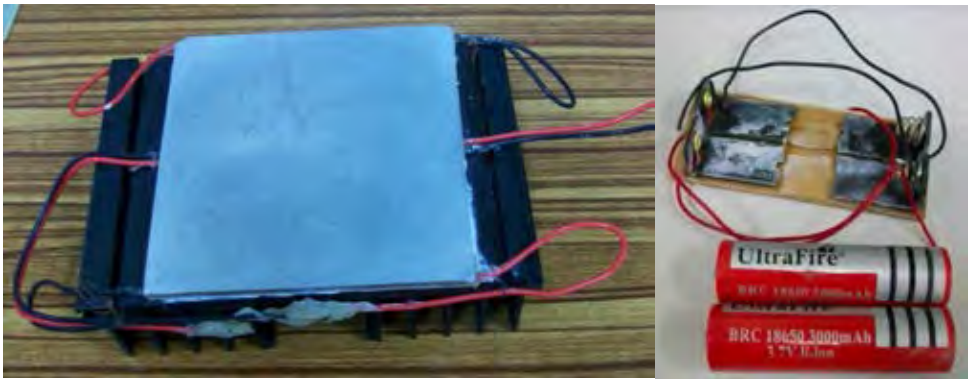


Figure 4.12 The TEG module set and Li-ion battery with 3,000 mAh capacity

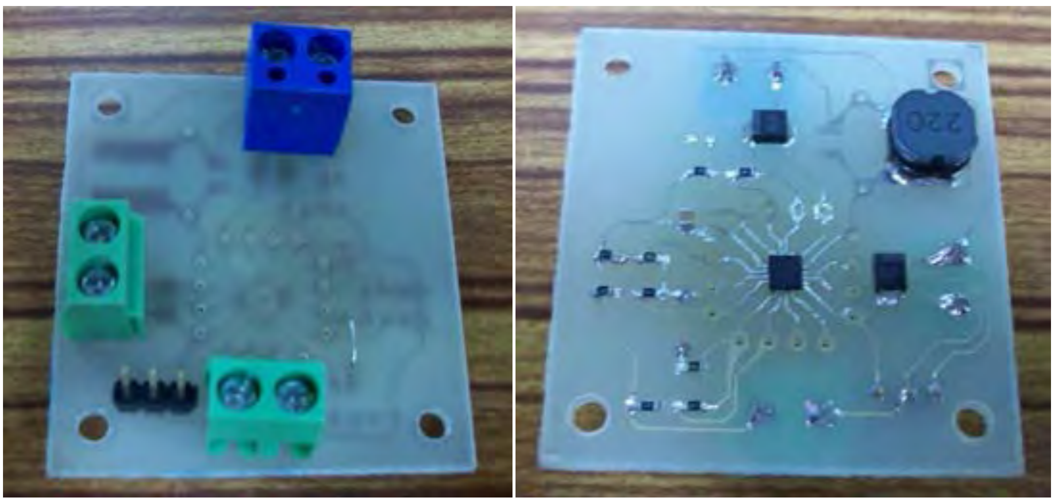


Figure 4.13 The PCB prototype for charge control and battery power management

Figure 4.14 Various equipments for heat power input using in the research: (left) a solar-thermal power trap or “green house” module prototype; (middle) a cooking device heated from LPG burner; and (right) candle flame

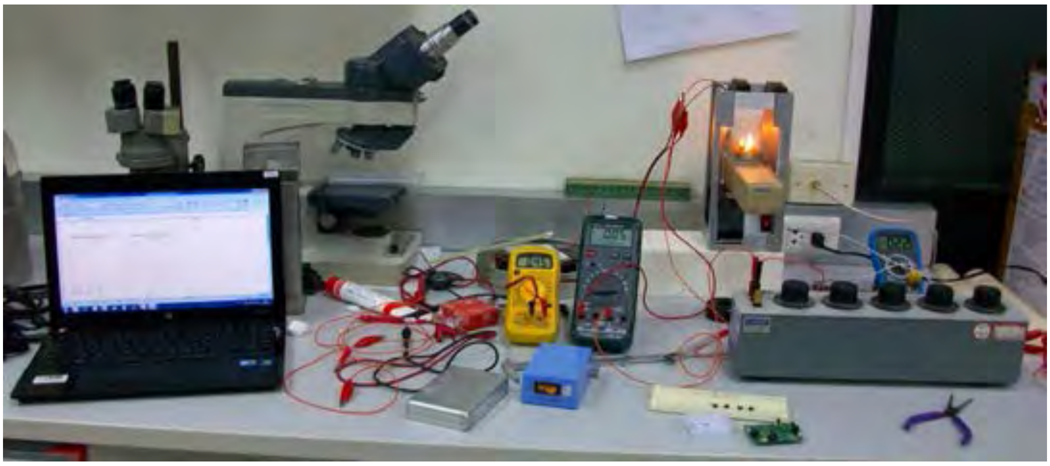


Figure 4.15 An example of prototype testing for the heat from candle flame

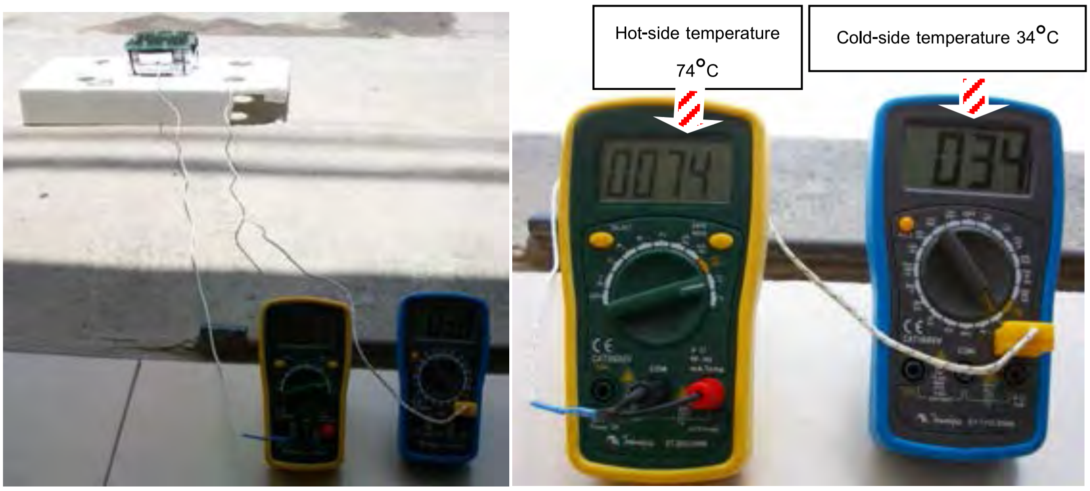


Figure 4.16 The PCB test for power supply function using heat from sunlight

The battery management module was composed of charge controller circuit, secondary batteries, and DC-to-DC final boost converter. The charge controller circuit, inside, was composed of DC-to-DC boost converter with maximum power point tracking (MPPT) algorithm, and battery charger circuit.

Commercial circuit module is available in electronic marketplace. MPPT algorithm remains necessary to ensure that the power input from TE module will be the maximum power [47]. Battery charger circuit, mostly integrated with boost converter circuit, was used to ensure the safety and appropriateness for charging.

The specification of the product was then concluded in Table 4.24. In addition, the product‟s parts, assembly, and application drawings were illustrated in Appendix D.

Table 4.24 The specification for innovative TEG power supply product

Qualification	Capacity & Extra Features
Brand / Concept	“IndyPoww” (independent power for active people)
Dimension	140.0 mm × 80.0 mm × 5.0 mm for foldable heat trap module and 75.0 mm × 60.0 mm × 40.0 mm for Charge Controller Box, Connected by USB wiring integrated in a reel
Weight	300 g for TEG module and heat sink module (excluding water) and 200 g for Charge Controller box
Maximum Output	5 Watts @ Hot-side temperature of 250 °C, Cold-side temperature of ambient temperature
Materials	Bi_2Te_3 for TE module (3-4 modules) and Aluminum case
Highest Operating Temperature	Not more than 280 °C
Type of Battery for Charging	Li-ion 3.7V, 3,000 mAh
Heat / Coldness Source	Direct Sunlight / Cooking Devices/ Fire or Flame / Hot or Cold Beverage Cup/ Food Containers / Water-cooled
Accessories	Heat-sink module/ “Green house” module/ Waste-heat Trap Module

4.4 Prototype Testing and Evaluation

The prototype of “IndyPoww” was tested, evaluated, and compared with other potential competitive product with TEG base as well for aspects of practical use in daily life based on the target customer requirements studied before.

4.4.1 Prototype Characteristics Evaluation

The simulation of uses for the product was conducted by charging the Li-ion battery (UltraFire® BRC 18650 3,000 mAh, 3.7V) with IndyPoww (TEG-based charger). The charging test diagram is illustrated in Figure 4.17.

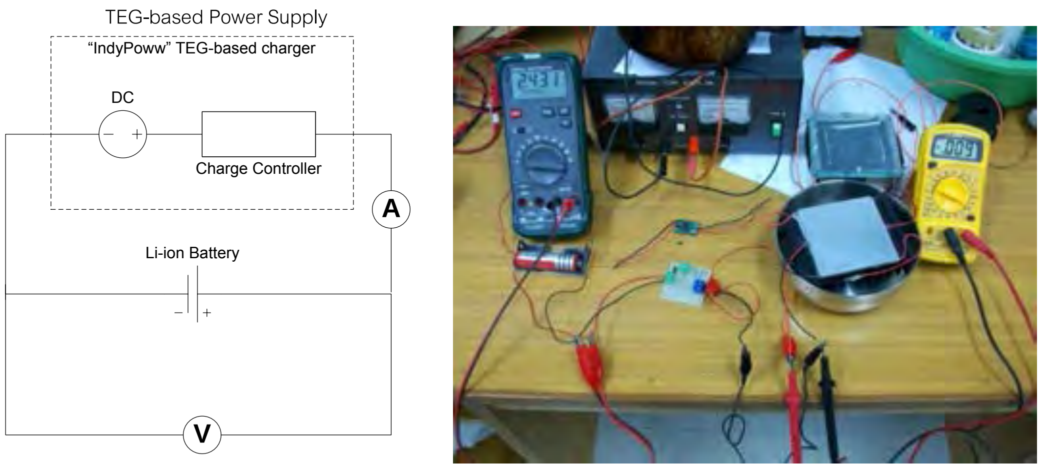


Figure 4.17 The charging test diagram of the functional prototype of “IndyPoww”

The test aimed to simulate 5 practical scenarios to applying ambient heat / coldness sources to charge the referred Li-ion battery for the target users i.e. (1) dissipating heat from hot pan burned with LPG stove, (2) heat from a flame of candle, (3) dissipating heat from hot bowl of soup, (4) dissipating coldness from a cold beverage container, and (5) radiated heat from sunlight. The Li-ion battery was discharged until the typical lower threshold voltage of 2.5V, and the test was to charge the battery by the referred approach until the typical full voltage of Li-ion at 4.2V or the ultimate voltage able to supply by the heat / coldness source. The time of charging was recorded as well as the voltage and current output through the battery. The characteristics of charging test were summarized in Table 4.25, and the data of electrical parameters and power were plotted in graph for each scenario as shown in Figures 4.18-4.22.

Table 4.25 The characteristics of functional charging test for "IndyPoww" prototype

No.	Sources of temperature gradient	Maximum Temperature Differential (°C)	Minimum Temperature Differential (°C)	Average Temperature Differential (°C)	Standard Deviation of Temperature Differential (°C)	Ambient Temperature (°C)
1	Hot Pan	175.0	147.0	164.2	5.7	32.0
2	A Flame of Candle	148.0	125.0	139.4	4.3	28.0
3	Hot Bowl of Soup	66.0	21.0	42.4	11.8	30.0
4	Cold Beverage Container	26.0	18.0	22.1	2.3	31.0
5	Heat from Sunlight	49.0	22.0	35.0	6.9	33.0

Table 4.25 (continued) The characteristics of functional charging test for "IndyPoww" prototype

No.	Sources of temperature gradient	Charging Status	Duration until charging finished/ terminated (hr:min)	Maximum Charging Current (mA)	Maximum Power (W)
1	Hot Pan	100.0%	2:28	1,730.0	4.82
2	A Flame of Candle	100.0%	3:18	1,012.0	2.56
3	Hot Bowl of Soup	7.6%	1:30	75.0	0.19
4	Cold Beverage Container	5.3%	1:15	13.2	0.03
5	Heat from Sunlight	23.5%	5:00	75.0	0.21

The heat sources from LPG stove, electric stove, a flame of candle and sunlight can continuously supply heat to the modules, whereas those from a hot bowl, and a cold beverage container are gradually decreasing due to less internal energy expressed in less temperature difference after the time passes. Therefore, the battery could not be fully-charged for the sources no. 3-5 in Table 4.25 due to limited heat power transfer and decreasing temperature differences. The results from Table 4.25 showed that IndyPoww was able to fully charge the 3,000 mAh Li-ion battery within one time by a stove and a candle which were mostly deliberate heat sources. Charging status could be determined by the voltage level during charging process calculated in percentage of the full charge (4.2V) in reference with the starting point of charge at 2.5V. As the charge density is directly proportional to the voltage of the battery, so this can be referred as the level of charge percentage as well. The characteristics revealed that entire heat energy from every source could be partly transferred to TE module surface. The more couples of TE materials with more TE module surface, the more capability to transfer heat energy into electricity.

The result from Table 4.25 also showed an interesting characteristic of charging temperature difference. Stated by Texus Instrument Incorporated for the chipset bq25504, as a charge controller module has a specification of typical cold-start voltage not lower than 330 mV and input voltage for continuous energy harvesting not lower than 80 mV to produce a 5-Volt constant output voltage [46], lowest maximum temperature differentials from various heat input sources were considered to exceed cold-start voltage limit in the test. It implied a practical charging situation reference for the product as well. As a result, a cold beverage container yielded the lowest maximum temperature differential of 26°C compared with the others‟, and can produce 5-Volt constant output voltage with the maximum power of 30 mW resulting in 5.3% of charging progress. This is a distinctive characteristic in the research compared with other commercial products for its capability to charge electricity from low-temperature heat sources with such the lowest temperature differential as 26°C.

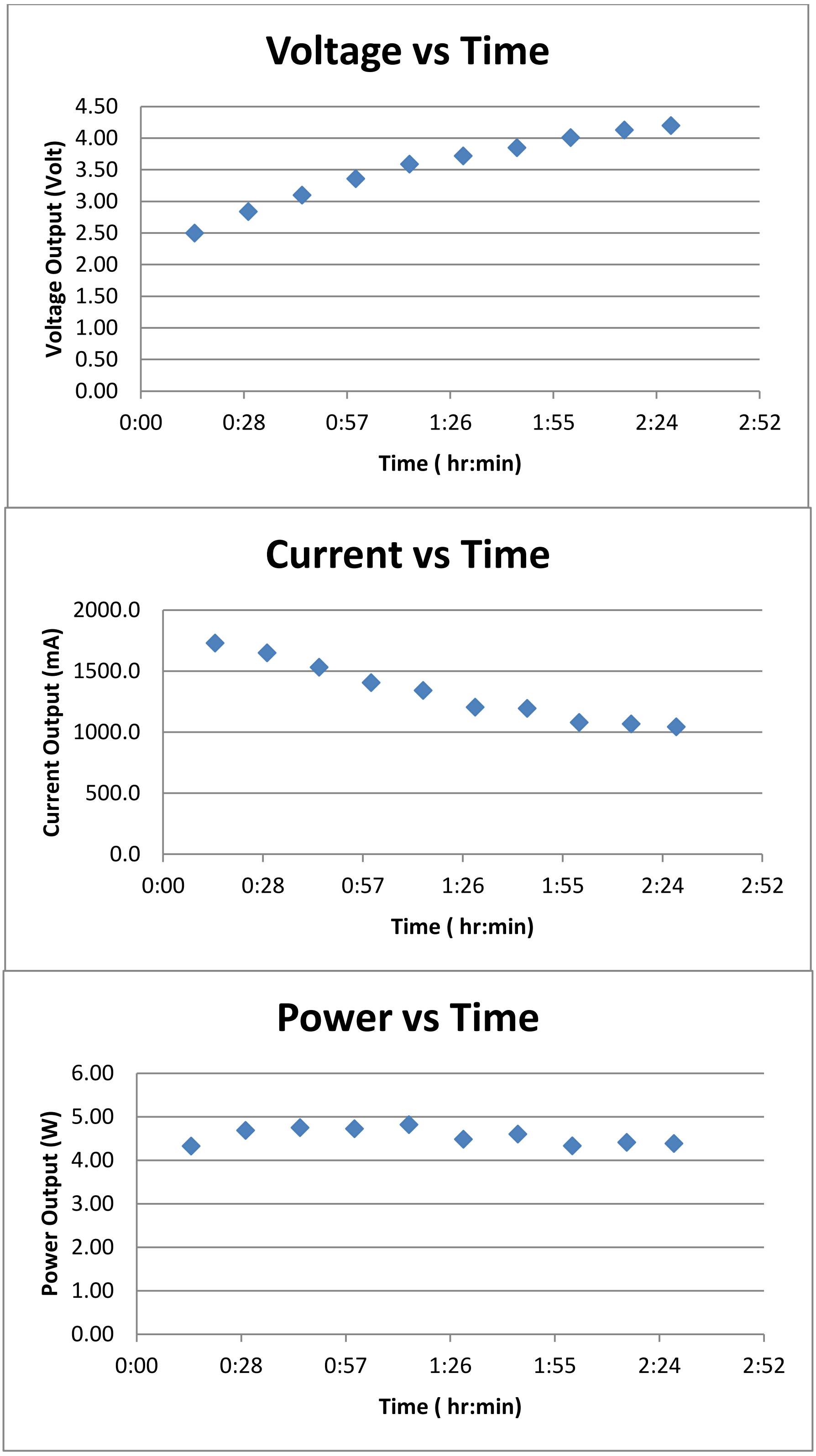


Figure 4.18 The charging characteristics from the power source of dissipating heat from hot pan burned with LPG stove

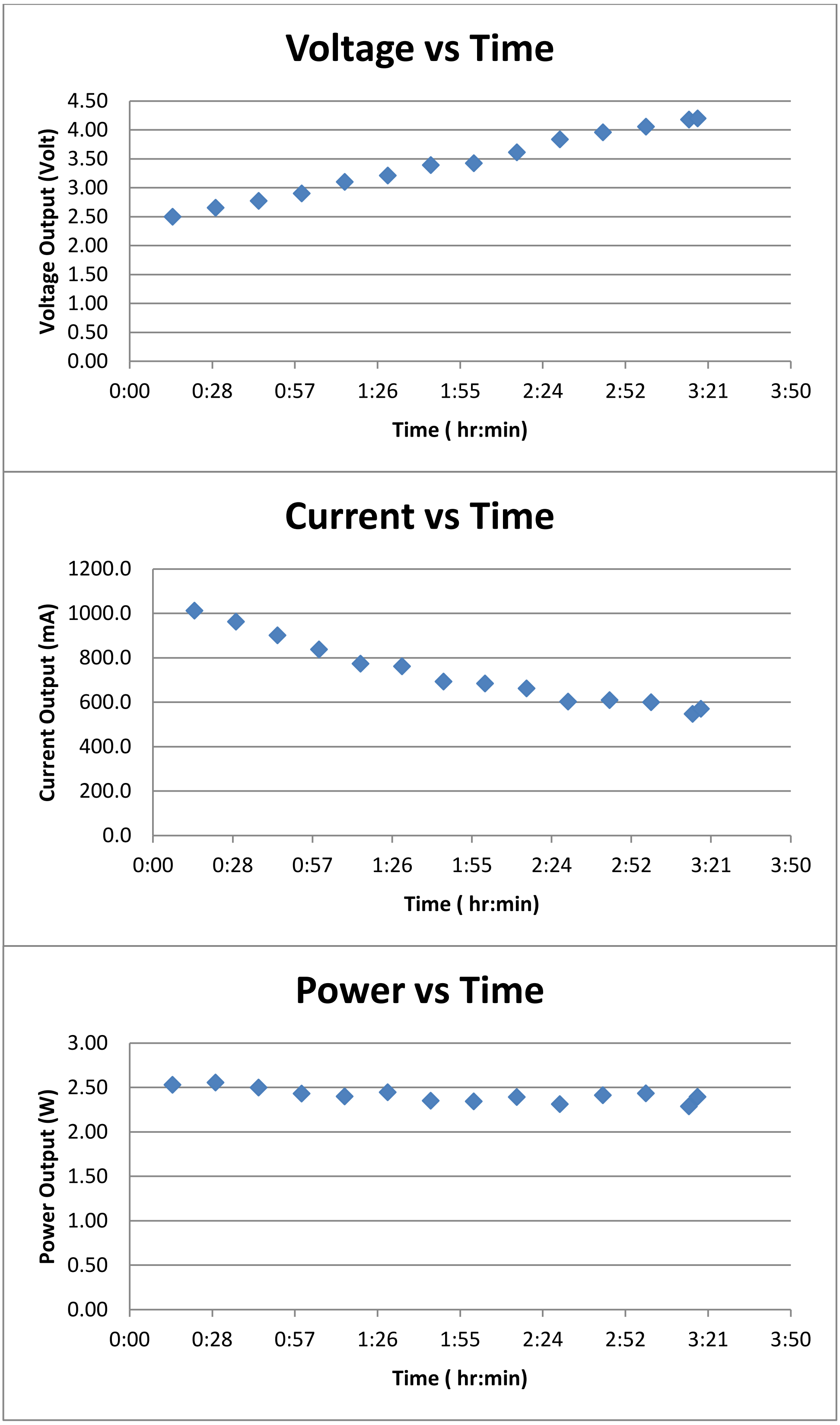


Figure 4.19 The charging characteristics from the power source of heat from a flame of candle

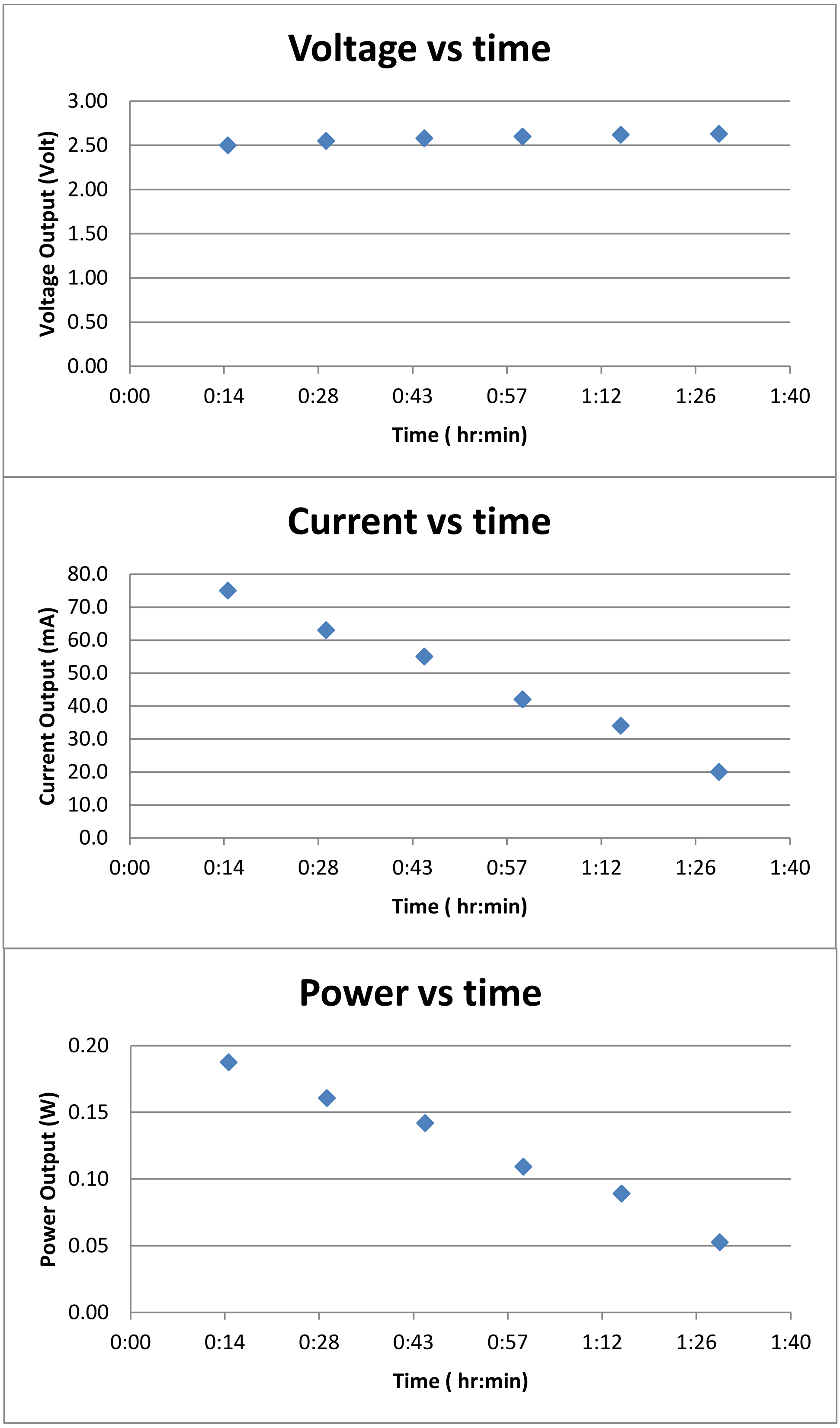


Figure 4.20 The charging characteristics from the power source of dissipating heat from hot bowl of soup

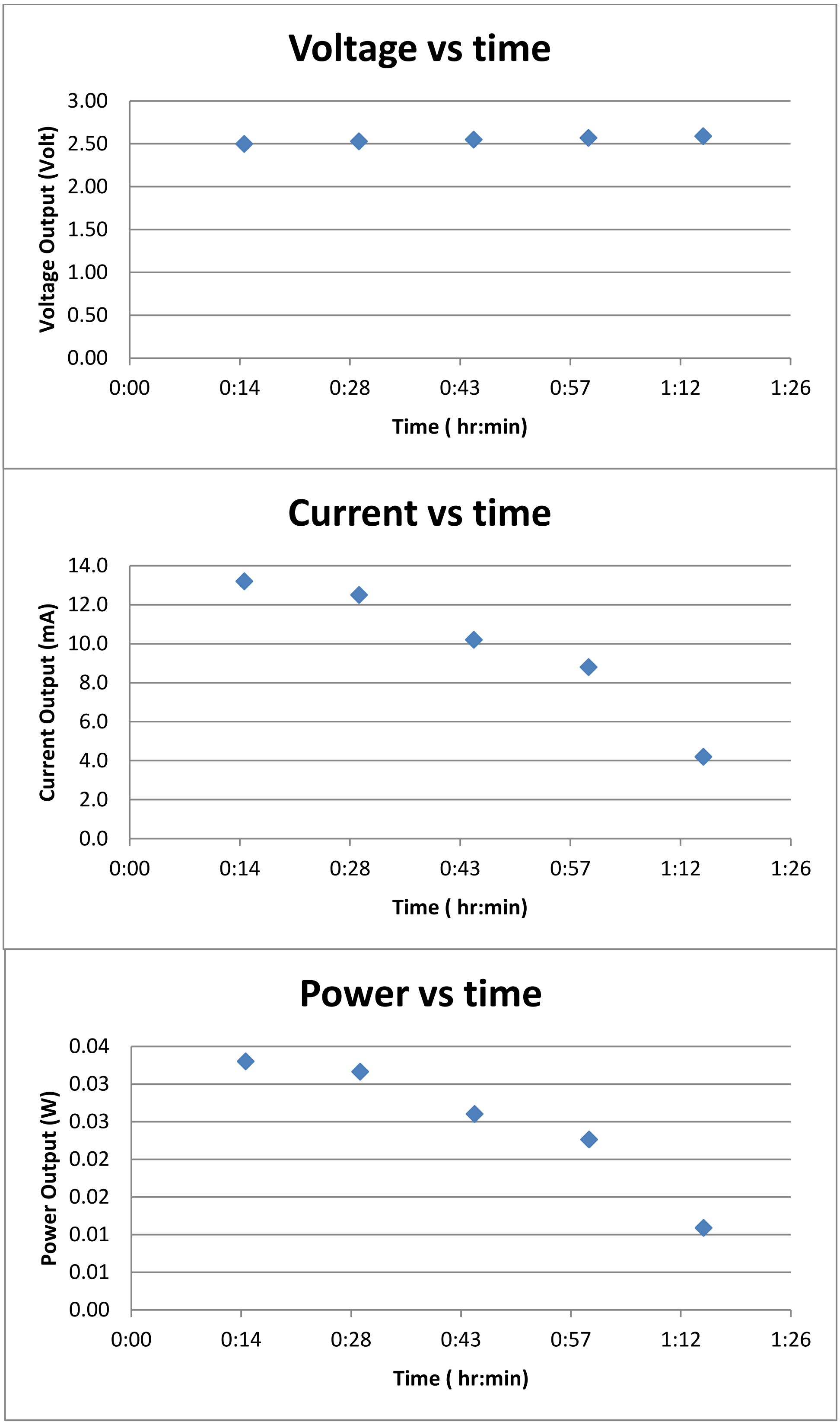


Figure 4.21 The charging characteristics from the power source of dissipating coldness from a cold beverage container

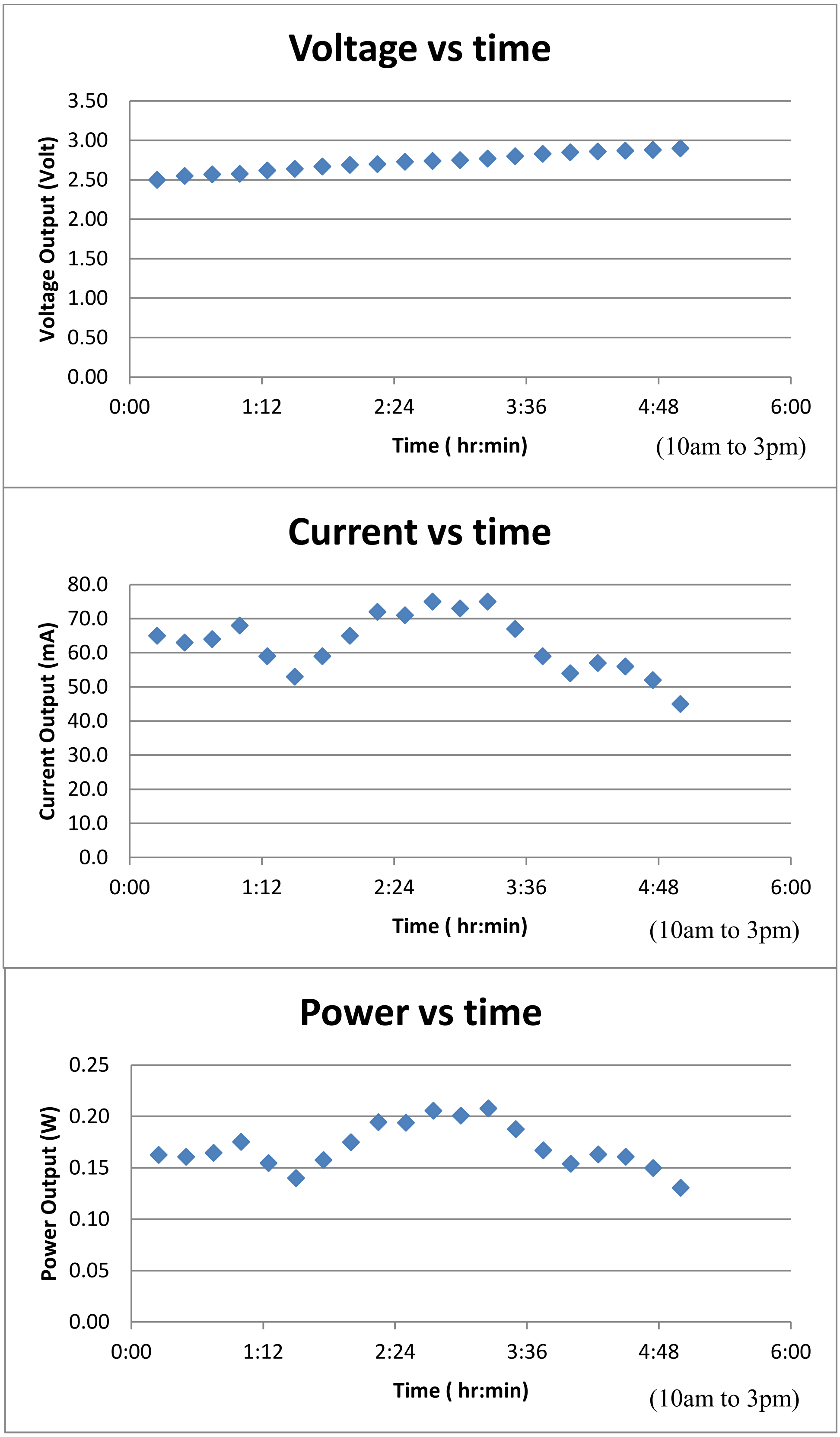


Figure 4.22 The charging characteristics from the power source of radiated heat from sunlight

The charging characteristics data from Table 4.25 could be a guideline for charging other gadgets with various size of battery. For example, typical smart phone batteries mostly have the capacity of 1,500 mAh, so the charging time can be approximately reduced into half of the time shown in the table.

Figure 4.18 revealed the power output of dissipating heat from a hot pan on fire of LPG stove. The data were deviated due to normal variation from such other factors as heat consistency around the module surface, and heat collection on the equipment.

Figure 4.19 revealed that the power output trend was gradually decreasing with the heat source of a flame of candle because of some factors i.e. the more clearance between the container and the flame when the candle was continuously lighted, and the decreased intensity of wax in the candle after the time passed.

Figure 4.20-4.21 expressed the characteristics of charging test using heat from hot bowl and cold container respectively. The lower heat transfer rate indicated the reducing collecting heat and lower temperature. Although the results of charging showed the power level saturation at 7.6% and 5.3% for hot bowl and cold container respectively in one-time charging, the power can be collected arbitrary for many times from other encountering heat /coldness sources. This got along with the product concept of waste heat recovery as well, and it reflected the potential of IndyPoww to charge a battery from low-quality heat by maintaining constant voltage of 5VDC despite of the very low and inconstant voltage yielded from TEG module (the specification of cold-start voltage ≥ 330 mV and the voltage of continuous energy harvesting of typically ≥ 80 mV).

Charging battery via the heat from sunlight was grasped by the analysis of Figure 4.22. Typically, this situation depends much on the sunlight condition. The experiment in this research took place in the day with clear sky in the summer time of Thailand during around 10 am to 3pm, and the results were assumed for a suggested trend when the clear sunshine was expected all time and the sunlight direction was always normal to the green-house module which is manual-inclined an hour a time. The trend revealed a few drops of power because of a cloudy condition in some times. Moreover, the late afternoon resulted in very inclined impacting angle of the sunlight, so it will not indeed perpendicular to the module surface and the heat transfer is reduced. Typically, the power intensity of sunlight in summer with clear sky in Bangkok, Thailand (assumed air mass = 1.0 for the condition of sea level with the sun directly overhead in equatorial or tropical region) reaches 0.9471 and 1.0418 kilowatts/squared meter for direct beam intensity and estimate of global irradiance respectively [48]. Mostly, the normal irradiance of 1,000 W/m^2 was the typical value applied for the standard test of photovoltaic devices [49]. The maximum power output from the experiment yielded 0.21 watt out of the four TE modules with 40.0 × 40.0 mm area surface. That can be converted into thermal-to-electric efficiency of 3.3% which is relevant to the module characteristic testing in technical feasibility as mentioned in the previous topic. To improve the capability of absorbing heat and converting it into electrical power, the green-house module should be vacuumed, improved for heat absorptive materials, and also well insulated.

4.4.2 Competitive Potential Product Testing and Evaluation

There are some commercialized products of TEG-based power supply in the world but with few representatives for that product in Thailand. Some of them were selected to study for their feature, characteristics, and compare with the prototype from the research to determine strength, weakness, opportunity for improvements, and the benchmarking for the feature and specification.

The two commercialized potential products were selected to study, i.e. (1) the PowerPot V from Power Practical Inc., and (2) tPOD5 from Tellulex Corporation as shown in Figure 4.23.

The experiment, illustrated in Figures 4.24 and 4.25, was set to determine the output voltage from TE module varying with supplying heat and temperature from 3,000-watt electric stove. The electric power transformed by TE module was regulated by a regulator to control the voltage output for a constant value at 5V supplying via a USB connector.

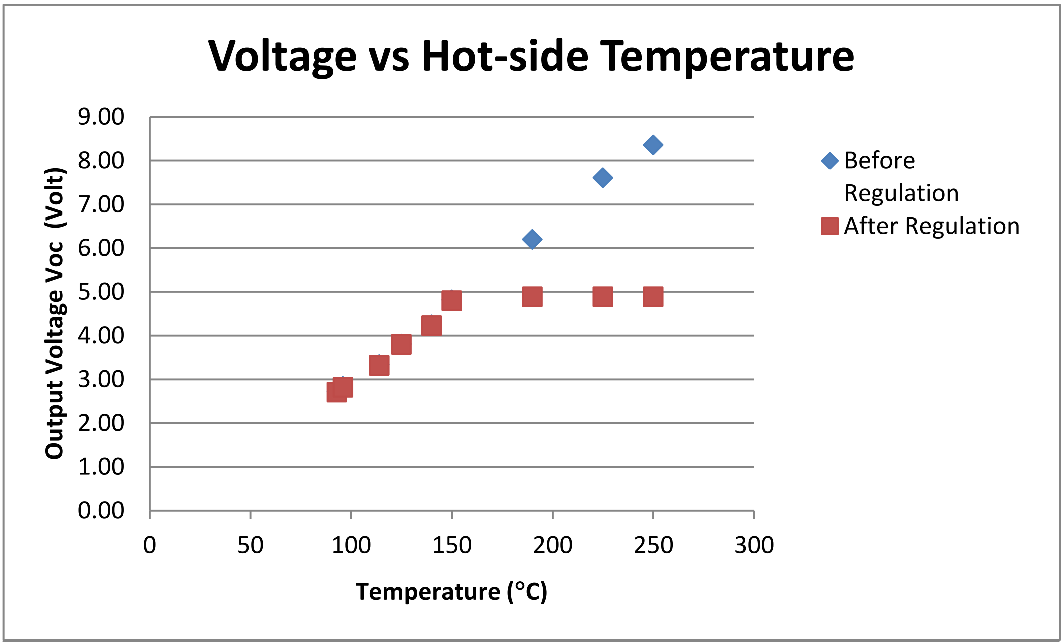
Figure 4.23 (left) the PowerPot V product, (right) tPOD5 product

Figure 4.24 The Product Testing and Evaluation: The PowerPot V

Figure 4.25 The Product Testing and Evaluation: tPOD5

1) The PowerPot V

The charging characteristic of the product was shown in Figure 4.26, and Table 4.26.



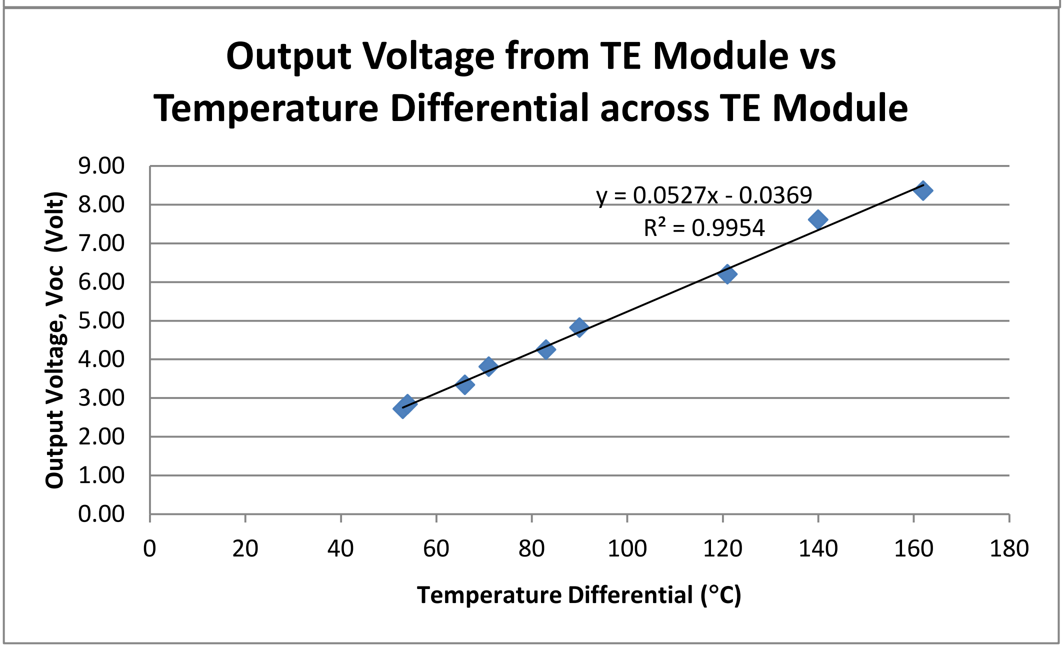


Figure 4.26 The thermal-to-electric conversion characteristic of the PowerPot V

Table 4.26 The Maximum Power Transfer Calculation and Verification for the PowerPot V

	Condition 1				Condition 2					
V_s(V)	R_{L1} (W)	V_{L1} (V)	I_{L1} (A)	I_{L1i} (A)	R_{L2} (W)	V_{L2} (V)	I_{L2} (A)	I_{L2i} (A)	R_s (W)	P_{max} (W)
4.89	100.00	4.78	-0.047	-0.048	10.00	3.98	-0.394	-0.398	2.31	5.19
4.89	1000.00	4.87	-0.005	-0.005	100.00	4.78	-0.047	-0.048	2.20	5.43
4.89	10000.00	4.88	0.000	0.000	1000.00	4.87	-0.004	-0.005	1.99	6.00
Average Value									2.17	5.54

The power conversion characteristic of the PowerPot V was revealed in Figure 4.26. Its regulator did not react as a voltage booster. Therefore, if the output voltage transformed by TE module is less than 5V, the regulated voltage will not be boosted to the constant 5VDC and not able to charge effectively under low-voltage constraint. While the output voltage from TE module exceeded 5VDC, the voltage would be regulated to remain constant at 4.89 V as shown.

The relation between the output voltage and temperature differential was directly linear with an approximate rate of 52.7 mV/°C as shown in Figure 4.26. The Seebeck coefficient (α) was calculated considering the number of all 254 couples of TE elements in 2 TE modules, to be 207 ±1 μV/°C for each couple.

As Table 4.26 revealed the maximum power calculations for 3 conditions of varying external resistance complying the maximum power transfer theorem, the maximum power was determined at 5.54 watts which was adjacent to the nominal maximum power referred by the manufacturer (5 watts).

2) tPOD5

The charging characteristic of the product was shown in Figure 4.27 and Table 4.27.

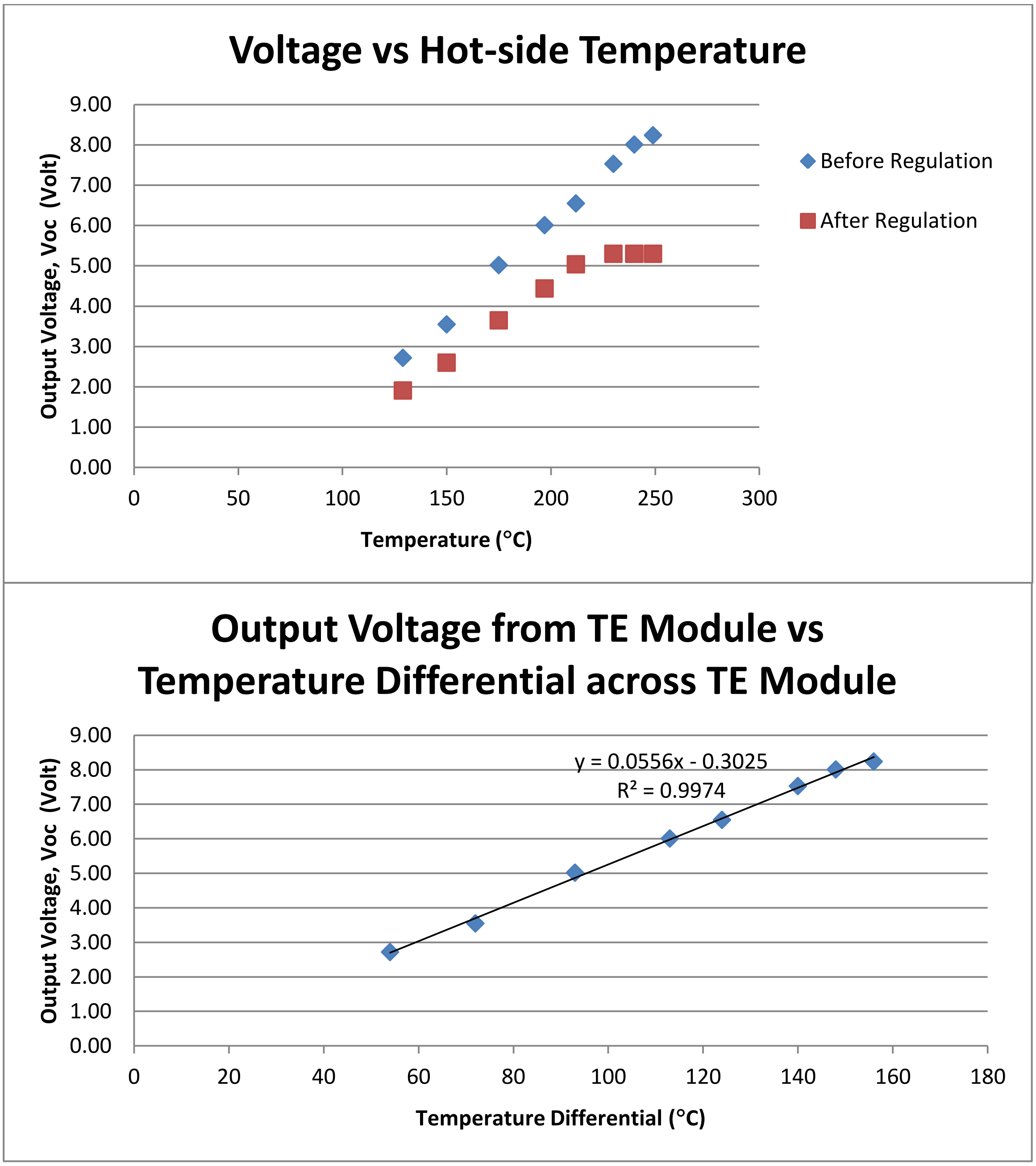


Figure 4.27 The thermal-to-electric conversion characteristic of tPOD5

Table 4.27 The Maximum Power Transfer Calculation and Verification for the tPOD5

	Condition 1				Condition 2					
V_s(V)	R_{L1} (W)	V_{L1} (V)	I_{L1} (A)	I_{L1i} (A)	R_{L2} (W)	V_{L2} (V)	I_{L2} (A)	I_{L2i} (A)	R_s (W)	P_{max} (W)
5.30	100.00	5.12	-0.049	-0.051	10.00	4.11	-0.411	-0.411	2.79	5.03
5.30	1000.00	5.24	-0.005	-0.005	100.00	5.12	-0.049	-0.051	2.74	5.13
5.30	10000.00	5.25	-0.001	-0.001	1000.00	5.24	-0.005	-0.005	2.55	5.50
Average Value									2.69	5.22

The power conversion characteristic of tPOD5 was revealed in Figure 4.27. Like the PowerPot V, its regulator did not react as a voltage booster. Therefore, if the output voltage transformed by TE module is less than 5V, the regulated voltage will not be boosted to the constant 5VDC and not able to charge effectively under low-voltage constraint. Moreover, the regulated output voltages in the range of lower than 5V were reduced below that of the output voltage from TE module because there is some divided power to use for the cooling fan and resulted in the voltage drop of 23-30% as shown which is a major obstacle in a design for low-profile energy harvest. Similar to the PowerPot V, while the output voltage from TE module exceeded 5VDC, the voltage would be regulated to remain constant at 5.30 V as shown.

The relation between the open-circuit output voltage and temperature differential was directly linear with an approximate rate of 55.6 mV/°C as shown in Figure 4.27. The Seebeck coefficient (α) was calculated considering the number of all 254 couples of TE elements in 2 TE modules, to be 218 ±1 μV/°C for each couple, which was slightly higher than those TE modules used in the Powerpot V.

As Table 4.27 revealed the maximum power calculations for 3 conditions of varying external resistance complying the maximum power transfer theorem, the maximum power was determined at 5.22 watts which was adjacent to the nominal maximum power referred by the manufacturer (5 watts).

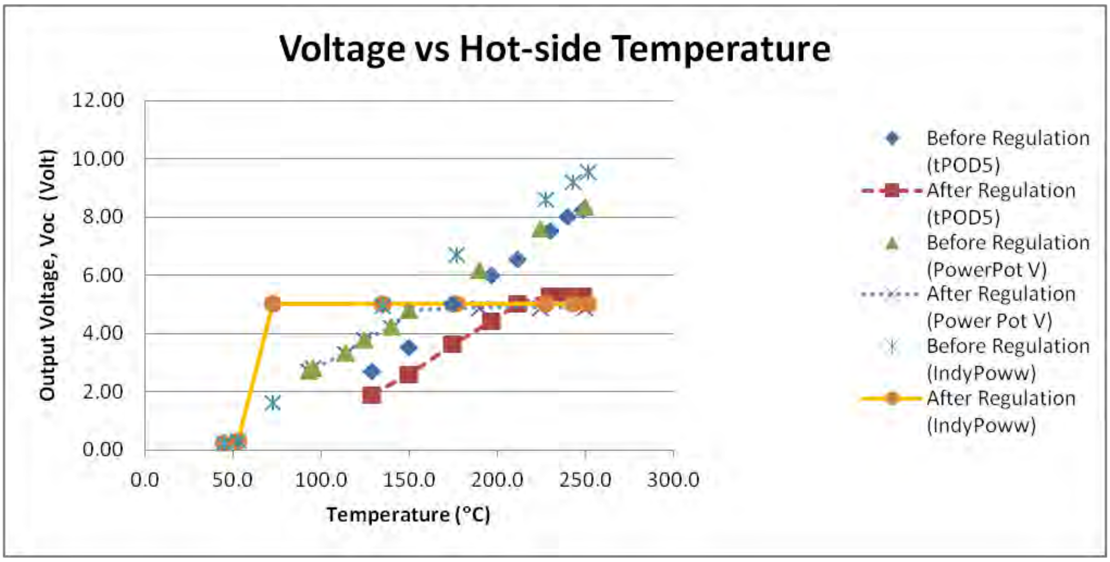


Figure 4.28 Comparisons of electrical power output characteristics among the prototype and the tested commercial products

Compared with the electrical output characteristic of the Power pot V and tPOD5 as shown in Figure 4.28, IndyPoww outperformed the others in availability of 5-volt power output at much lower temperature difference. The lowest hot-side temperature from experiment to gain 5-volt power output was at 73°C and it differed from that of the cold side for 31°C. The PowerPot V performed better characteristics than tPOD5 not only for thermal-to-electrical transformation outcome but also the responding power output at lower temperature difference.

This comparison was based on the varying power input from electric stove to determine relationship of rising output voltages from rising hot-side temperatures, and also ambient conditions in identical approaches for those 3 products.

4.4.3 <u>Product Feature and Performance Comparison</u>

Charging tests were set up to study the comparison of the prototype from research and other competitive products. The heat source and heat supply was the controlling parameter. The 3,000-watt electric stove was selected with the constant power rate of heat transfer at the middle level of its full heat supply capacity. The power input and heat energy was then controlled in identical conditions for the test of 4 products. The testing targets were defined for 4 product patterns i.e. (1) the PowerPot V, (2) tPOD5, (3) the research prototype with 4 modules, and (4) the research prototype with 3 modules. The 2 conditions of the research prototype testing were aimed to study the effect of the number of TE modules as an alternative for a decision in the product development as well.

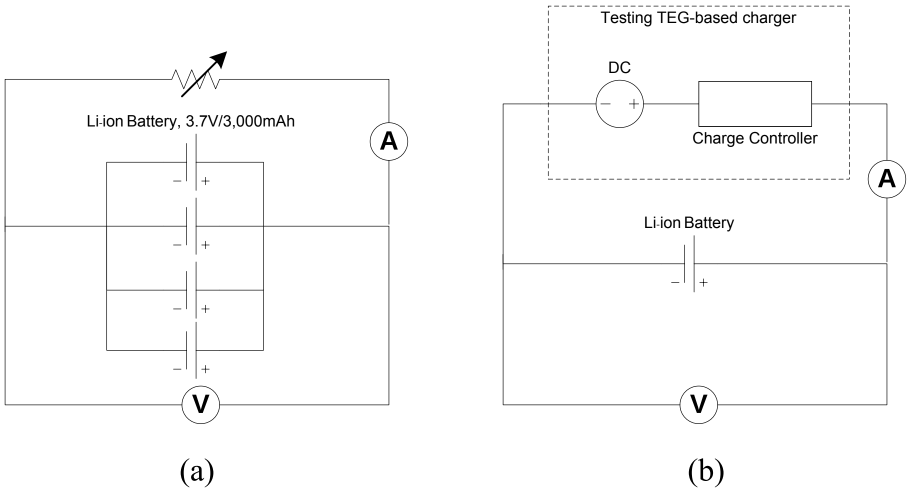


Figure 4.29 The testing circuit diagram for battery charging characteristics (a) discharging process, (b) charging process

Like the functional prototype testing process but with various products at the same condition, 4 Li-ion batteries were discharged until the typical lower threshold voltage of 2.5V. During discharging process, all batteries interconnection were parallel and simultaneously discharged to a resistance in order to ensure the identical starting point voltage for all tests. The test was to charge the battery by various TEG-based power supply i.e. the PowerPot V, tPod5, IndyPoww (4 modules), and IndyPoww (3 modules) with the referred approach in Figure 4.29 until the typical full voltage of Li-ion at 4.2V, implying equivalent supply energy to be charged by each product into a battery until full load. The charging process by each power supply was repeated for more 4 times while rotating the batteries to one another products for charging in order to reduce a bias of differences in each battery characteristics. The time of charging was recorded as well as the voltage and current output through the battery. The output power was calculated and plotted in graph to compare all characteristics of each product pattern. The characteristics of charging test were summarized in Table 4.28 , and the data of electrical parameters and power were plotted in graph for each product pattern as shown in Figure 4.30-4.33.

Table 4.28 A summary of comparison in TEG power supply product charging test

No.	Tested Product	Tested Battery	Duration until Charging Finished	Maximum Current (mA)	Maximum Power (W)	Max Power per Unit Area (mW/sq.cm)
1	The PowerPot V	#1	3:20	932.0	3.09	96.6
		#2	3:19	918.0	2.98	93.1
		#3	3:24	945.0	3.16	98.6
		#4	3:28	913.0	2.94	91.8
		Average	3:22	927.0	3.04	95.1
2	tPod5	#1	3:52	895.0	2.80	87.5
		#2	3:47	822.0	2.80	87.4
		#3	3:50	864.0	2.76	86.3
		#4	3:46	879.0	2.84	88.8
		Average	3:48	865.0	2.80	87.5
3	IndyPoww (4 Modules)	#1	2:21	1,332.0	4.97	77.7
		#2	2:26	1,311.0	4.78	74.7
		#3	2:26	1,321.0	4.88	76.2
		#4	2:18	1,347.0	5.04	78.8
		Average	2:22	1,327.8	4.92	76.8
4	IndyPoww (3 Modules)	#1	2:49	1,155.0	3.97	82.6
		#2	2:54	1,116.0	3.87	80.5
		#3	2:51	1,139.0	3.97	82.8
		#4	2:46	1,162.0	4.04	84.1
		Average	2:50	1,143.0	3.96	82.5

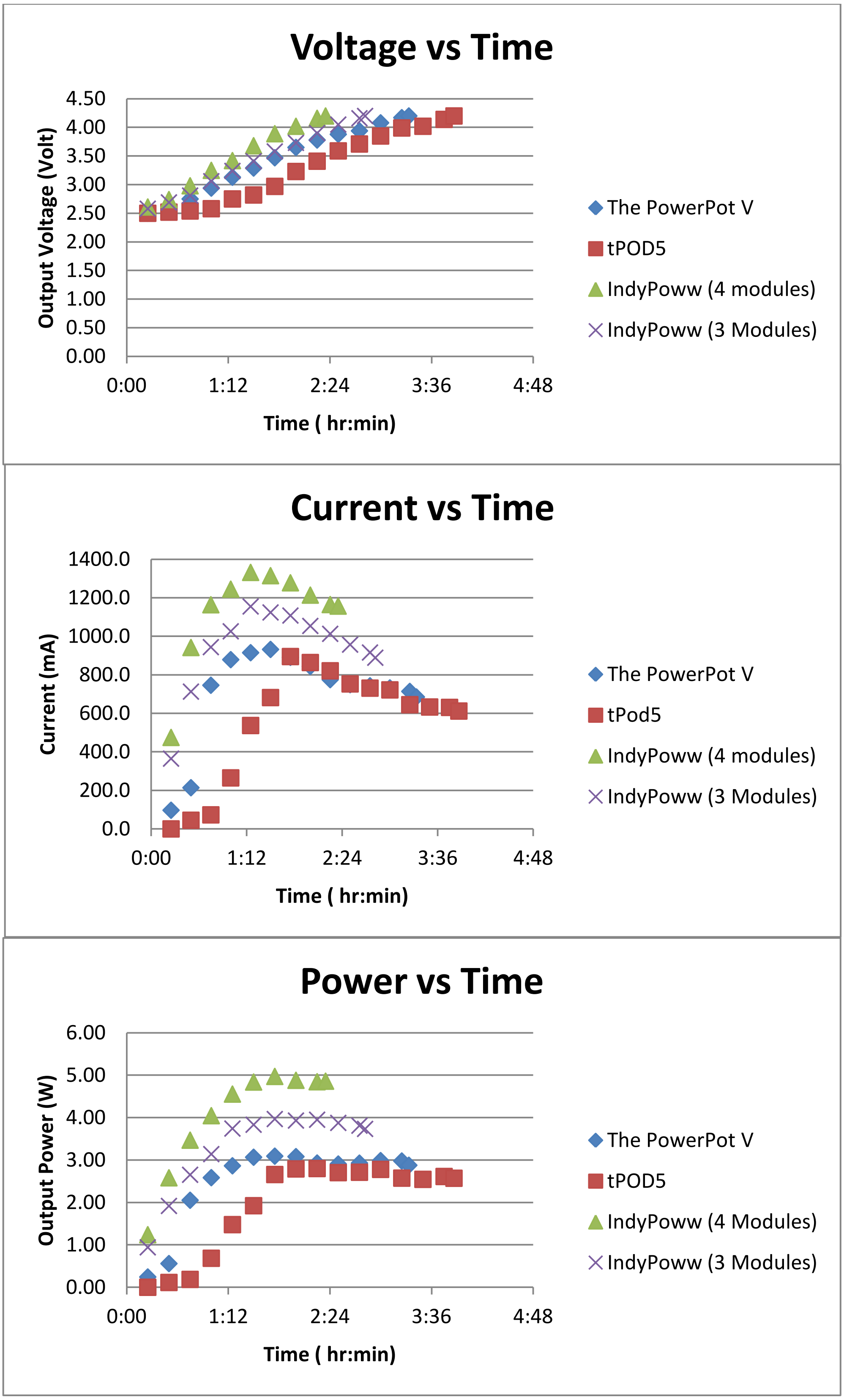


Figure 4.30 Comparisons for charging characteristics of TEG product (Replication #1)

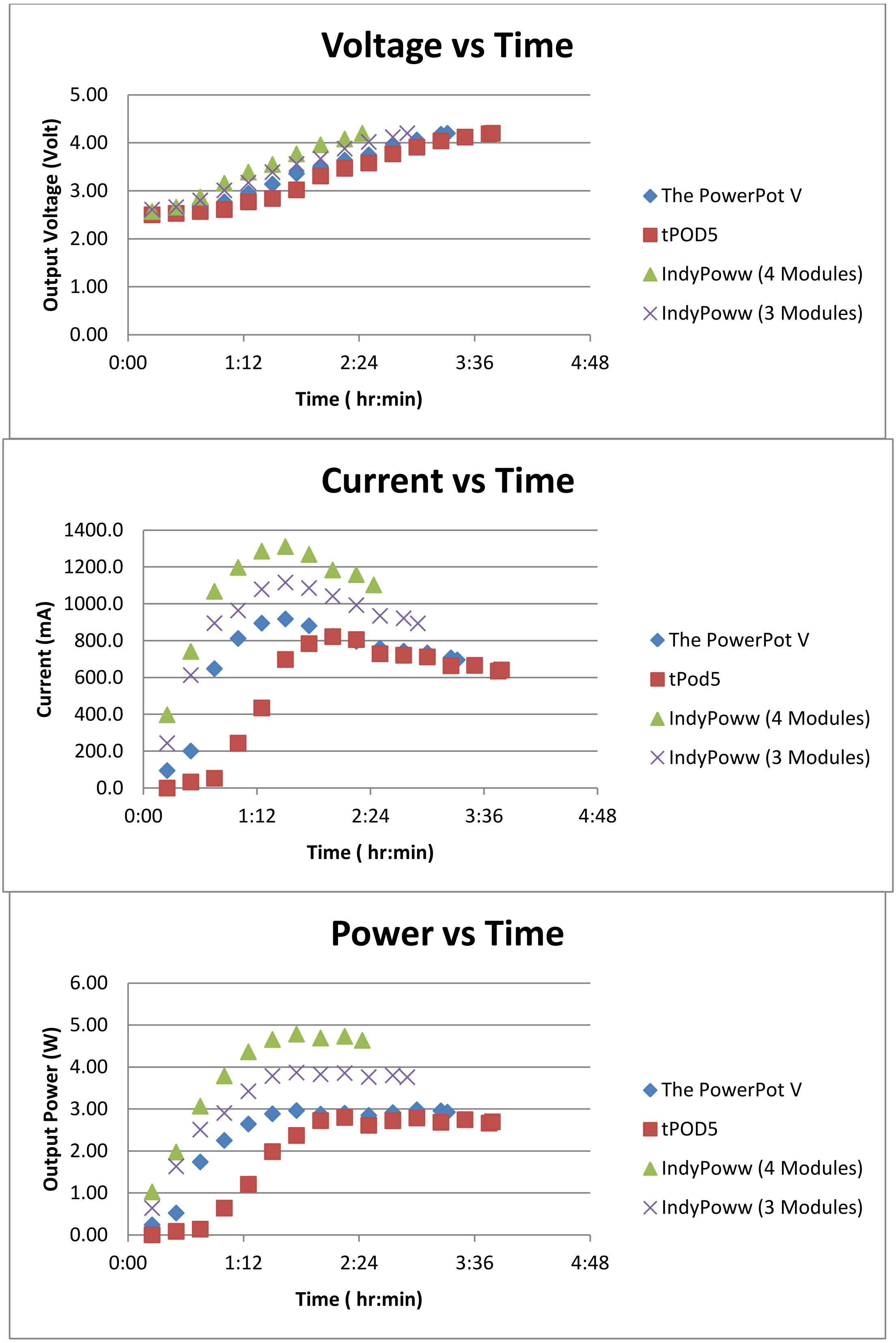


Figure 4.31 Comparisons for charging characteristics of TEG product (Replication #2)

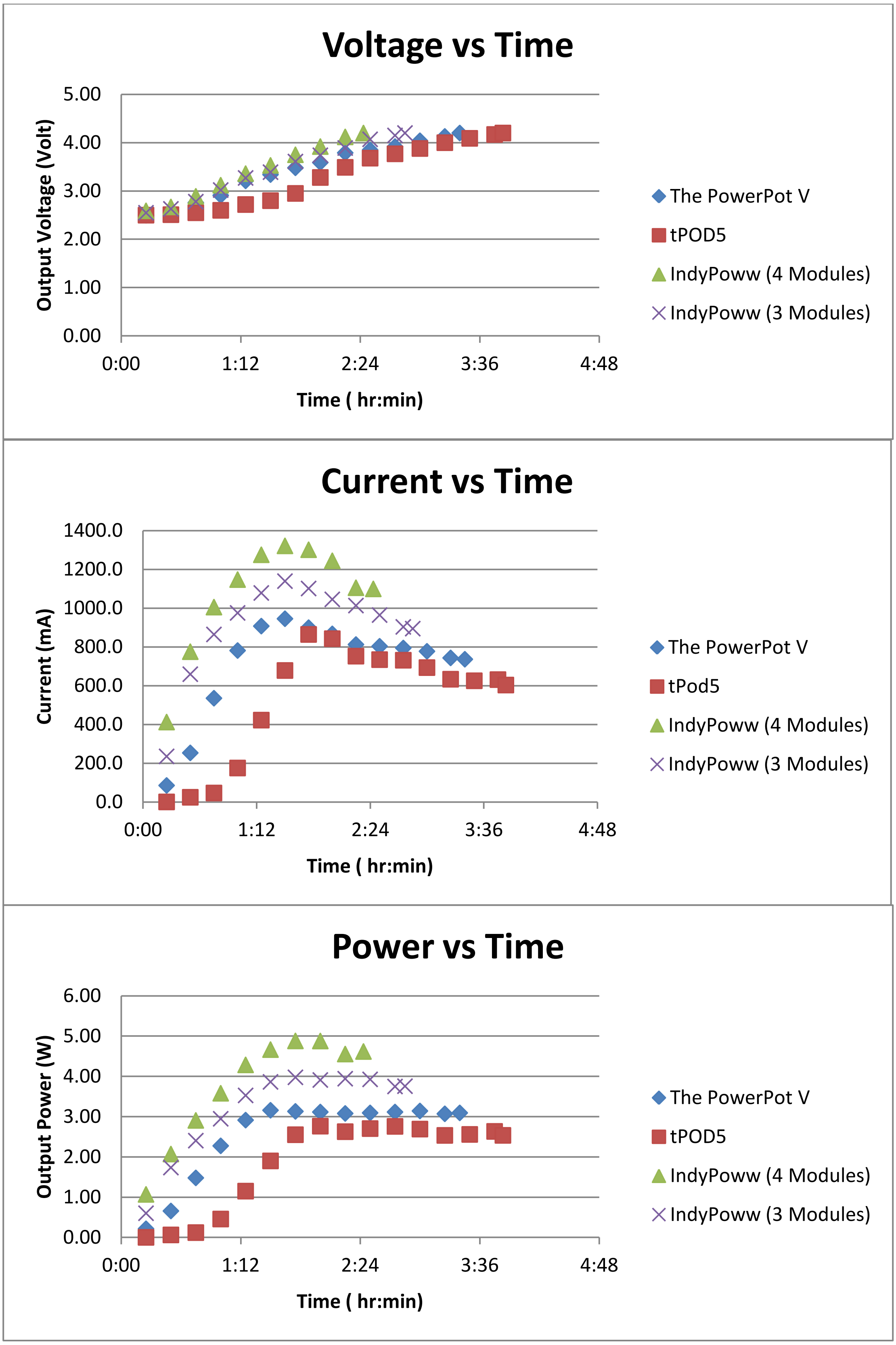


Figure 4.32 Comparisons for charging characteristics of TEG product (Replication #3)

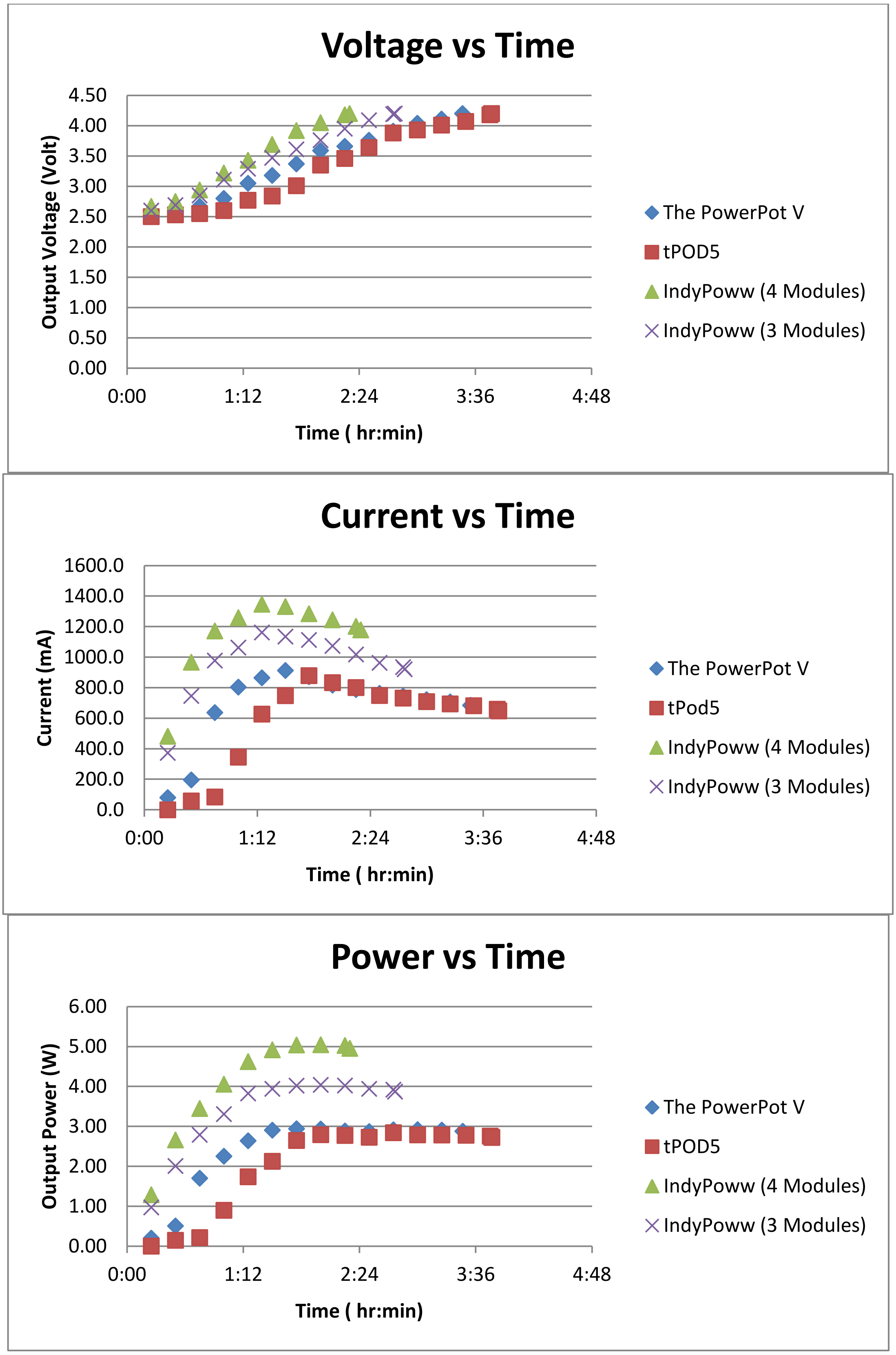


Figure 4.33 Comparisons for charging characteristics of TEG product (Replication #4)

The maximum power obtained from each experiment revealed the unexpected values for not exactly proportional depending on the number of TE modules in each product. This was due to the different Seebeck coefficient of each product as previously mentioned. Moreover, as Junkrob *et al*. [50] proposed in their research that the power generation capacity will decrease from expectation for 10.7% per an added module in series when the module is added owing to different characteristics of each module, so the more series modules added to the product would lead to inefficiency for power output as well.

Comparing tPOD5 with the PowerPot V, the output power from tPOD5 were outnumbered by those of the PowerPot V despite the same number of TE module because the partial power was used to drive the cooling fan and that leaded to the voltage drops, and less potential to charge current into a battery.

The curve of voltage vs. time revealed an advantage of a feature for IndyPoww as it could boost the voltage in range of low power profile more efficiently than other products. This was due to more amount of TE module in a product and the effective charge controlling mechanism to maintain the preferable output voltage of 5V from the low input voltage as well. The TEG products with 2 modules could yield better performance for the power intensity per area than those with more modules, but less surface area leaded to less entire power transfer across TE module. That would result in a problem of power insufficiency especially in case of using with low power profile.

IndyPoww itself when compared for the 2 options with 3 and 4 modules, the prototype pattern with 3 modules yield 19.7% more time to charge in average, and 19.5% less output power in average, but 7.4% more power per unit area of TE surface. This implied the options to develop the product design to reduce the major cost of TE module and accomplish the trade-off with customer requirements and the efficiency of overall thermal-to-electric conversion.

The experimental sets were based on the assumption of the identical power input, and it could reflect in the equivalent area under curve for power vs. time for each product pattern. The product pattern with lower trend values of output power needed more time to fulfill the equivalent charge. At the beginning of charging, the curve revealed that the output power was pretty low and increasing because of the rising temperature difference and also the output voltage leading to more potential to overcome the remaining voltage in a battery.

The pros and cons of the competitive product from the study were described in Table 4.29.

Table 4.29 Pros and Cons of the other competitive product of TEG power supply

Product	Advantage / Hilighted Feature	Disadvantage/ Gap to improve
The PowerPot V	• Generate 5W USB power while boiling water for cooking/purifying • Charge any USB powered smart phone, GPS, radio, flashlight • On demand power anytime • Great to have in case of power outages or other emergencies • USB cable and a wide variety of charging tips are included • Heavy-duty, flame-resistant cable • Carry fewer extra batteries • Can be used in hot springs • Comes with 5 LED USB lamp • Durable • Reliable • Effective	• Needs water to operate • Can"t cook thick soups/stews • Reduced performance on small low heat wood fires when windy • Damage can easily occur if water boils dry or thick foods are cooked • No battery pack included (sold separately) • A little heavier than normal camp pots that don"t generate electricity • Not effective to use with low power heat / coldness sources • Aimed to intentionally charge with fire or stove (high-potential heat sources)
tPOD5	• Charge any USB powered smart phone, GPS, radio, flashlight • On demand power anytime • Great to have in case of power outages or other emergencies • USB cable and a wide variety of charging tips are included • Heavy-duty, flame-resistant cable • Carry fewer extra batteries • Durable • Reliable • Effective	• Generate 5W USB power while intending to obtain electricity only • Much weight • Bulky size • Reduced performance on small low heat wood fires when windy • No battery pack included (sold separately) • Disable to use with low power heat / coldness sources

Table 4.29 (continued) Pros and Cons of the other competitive product of TEG power supply

Product	Advantage / Hilighted Feature	Disadvantage/ Gap to improve
IndyPoww	• Enable to use with low power heat / coldness sources • Waste heat recovery concept for power deposition instead of charging with intentional heat source utilization • Generate maximum 5W USB power while attaching with burning equipments or fire • More power generation and less charging time compared with the other products in the same condition • Charge any USB powered smart phone, GPS, radio, flashlight, and others • Lighter more compacting than the others • Battery pack included as a power bank/ buffer for users • On demand power anytime • Great to have in case of power outages or other emergencies • USB cable and a wide variety of charging tips are included • Heavy-duty, flame-resistant cable • Carry fewer extra batteries • Can be used in hot springs • Durable • Reliable • Effective	• Needs water to operate and enhance temperature gradients • Damage can easily occur if exposed to high temperature and no water is filled to absorb heat • Less efficiency per module, especially for the 4-modules option, compared with the other TEG-based power supply products • Many accessories related to the product may cause a confusion or inconvenience of use

4.4.4 Other TEG application advancement

In the last decade, there were lots of researches focusing for the application of TE in case of cooling application, and there has been increasingly interests to improve the potential of TE for a generator application in various approach as categorized.

1.) Application in secondary electricity generation for areas with electricity insufficiency problem.
2.) Application in thermal industry where there is large amount of industrial waste heat
3.) Automobile‟s waste heat application

In category 2.) and 3.), they mostly were applications dealing with large amount of heat recovery ,medium and higher temperature (≥ 300°C). Therefore, their concepts, approaches of the design, and component materials were different and not relevant to this research.

There have been researches to develop heat recovery approach from household heat stove for a decade to serve the need of electricity for 20% target of the global population lacking of electricity as World Health Organization revealed [51]. O‟Shaughnessy *et al.* [51] developed the household power supply prototype combined with gas stove to recover waste heat and transform into electricity. The maximum temperature of the heat source is set at 250 °C. The charging circuit was similar to this research but cooling fan was applied using partial power to drive it. The maximum output of 5.9 watts was achieved to charge the battery, and energy of 3 W-hr was stored in a battery after a long run period of 1 hour. The rate of energy transfer was relevant to this research. However, it did not aim at portable application and not to harvest low power heat / coldness sources as this research did, it focused on household application instead in order to supply family with the power for their electronic gadgets.

This application is considered adjacent to the area of this research in terms of output power range, TE materials, approaches to improve proper output characteristics, and target applications for electricity uses. Champier *et al*. [52] stated the different prototypes to recover waste heat from a stove using Bi_2Te_3 commercial modules as shown in Table 4.30.

Table 4.30 Different TEG Prototypes Using Bi_2Te_3 Commercial Modules

Authors	Heat Sink (Cold Side)	Power per Module
• Nuwayhid *et al*., 2003 [53]	Natural air cooling	1 W
• Nuwayhid *et al*., 2005 [54]	Natural air cooling	4.2 W
• Nuwayhid and Hamade, 2005 [55]	Heat pipes cooling	3.4 W
• Lertsatitthanakorn, 2007 [56]	Natural air cooling	2.4 W
• Mastbergen and Wilson, 2007 [57]	Forced air cooling (1W)	4 W regulated
• "BioLite" 2009 [58]	Forced air cooling (1W)	1-2 W
• Champier *et al*. "TEGBioS" 2009 [59]	Water cooling	5 W
• Rinalde *et al*., 2010 [60]	Forced water cooling	10 W [1]
• This research prototype	Water / Natural air cooling	4.82 W

[1] part of this power should be used to drive the water pump

There were some aspects to take in considerations for the prototype design. Nuwayhid *et al*. [54] stated that the output power per module dropped when the number of TE modules in the TE generator rose because of the reduction of the temperature difference between the hot and cold surfaces. This point was relevant to the result of the prototype testing with varying the number of TE modules. Champier *et al*. [52] recommended that the heat exchanges with water are generally better than exchanges with air and the use of water ensures that the cold heat sink temperature will always remain under 100°C. The output from this research revealed those advantages relevant to that statement and should be take in considerations to design a proper water-cooled heat sink for a portable application.

4.5 Commercialization and Business Plan

4.5.1 Context and marketplace analysis

4.5.1.1 PEST Analysis

First of all, external factors impacting on the commercialization of TEG-based power supply in Thailand was analyzed for political, economical, sociocultural, and technological aspects or PEST analysis as shown in Table 4.31.

Table 4.31 PEST analysis for the commercialization of TEG-based power supply in Thailand

Political	Economical
• Reduction in business tax (20% in 2013) • ASEAN Economic Community (AEC) collaboration in 2015 • ACFTA (reduced Tariff in imported components) • Political instability (2006-2013) • Need to register with Thai Industrial Standard (TIS) • Border stability (lower secondary target group) • Recently rise of minimum wage (300 THB/day)	• High growth of Thai economy (6.4% in 2012) • Growth of middle-high class (86.8% in 2011) • Appreciation of Thai currency (1998-2013) • Low initial investment • Cost reduction in components • Price of direct competitive products • Price of indirect competitive products
Sociocultural	**Technological**
• Less language barrier • Environmental concern of consumers and entrepreneurs • Health care concern in Thailand • More people use internet to search for products. • Online social networking for digital era • Decline of primary target group i.e. travelers in national park (-4.5% / year)	• Improvement in information and communication technology (ICT) • Low cost of technology infrastructure • Mature of thermoelectric generator (TEG) technology • PCEDs expand continuously in the global market • Developing personal screen for life • High internet coverage [1]

[1] http://investvine.com/3g-has-power-to-revolutionise-media-savvy-thailand/

4.5.1.2 Industry Analysis

The industry is very fragmented without a dominant company setting the pace as sales leader. Because the technology of TEG and competing products is relatively new, there is not a dominant leader in this market. Many small companies offer solar powered battery chargers, motion powered chargers, and also spare batteries that are marketed by both the original manufacturer and knock-off spare batteries manufactured in low-cost regional hubs. Until a point when this industry experiences consolidation through acquisitions of small manufacturers by device making industry giants, it will remain fragmented. The technology itself in each competing product is easily copied which tends to play a role in why the industry remains fragmented at this time.

4.5.1.3 Five Forces Analysis

Porter"s five force model [61] as shown in Figure 4.34 was brought to analyze the market to comprehend the business context that affected the business administration in the future.

Figure 4.34 Porter"s five force model [61]

(1) Rivalry among existing competitors

- *Purposes of existing competitors*

Competitors for the product range needed to serve customers for their individual secondary power supply to respond digital era and online social networking. However, various technologies were introduced for application into the customer requirements with different pros and cons in distinctive suitable situation of use. There is also a niche for each energy harvesting technology for competitors to develop their own product to maximize the profit margin from specific customer requirements. Therefore, this factor leaded to medium intensity of rivalry among existing competitors.

- *The characteristic of competition*

Advantages in competitions were considered for specific features to use or to serve customer satisfaction. The competition, thus, would not in the kind of the same product pattern. Criteria for customers to select the product were composed of ease of use and usefulness matching with their lifestyle with reasonable price to pay for. Therefore, this factor leaded to low intensity of rivalry among existing competitors.

- *The growth rate for industry*

Due to the eras of social networking and online trend for consumer behavior referred from Moore"s law as described in Chapter I, the growth for secondary power supply was more necessary for those who considered electronic gadgets a necessity for their lives. Therefore, the growth rate has been continuously high in many years so forth. Therefore, this factor leaded to low intensity of rivalry among existing competitors.

- *Barriers for launching in the market*

The prime obstacle for launching a new product was the limitation for energy harvesting technologies. The high cost of investment and production was consequently impacted by this aspect. Some entrepreneurs who are interested in this field are necessary to acquire know-how as a knowledge base for competition as well. Therefore, this factor leaded to high intensity of rivalry among existing competitors.

- *Profitability*

Due to the specific requirement of niche, the product that serves the required condition will raise its profitability and be interesting to make profit. However, for general purposes of secondary power uses, there are some competitive and substituting products with higher competitions and so the profitability has low potential. Therefore, this factor leaded to medium intensity of rivalry among existing competitors.

In conclusion, the current intensity or rivalry among existing competitors was considered in the medium level.

(2) Bargaining power of suppliers

In this aspect, there are some key technological components of the product which are difficult to find a source for economy-of-scale production i.e. TE modules, and battery management integrated circuit set. TE module has to be imported from some sources with reasonable and competitive cost e.g. from China but with proper quality control process to ensure the quality for consumers. In other words, the battery management IC module can be customized by the option of outsourcing with own special supply for some critical part such as boost controller with MPPT module.

- *Identity of the product*

Some critical parts need high technology to produce with some slightly difference of product specification e.g. TE module. However, there are some standardized product models which can be substituted by other supplier but maybe with slightly different quality. Therefore, this factor leaded to medium bargaining power of suppliers.

- *The number of suppliers*

Some critical high-technology parts in acceptable quality were produced by a few specific manufacturers, e.g. TE module, battery management chipset. Therefore, this factor leaded to high bargaining power of suppliers.

- *The importance of parts for finished goods*

Some parts for product manufacture plays vital role to the product performance and function ability. Therefore, this factor leaded to high bargaining power of suppliers.

- *Switching cost*

The cost for switching from a supplier to another supplier is not significantly impacted because general purchase order was dealt for each lot of purchase. However, big lot or long term of purchase may lead to incentives for significant discount as well. Therefore, this factor leaded to medium bargaining power of suppliers.

In conclusion, the current bargaining power of suppliers was considered in the relatively high level.

(3) Bargaining power of customers

- *Quantity of buying*

Naturally, this product focuses consumer target group, so the quantity of buying at a time is few. Therefore, this factor leaded to low bargaining power of customers.

- *Uniqueness of product*

The product was designed for specific purposes and targets, and other product in this field was different in features and experience of uses. Therefore, this factor leaded to low bargaining power of customers.

- *Proportion of product price to buyer's income*

The product price for TEG power supply is rather high compared with an affordable price rate for general product in this type. Therefore, this factor leaded to medium bargaining power of customers.

- *Switching cost for customers*

Customers cannot switch to use another product with the same features and experience, but they can switch to use others in different way or approach to obtain similar objective for energy harvesting purpose as well. Therefore, this factor leaded to medium bargaining power of customers.

In conclusion, the current bargaining power of customers was considered in the relatively low level.

(4) Threat of substitute products or services

Other energy harvesting technology from surroundings as photovoltaic module (solar cell), fuel cell, piezoelectric module, and others are all not suitable for the thermal condition from heat sources. Furthermore, among thermal conversion technologies, TEG is the most appropriate approach to use in the condition of silence mode, high reliability, compact size, and portable applications. In summary, the threat of substitute products and services are not significant to affect the commercialized product.

- *Perceived quality and performance of substitute product*

The product has specific features to use in the target condition. Therefore, this factor leaded to low threat of substitute products or services.

- *The price of substitute product*

The price for some general-purpose product for energy harvesting is lower than this product. Therefore, this factor leaded to medium threat of substitute products or services.

- *The switching cost for substitute product*

Switching product to substitute product is hard because of its unique features to use and serve users. Therefore, this factor leaded to low threat of substitute products or services.

In conclusion, the current threat of substitute products or services was considered in the relatively low level.

(5) Threat of new entrants

The commercialized product is classified as an architectural innovation, which is corresponded to new system or linkage of improved components. Therefore, if the product is popular in the market, new entrants may be able to copy and development or doing "reverse engineering" to compete in the future. Product design patent can be one strategy to use to protect the opportunities, but another aspect of product development can be disadvantageous for this product eventually. Thus, branding and its reliability are important to impress consumers since the first time launching to markets. Continuous product developments are significant to keep track of the competitive advantage. Fresh designs, high quality product, with competitive cost are the key success factor to encounter those new entrants.

- *Barriers for entering the market*

This required the competency of applying technology, adequate amount for economy of scale. However, raw materials and distribution approach is not hard to access, and needs moderate cost for investment. Therefore, this factor leaded to medium threat of new entrants.

- *Reactions from existing competitors*

If there are some new entrants, there are a few reactions from existing competitors that mainly focus on their specific target. Therefore, this factor leaded to medium threat of new entrants.

In conclusion, the current threat of new entrants was considered in the medium level.

Referred to five forces analysis, the result of intensity for a competition in the industry was concluded in Table 4.32.

Table 4.32 The conclusion of intensity for a competition in the industry analyzed by five forces analysis

Force or Impact to organization	Intensity
Existing competitors	Medium
Suppliers	Relatively High
Customers	Relatively Low
Substitute products or services	Relatively Low
New entrants	Medium

4.5.1.4 Competitors and Potential Customers

(1) Direct Competitors

Even though TEG products are relatively new products in the domestic market, there are a few products with same principle of operation, which are sold worldwide. Table 4.33 shows the example of similar products and their prices. To avoid market dumping from foreign competitors, Thai TEG Company Limited must set the price close to the lower end of their retail pricing. The detail for competitive product testing and comparisons were revealed in the next section.

(2) Substitute Products

Since the PCEDs are becoming more useful in everyday life, many manufacturers offer various means to satisfy the demand for PCEDs and their thirst for electric power or batteries. Consequentially, there are many substitutions to TEG product in both the domestic and global markets as shown in Figure 4.35 for examples. Several popular substitutes are power bank and backup batteries. These two products provide a fixed amount of power to be used for the PCEDs but neither is capable to charge a battery without electricity. Therefore, they are not suitable for extend periods of camping in the outdoors without electricity available.

Table 4.33 Examples of similar products from direct competitors

No.	Product	Manufacturer/ OEM	Maximum Power Output	Net price	Product picture
1	The PowerPot ™	Powerpot (https://www.thepowerpot.com)	5 W	US$ 172.50 (Shipping included)	
2	15-W high temperature TEG panel	TEG Power (http://www.tegpower.com/)	15W	US$ 94.99 (Shipping included)	
3	TEG power brick (AKA "Ice TEG")	TEG Power (http://www.tegpower.com/)	5.145W (regulated) /14.4W (un regulated)	US$ 267.99 (Shipping included)	
4	Tellurex tPOD5	TELLUREX (http://www.tellurex.com)	5W	US$ 192.45 (Shipping included)	

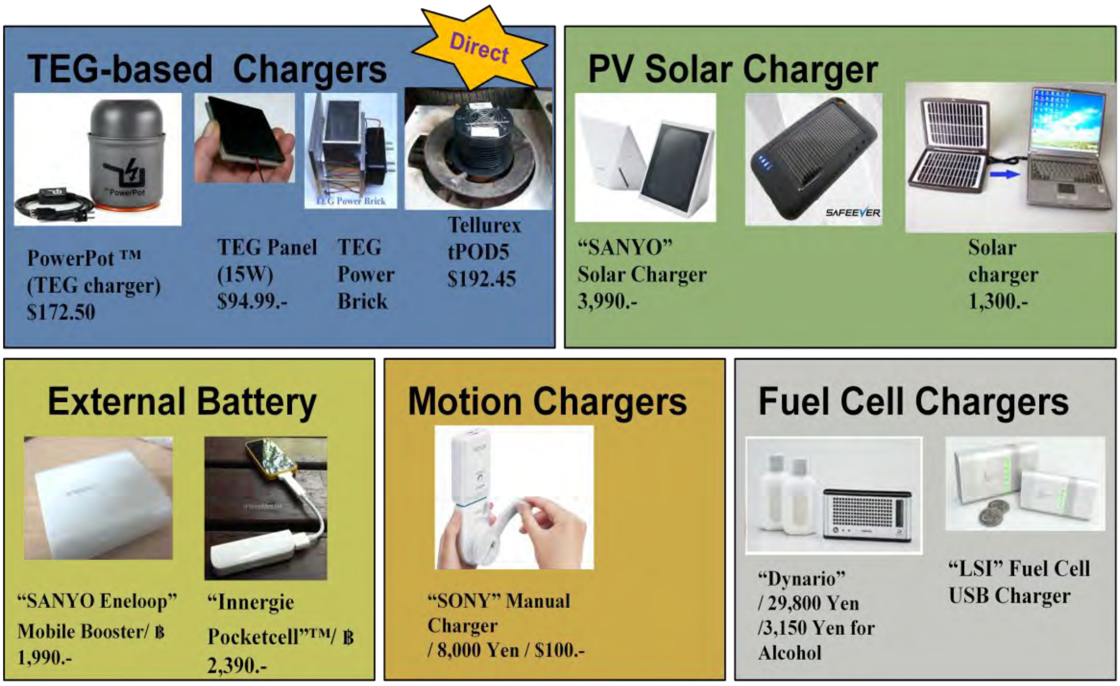


Figure 4.35 Examples of substitute products for TEG based power supply

However, there are some substitute products that have the ability to charge batteries without using electricity. Therefore, they can be used in the same situation with TEG products. These substitute products are solar chargers and motion chargers. The following table compares advantages and disadvantages of these substitute products compared to TEG products.

(3) Competition and Buying Patterns

Buyers tend to look towards specialty electronics web sites, which sell a vast array of electronic components along with battery and battery charging accessories. Solar powered chargers, motion powered chargers, and spare batteries are all offered either by direct sales via specialty electronics web sites or direct sales of charging products by the manufacturer on its website.

Companies sometimes market their products through established local retailers; but because there is a vast array of battery products and accessories to serve a vast array of electronics products, the retailer cannot afford to stock such large quantities of differing battery charges and accessories. Without a dominant brand to stock the shelves of retailers, the retail market produces very little of industry sales.

The only exception to this retail trend is for spare or backup batteries that are sold by the device manufacturer. Spare batteries are often marketed alongside the devices for which they are used in for certain, but not all, electronics devices. Cameras and some mobile phone devices provide for easy interchangeable batteries. Other mobile phone devices, such as i-Phone, do not allow for easy interchange of batteries by the general mass market consumer. Batteries that are not easily accessed can damage the device if users attempt to interchange spare batteries often. Thus, for these devices it is not practical to utilize spare batteries.

(4) Industry Participants

The battery charger industry remains very fragmented. Many small companies without brand recognition make competing products for certain consumer electronics devices. However, many of these chargers are designed to only charge for a certain device. TurboCharger XL has a line of chargers for Minolta, Canon, Fuji, and Sony cameras. But each device is specialized and not compatible with different brands of devices. These chargers also rely on traditional electricity when connected to a wall socket.

- Solar powered chargers – Energizer, Duracell, NRG Dock, Solio, Solar Style, and Soldius among many other brands.
- Wind Turbine charger - Kinesis K3

Each year new brands of "green chargers" emerge and others fail and are forgotten. Because the industry is very fragmented and without an industry leader, many small companies from low-cost producing countries enter the market to compete with existing products. Since distribution of these battery charging products is also highly fragmented, it remains to be seen whether one or two brands will ever emerge as industry leaders. There are more than a 1,000 retail web sites easily retrieved from a simple Google search for consumer electronics battery chargers. Table 4.34 shows advantages and disadvantages of these products, compared to TEG product.

Table 4.34 TEG-based power supply in comparison to other substitute products

Product	Advantages to TEG	Disadvantages to TEG
Solar Charger	- They are slightly less expensive. They are sold around USD 25 - 100. - It is lightly more power extraction, about 15% compare to 5% of TEG	- Lower Availability. It cannot be used indoor or at night. - Less flashy. Make it less attractive to inventors and early adopters.
Motion Charger	- Offer higher availability. It can be used anywhere without limitation, while TEG need to have difference in temperature in order to generate electricity.	- More Expensive. Most of which are sold between USD 200-300. - Require more effort to charge. Usually, require 3 minutes charging time for 1 minutes talk time. - Less flashy. Make it less attractive to inventors and early adopters. - Lower durability, since it uses moving mechanical parts to generate power.
Backup Battery	- They are relatively cheap. They are sold around USD 10-50. - They can be used instantly.	- Less flashy. Make it less attractive to inventors and early adopters. - Lower flexibility. It cannot be used with other devices. - Offer limited power supply. They cannot be recharged without electricity.
Power Bank	- They offer high power supply that can be used instantly. - Their price range starts from cheaper to higher than TEG products, depending on power capacity.	- Less flashy. Make it less attractive to inventors and early adopters. - Offer limited power supply. They cannot be recharged without electricity.

(5) <u>Potential Customers</u>

Since TEG product is relatively expensive and need to use in the situations where there is limited or none electricity, the target consumers are defined as:

1. People who can afford to use expensive products.
    - People with high income (Demographic: Income)
    - People who are given the device for free (Demographic: Occupation)
2. People who have to go to the places without or with limited electricity for two or more days.
    - People who go for traveling (Psychographic: Activities)
    - People who go for work (Demographic: Occupation)
3. People who use the PCEDs (Psychographic: Lifestyle)

4.5.1.5 SWOT Analysis

SWOT analysis is one of the marketing tools to thoroughly analyze the internal factors (strength and weakness) and external factors (opportunities and threats) for both positive and negative impact to the commercialized product. The analyzed data has shown in Table 4.35.

Table 4.35 SWOT analysis for the product

Strengths	Weakness
• Strong research base and connections for TEG technology • Advantageous property of TEG technology for their silence, compact, reliability, and no moving parts (maintenance free) compared with other thermal energy harvesting technology • Advantageous for specific condition to harvest especially in the case of no electricity sources, weak sunlight, or in the dark • Environmentally-friendly product to respond the trend of "green" and energy savings • TEG products extract unclaimed resources and convert those sources into usable energy. These resources are free and readily available in many different environments. The user does not have to have access to traditional electrical socket, which are not available in many outdoor activities. • TEG products currently have a certain "new" and "cool" factor that attracts people who want to be different to their peers and also love technology products. • TEG products are highly compatible with PCEDs that utilize a standard USB connection.	• Incapable status to commercially produce the key component of product: proper TE module • Disadvantageous Inherent TEG characteristic for lower power efficiency compare with other technology • Moderate to high cost compared with other substitute products • Narrow market segment available if TEG products cannot successfully penetrate into the outdoor camping, hiking, nature tourist, or outdoor government employee markets. • An environment with two temperature variances must exist for the TEG unit to create energy • TEG technology is a new product which has not yet been presented to consumers and gained wide-spread acceptance as a successful product. • Knowledge about TEG devices and how they operate is limited to the general public.

Table 4.35 SWOT analysis for the product (Continued)

Opportunities	Threats
• Global warming trend and energy crisis solved by waste heat recovery • PCED secondary power needs due to social networking and online culture • The need for secondary power supply to serve more sophisticated PCEDs in the same time • More chances for emergency events due to natural disasters e.g. flood, tsunami, earthquake lead to secondary power supply especially for communication gadgets. • Rural off-grid area with the problem of insufficiency main power supply • Export opportunities for some areas with the problem of electricity insufficiency e.g. countries in Africa, Japan, Philippines, Indonesia • Sufficient and qualified electronic part sources in Thailand • Outdoor enthusiasts who go on extended camping, hiking, and other nature tourist activities have limited options with how they can recharge their electronic devices. Many times tradition electrical sockets are not available for use. Other times, travelers to a foreign country do not have the correct interface cable to connect with traditional electric sockets that may or may not be available. • Government officers who patrol rural areas often go to places where electric power is either not available or not always available, yet PCED gadgets or tools that they rely upon will eventually need recharging.	• Competitors can take not much time to study and imitate the product. • The product is not regular commodity but for a niche with the condition of using. • TE module technology has been being developed to reach the dominant design in the future and may cause the change of product configuration for better capability in the near future. • Charging by TEG may not be necessary when using in the context of sufficient traditional electrical power supply via a wall socket. • Other competitive secondary power supply technologies e.g. fuel cell, solar cell, secondary battery • Some substitute products may be easier to use depending on the situation in which the consumer is operating. • Some substitute products are already sold, used, and readily accepted in the market. • New technology could introduce new products which operate better, are cheaper, more efficient, or contain other characteristics that are of higher value to the consumer.

4.5.2 Marketing Plan

4.5.2.1 STP Analysis

(1) Segmentation

i. Demographic segmentation

This criterion leaded to the consideration of the age as follows.

- "Children & Teenager" : 6 – 19 years old
- "Young working people": 20 – 39 years old
- "Experienced working people" : 40 – 59 years old
- "Retired people" : 60 – 80 years old

This criterion leaded to the consideration of the occupation as follows.

- Indoor or office workers
- Semi outdoor workers
- Outdoor workers

ii. Geographic segmentation

This criterion leaded to the consideration of the residence as follows.

- Residence in urban area
- Residence in rural area

iii. Behavioral segmentation

This criterion leaded to the consideration of the behavior as follows.

- People who love nature photography
- People who like camping
- People who like nature tourism / ecotourism
- People who like geo-tourism
- People who like rural tourism
- People who like adventure travel

(2) Targeting

The potential customers was people that use PCEDs and have to travel or work to the areas with limited or without electricity for more than two days. In particular, travelers who use more than one PCED would be ideal targets. Multiple PCEDs such as a smart phone, GPS, D-SLR camera, wireless communication gadget, and other devices that would require recharging to continue to use on extended trips would create further demand for TEG products among this segment of user. From this matrix, we can define the target into 3 types as follows.

- *Primary Target*

People with high income and like to travel into the places with limited or no electricity for more than 2 days in one trip. For this group, the company should find the customers who use multiple PCEDs and like travel into such places for several time a year. According to the department of national parks, wildlife, and plant conservation, there are 8.62 million Thai visitors who visit 148 national parks in 2012 (totally in 2012 of 9.95 million visitors). The assumption was set that there are approximately 5% within this group, who camp more than four times a year. This figure resulted from the preliminary survey for around 5 out of 100 people entering some national parks were interested to TEG-based power supply product due to long trips with a scarcity of electricity to charge their PCEDs. Therefore, the size of the target group will be approximately 432,000 people. However, this target group is declining in the past 10 years as shown in Figure 4.36, due to the development of new domestic and foreign tourism areas, which are cannibalizing demand within the target market. The assumption should be verified by survey to ensure the validity of this business plan.

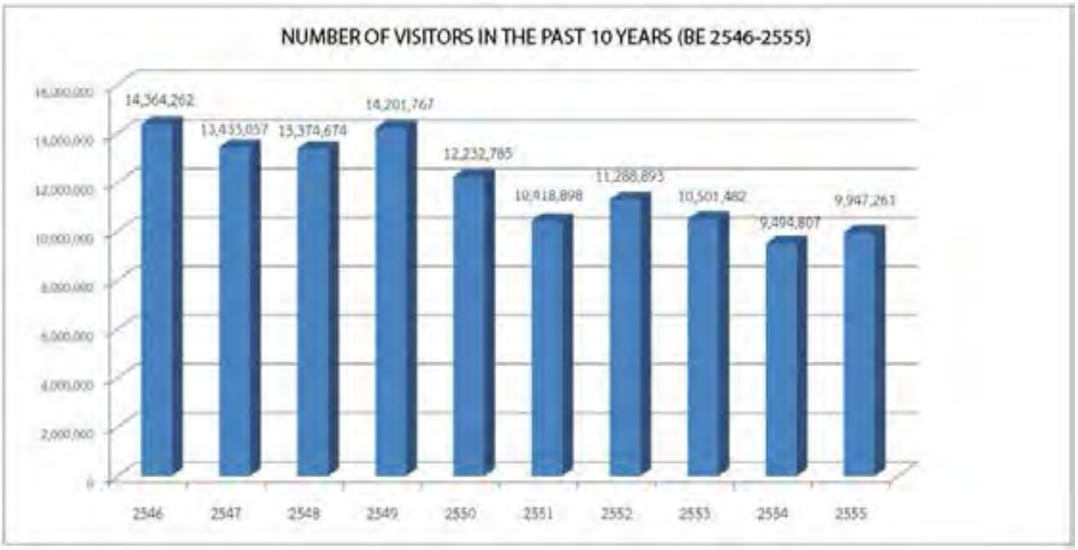


Figure 4.36 Number of All Visitors of all Thai national parks in 2003-2012 [62]

- *Secondary Target*

The secondary target is government officers whose job requires their position to be located in remote locations, with limited and inconsistent access to standard electrical sources. Border Patrol Police, Rangers, and many other government personnel are required to patrol vast areas of Thailand, which do not always have reliable and convenient sources of electrical power.

There are currently only two units that fit in this category, which are Border Patrol Police and Rangers. The number of the Border Patrol Police is around 40,000 [63], while that of Ranger Forces is around 9,000 in 2008 [64]. The number of these two forces is declining by around 50% in the past two decades from stabilizing of the border areas.

In conclusion, the number of target customers in the first two categories of target market was shown in Table 4.36. Additionally, the business firm intends to serve only the domestic market, because the cost of manufacturing is currently too high to be competitive in export markets. Focusing marketing efforts within Thailand offers a more concentrated marketing plan toward our target segments.

Table 4.36 Primary and secondary target market analysis

Market Analysis	Growth	Year 1	Year 2	Year 3	Year 4	Year 5	Compound Annual Growth Rate
Potential Customers							
Campers	-4.50%	432,000	412,560	393,995	376,265	359,333	-4.50%
Government Officers	-4.50%	49,000	46,795	44,689	42,678	40,757	-4.50%
Total	-4.50%	481,000	459,355	438,684	418,943	400,090	-4.50%

- *Additional Target*

Due to the outstanding technical result of product in the lowest starting temperature differential to enable charging of 26°C as shown in Section 4.4.1 in Table 4.25 and flexibility to charge electricity via various heat sources or sinks, general PCED users will be more convenient to use the product as a spare personal power supply for their emergencies and sudden needs. Those people will be able to tap the waste heat trap module anywhere and anytime they exposed to daily heat sources or sinks to collect the electrical power into their TEG-based power bank. This is the further potential target to address in order to increase sales and ensure revenue to meet the set target. The additional target will be gradually growing in the future due to the more developed thermal-to-electric efficiency of TEG technology. Moreover, the further research is needed for studying in details of complicated product appearance design, integrating with various forms of TEG-based power supply, for higher level of attraction for general PCED consumers. The purchase decision of the product should be made after the design process in order to confirm the potential customers in the expanding target segment. Basically, the sensitivity analyses were made to roughly estimate the potential impact from sales increases by 20% of the target sales on some key financial figures as shown in financial plan section next. This additional target will be grasped thoroughly in a future work for a decision option to reinvest for the target market later on.

(3) Positioning

Customer perceptions or attitudes toward the product compared with other competitors‟, and obvious positioning to communicate to them will develop a unique characteristic or strong brand for target customer.

Product positioning would emphasize on functions or product features as the first priority. In other words, thermoelectric technology is one of energy harvesting technology. It has pros and cons in different aspects compared with such other technologies as solar cell, fuel cell, manual dynamo. The primary threat is the availability of electricity which raise the product of secondary power supply powered by direct electricity i.e. external battery, or even spared battery to be more advantageous. Therefore, the primary position of product for the function aspect would emphasize to the applications or areas with scarcity of electricity.

Next, for the same type of TEG product, the position was considered by flexibility for functional use, and price. Existing TEG power supply in the market has no domestic brands or OEMs. Imported products cost higher than THB 2,500 but not flexible for uses. The designed product would set the position by its feature of uses and lower price than those existing products as shown for Thai TEG position in Figure 4.37.

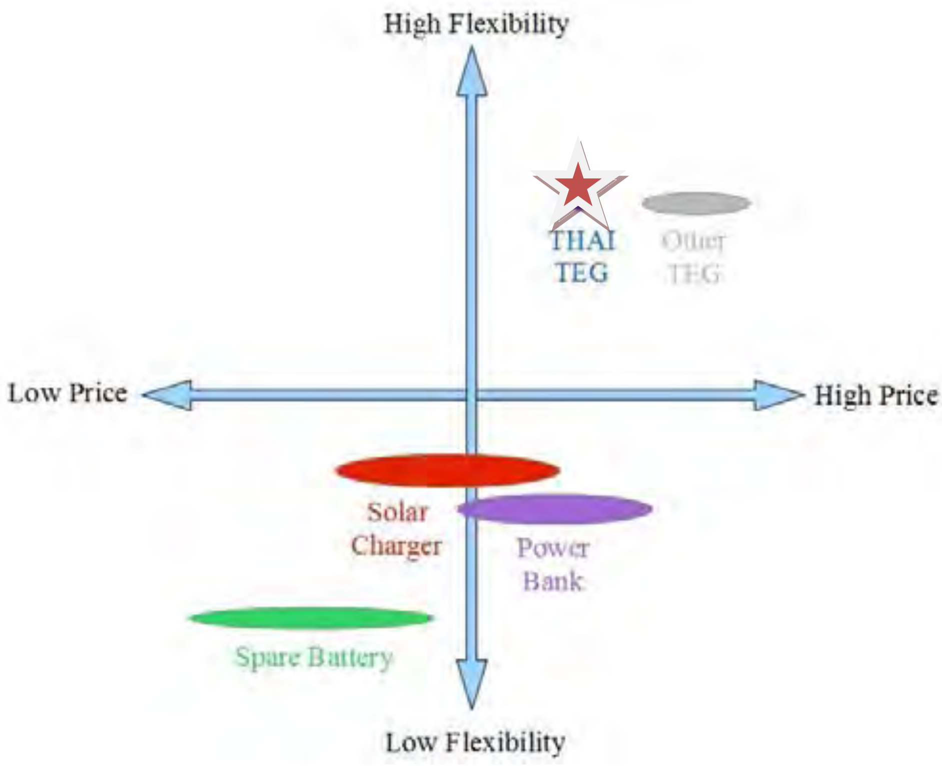


Figure 4.37 Product positioning diagram

4.5.2.2 *<u>4P Market Mix</u>*

(1) <u>Product</u>

TEG: A small device that can be used to harvest the power from difference in temperature between two sources. Each of the two input cables must be placed near each source that has a temperature difference from the other source. TEG technology uses the temperature difference in the two sources to create energy, which is stored in the TEG charging device. An electrical output is provided via a USB port so that consumers can easily and conveniently recharge PCED devices that are commonly used in everyday life. A wide variety of PCED devices could utilize this small, portable battery charging device when a traditional electrical socket is not available to recharge the battery.

- *<u>Product's Attractive Features:</u>*

1) *Extracting Unclaimed Resources:*

The greatest advantage of TEG lies in extracting unclaimed resources and converting those sources into usable energy. Simple temperature differences, which would soon dissipate into its environment, can be converted into usable energy by the TEG technology. The device can be used to steal power from ice, cooking or camp fire, lamps, and even river water.

2) Durability

Since the TEG modules have solid-state constructions, it is very durable. Thai TEG Company Limited can offer a longer, more complete warranty than many substitute products that are more fragile

3) Unique Experience

TEG uses an unconventional method to claim waste energy into electricity. Therefore, it has a certain "new" and "cool" factor that attracts people who want to be different to their peers and love technology products. According to the consumer research survey, the creativity and new experience are substantially significant to the buying decision for products in its category.

4) Compatibility

Since the PCEDs usually use USB chargers, TEG offers a standard USB interface, which allow for wide-spread compatibility to modern electrical devices.

5) Availability

Since TEG can use many means to extract energy, it can be used in many situations that provide difference in temperature.

- *Technology*

TEGs are solid-state devices without moving parts and utilize "the Seebeck effect", which is the basis of thermoelectric power generation. Electric flows occur by two dissimilar metals or n-type and p-type semiconductors of thermoelectric materials subject to the temperature gradient along the sensors length.

The power output appears in the form of a voltage, directly varies with a temperature differential between the hot side and the cold side, and an electrical current, resulting from a heat flow. However, the additional systems are required to make TEG product to be suitable for intend applications. The detail of product specification was revealed in Section 4.3.2: Design for Manufacturing and Assembly.

(2) Price

The price will be constant throughout the product life cycle. It is assume to have no direct competitor entry within the first five years, as the low set price (compare to foreign competitors) of THB 2,500 and first market entry will discourage market penetration from existed players.

However, the market entry from future Chinese competitors may be possible, as they can gain economy of scale from the size of their market. In such case, the company may need to use the market exit strategies, prepared for each phase.

(3) Place

- *Direct Sales Strategy*

Thai TEG Company Limited will employ sales representatives to partake in direct sales. Direct sales will be targeted at both retails stores, (specifically camping and wilderness stores), and government entities.

The company"s sales reps will employ cold call marketing, email marketing, mailing of samples, and in person B2B visits with retail stores and government entities. The main benefit of direct marketing sales strategy will be that the company can have a high level of influence on the customer, and immediately process custom feedback to determine how they feel about the TEG product, product features, and pricing.

The company will also seek indirect marketing on TV shows aimed for eco-tourism, trekking, and camping. Indirect marketing and proper product placement will be a very cost effective method in increasing sales.

- *Strategic Alliances*

Thai TEG Company Limited will form strategic alliances with camping websites, camping and wilderness blogs, camping and wilderness stores. These strategic alliances will be cost free, and be formed on building a B2B symbiotic relationship. Thai TEG Company Limited will highlight camping/wilderness websites and stores on the company website and in some literature.

For example, the website will show a complete listing of stores where Thai TEG Company Limited's TEG product is available for sale in the country. Links to camping websites will also be prominent on Thai TEG's website.

- *E-Commerce*

Thai TEG also need to employ E-Commerce strategy, as one of its sales channels, to reach directly to the end customers. E-retailing on websites with Paypal, Credit Card, and Bank Transfer payment methods will enable the company to gain additional income via its website.

(4) Promotion

Thai TEG Company Limited's marketing promotion will include the use of targeted online media advertising to capture internet searches for campers, nature tourist, and people who are frequently involved in outdoor activities for several days. Additionally, camping stores, camping grounds, and other operators of extended outdoor travel will be targeted for both advertising at those places of business and also strategic alliances that would allow TEG products to be introduced to its primary targeted consumer via those camping stores and outdoor operators. For government agencies, the company will deploy sales representatives and direct mailings of sales literature. The company will initially target government agencies that frequently travel to remote areas.

- *Internet Marketing Strategy*

Thai TEG Company Limited will create and launch their company website immediately upon funding. The website will include:

a) Product Details
b) Product Photos
c) Product Specifications
d) Product Instructions
e) Video clips of the how the TEG product works, using various heating sources.
f) Product advantages and comparison table
g) Pricing and Purchasing information

Thai TEG Company Limited will employ the below strategic tools, which will comprise the company's Internet marketing plan:

1) Optimize Web Site Content

Use click and conversion data from PPC (pay-per-click) ads and call tracking to revise web site content including body copy, heads, and more. Ensure the marketing message focuses directly on Thai TEG Company's largest target market, the camping industry, and create a clear message for potential customers to discover through search.

2) Employ Strategies to Attract Search Engines

Complete intensive keyword research. Add proper keywords to copy, image tags, titles, headings, internal links, revise sitemap, and other areas. Submit site to major search engines. Establish strategies to target specific camping grounds.

3) Search Engine Advertising or PPC

Google AdWords will be employed, and if needed for additional traffic, Microsoft adCenter. By using PPC advertising Thai TEG Company will be able to benefit from a highly targeted audience, controlled message, leads produced as incoming calls and web forms. Useful as a research tool for business decisions as well as to drive web traffic. Examples: gauge interest in new offering or new markets.

4) Directory Entries and Link Development

Create concise description of company and submit for new directory entries such as online industry trade directories. Create more links to/from the web site. Identify associations, industry groups, and customer affiliation groups for inclusion. Add outbound links from to camping and camping equipment sites in exchange for inbound links from these sites.

5) Utilize Google Maps/Google Local Search

Create a searching index of all business listings with Google that sell the Thai TEG Company product. This will allow customers to easily locate a local store to purchase the product, and build good-will with the business carrying the company‟s product.

6) Informational Articles for Marketing

Use existing informational articles focusing on Thai TEG Company Limited as a marketing tactic. Convert articles to PDF format, make available on web site, use as “lead bait” on site. Submit as information to relevant sites, with link back to the company‟s website.

7) Create Video for Marketing

Create a simple video for marketing purposes, place on Home page and promote it throughout site. For example, a subject could be "Five possible heat sources for the TEG product". Use this to attract leads and traffic. Post video on YouTube with link back to company website.

8) Establish Sustainable Building/Eco/Green Page

Create a page detailing the eco-friendly benefits of the TEG product. This page link can then be posted on environment boards and blogs.

9) Web Press Release

Create and send out an electronic press release with news/information announcement, link back to web site. This type of publicity is designed to create more "buzz" about Thai TEG Company Limited, and increase site visits through links on site carrying the press release.

10) Email Marketing Campaign

Collect email addresses from customers and web site visitors. If possible, get email addresses from camping stores carrying the TEG product. Create and send out periodic emails with information, subtle sales pitch and special offers. Create special landing page on the web site for the subject of email, and to track the response.

11) Integrate traditional advertising content with online marketing

Integrate current marketing programs such as flyers, mailers with online marketing. For example, add mention of specific features or offers on web site to all mailers. Add mention of brochures and other materials to web site.

12) Ongoing Web Site Maintenance/Measurement

Periodic updates to site content, update keyword research. Create new landing pages for special offers. Monitor and report traffic from site.

13) Set up Blog

Set up blog for Thai TEG Company Limited, and strategy for networking. Create initial blog entry. Employees and customers should be allowed and encouraged to write regular blog entries. Enable RSS feed for blog.

14) Social Media Marketing

Create strategy for social network marketing. Set up a Thai TEG Company Limited profile on several social networking sites. Employees should be active on profiles. On all postings, link back to web site, blog, and any articles online. LinkedIn can give Thai TEG Company Limited the chance to develop contacts with suppliers, potential suppliers, customers, and others. Facebook is used by many companies to create product pages, establishing a presence and links in a huge online community. Profile pages from these sites often appear when a company name is entered in Google.

Some of the best market research is within the social communities where customers interact, share information and make recommendations. It will also help tremendously with Thai TEG Company Limited brand visibility, promotion of products, providing information to educate customers about products, and link building.

- *Specific Marketing Strategy*

Specific sales programs were described as follows.

1. Website Advertisement: Advertisement in Trekking, Camping, and Eco Tourism website. It will generate the product awareness to the people that fit the primary target. The budget for this program is THB 3000 / month.

2. Catalog sales: develop placement within an existing camping and outdoors tourism catalog which sells many different branded products for use in outdoor activities. The budget is THB 30,000 / year for this program.

3. Distribute brochures and flyers to camping operators to be distributed to the camp operator's customers to develop both the image and brand awareness of Thai TEG Company Limited. The budget for this program is THB 10,000 / month.

4. Traditional print advertisements that could be printed within camping, nature tourist, and hiking magazines. The goal is to place advertisements within the top 3 magazines in the market. The budget for this program is THB 15,000 / month.

5. Indirect marketing in eco-tourism, trekking, and camping TV and Radio programs. This will be considerably cheaper than direct advertisement. The total budget for this program is THB 500,000 / year.

6. Participate in tourism tradeshow to get more leads within the target segments. Additionally, it may leads to get more leads from inventors and early adopters from other market segmentation. The budget for this program is THB 500,000 / year.

- *Sales Literature*

Thai TEG Company Limited will have several types of traditional sales literature in addition to the company website. Flyers, brochures, one page product sheets, catalogs will all be part of sales literature the company utilizes. Thai TEG Company Limited will also seek placement within existing camping and outdoor tourism catalogs which already carry various branded products. Beyond printing and distributing sales literature, Thai TEG Company Limited will seek utilize press releases and will most likely take advantage of possible articles in the Thai newspapers and magazines.

4.5.3 Manufacturing and Operational Plan

4.5.3.1 Master Sales Plan

Thai TEG Company Limited aims to satisfy 30% of the total market size of 481,000 people. The strategy will be divided into three phases divided by accumulated sales.

First Phase 0-24,000 Unit Sold:

- Pull Strategy: Use minimum safety stock for both raw material and finish goods.
- Use relatively cheap marketing leads to generate sales, especially website and social network.
- Use only one salesperson to focus on primary market segment.
- Direct marketing in Camping Stores
- Advertise in Camping and Trekking website e.g. http://www.trekkingthai.com, http://www.khonbaakpae.com/, http://www.weekendhobby.com/
- Distribute the flyer in famous camping sites

Second Phase 24,001 – 72,000 Unit Sold:

- Pull Strategy: Use sales forecast to determine stock for raw material and finish goods.
- Use website and social network marketing.
- Direct marketing in Camping Stores and invest to add the product into their catalog.
- Advertise in Camping and Trekking website e.g. http://www.trekkingthai.com, http://www.khonbaakpae.com/, http://www.weekendhobby.com/
- Strategic alliance with bloggers and influential people in camping.

- Advertise in Camping and Outdoor Tourism Magazines
- Use two salespersons to satisfy both primary and secondary market segments.
- Direct marketing on Camping Websites, Camping Stores, Camping Sites, and Government Units.
- Distribute the flyer in famous camping sites

Third Phase 72,000-144,000 Unit Sold:

- Pull Strategy: Use sales forecast to determine stock for raw material and finish goods.
- Use website and social network marketing.
- Advertise in Camping and Trekking website e.g. http://www.trekkingthai.com, http://www.khonbaakpae.com/, http://www.weekendhobby.com/
- Strategic alliance with bloggers and influential people in camping.
- Use main stream marketing leads, including magazines, and indirect advertisements on selected TV & Radio programs, to gain more leads.
- Use three salespersons to satisfy the increasing leads.
- Direct marketing on Camping Websites, Camping Stores, Camping Sites, and Government Units.
- Participate in government supported tradeshow.
- Distribute the flyer in famous camping sites.

4.5.3.2 Production and Quality Control Plan

From the production and operational process in Figure 4.38, the management will consider the product and production plan for each year to launch master production plan and transferring to action plan for materials and parts procurement in the timeline.

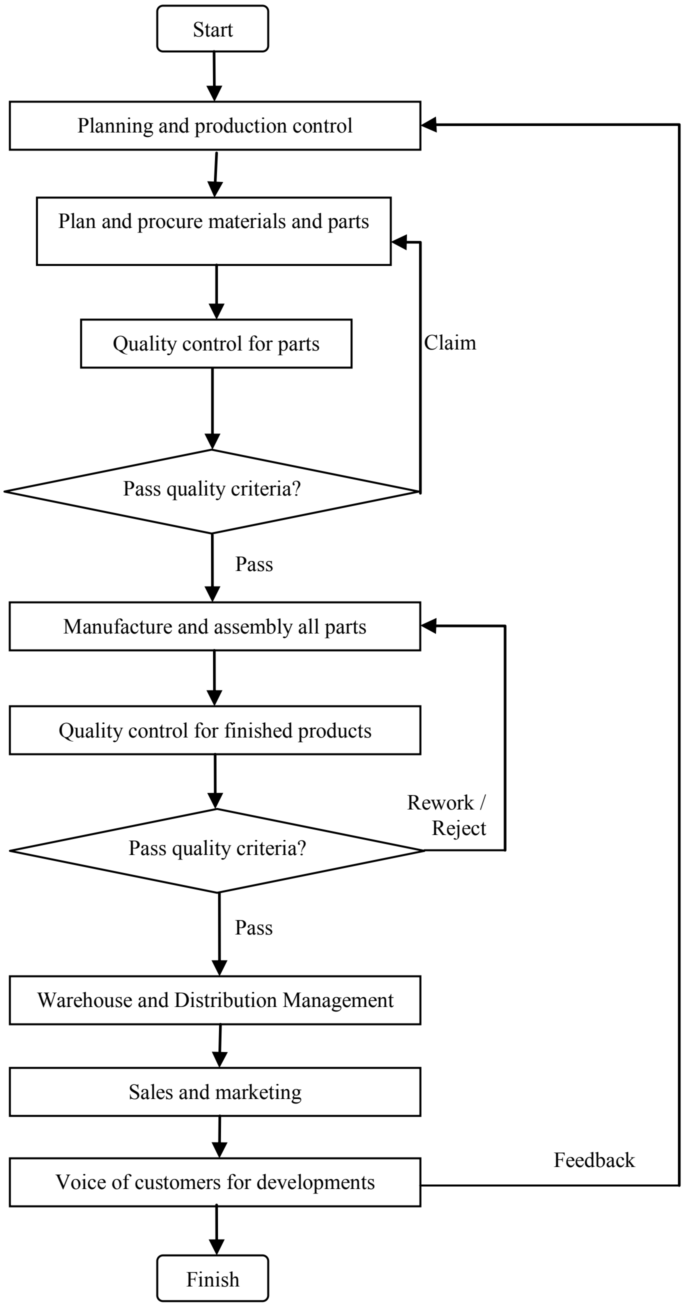


Figure 4.38 Production and operational process

As stated in Section 4.3.2 in Table 4.23, parts or components were bought and provided by suppliers. There are two operations which the factory plans to produce i.e. Top and bottom covering plate made from aluminum sheet, and heat absorber coated aluminum sheet. The rest of materials and parts were planned for outsourcing. In this process, quality control (QC) officer will inspect for the standard complying statistical procedure. If there are some rejected parts or materials, those will be turned back and claimed for repairs or replacements. After all parts are verified by QC officers, all parts are brought to assembly line and test for its function of use. All finished goods will be inspected again by QC officers to recheck the outcome with the product specification. For those which are rejected, they will be sent back to be reworked or discarded. The quality-passed finished goods will be stored in the warehouse. Sales and marketing officers contact dealers, distributors, or even directly to customers, and report the sales volume and additional voices of customers for improving and replenishing the products.

4.5.3.3 *Facility and Logistic Plan*

Considering supply sources and distribution channels from various connections and that the logistic operation was planned for mostly outsourcing, the factory should be located at the hub of transportation for inbound and outbound of Bangkok. And a site near Baromrajachonni or Kanjanapisek Rd. in Bangkok is a potential location to found the factory, as this location can be connected to the southern, northern, eastern, and north eastern parts of Thailand.

Thai TEG Headquarters will be located in Talingchan district Baromrajachonni Road as shown for a map in Figure 4.39. The scouted location is a 4.5 floors Commercial Building with 400 sq. meter of utility space. This location will be used as office, factory, and warehouse.

Since online store presence will be utilized in entirety to maintain low overhead costs, marketing via online advertising, relationships and advertising at local camping shops, and camping and outdoors websites will be the primary avenues to focus marketing efforts. Direct sales to government departments will also enhance product penetration. These marketing campaigns will all be centrally run out of the Thai TEG Headquarters in this location. Additionally, the office work will also be run here to minimum the renting cost.

Since there are a little work to be done to assembly the products. Therefore, the space requirement for production is quite small. The space required for one operator is only 6 sq. meter.

Likewise, the finish products are relatively small. Therefore, only one room in the building will be used as the warehouse.

Figure 4.39 Location map for the headquarter office and factory

4.5.3.4 <u>Sourcing and Logistic Plan</u>

Thai TEG will procure or outsource most of its components for the TEG products. Only a few parts and the final assembly will be completed in house at the corporate headquarters as shown for parts details in Section 4.3.2 in Table 4.23 Design for Manufacture and Assembly. Consequentially, required staff, facilities, workspace, and investment are all reduced significantly, when compares to in-house manufacturing.

The future production staff will be limited to three (3) people. Other employees of Thai TEG Company Limited will handle sales, marketing, finance/accounting, and R&D. The eight procured components and parts required are listed in Table 4.23.

Thai TEG will use Third Party Logistic Provider to deliver the products for e-retailing. For other sales channels, including government and strategic partners, the salespersons will handle both sales and deliveries.

4.5.4 Personnel Plan

The personnel plan requires an increase in the number of plant employees from 5 in year one, to 9 in year two, and 12 in years 3-5 and corresponding to the master sales plan as described. The organization chart for personnel in each phase was shown in Figures 4.40-4.42.

For the first 24,000 TEG units produced (1st phase), Thai TEG Company Limited will have a personnel as follows.

(1) 1 Production Staff

(2) 1 Quality Control Staff (Can be doubled as production staff, if required)

(3) 1 Sales Staff

(4) 1 General Manager

(5) 1 Clerk

Once 24,000 total TEG units have been produced (2nd phase in 3rd month fiscal year 2), Thai TEG Company Limited will slightly increase personnel as follows.

(1) 2 Production Staff

(2) 1 Quality Control Staff

(3) 2 Sales Staff

(4) 1 General Manager

(5) 1 Clerk

(6) 1 Accountant

(7) 1 Marketing Staff

Once 72,000 total TEG units have been produced (3rd phase in 4th month fiscal year 3), Thai TEG Company Limited will increase personnel as follows.

(1) 3 Production Staff

(2) 1 Production Manager

(3) 1 Quality Control Staff

(4) 3 Sales Staff

(5) 1 General Manager

(6) 1 Clerk

(7) 1 Accountant

(8) 1 Marketing Staff

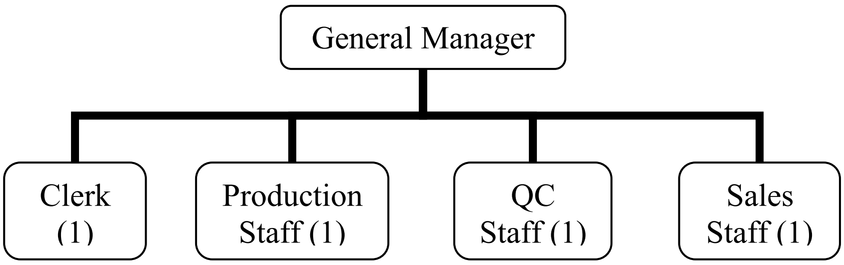


Figure 4.40 Organization chart for personnel in first phase of sales

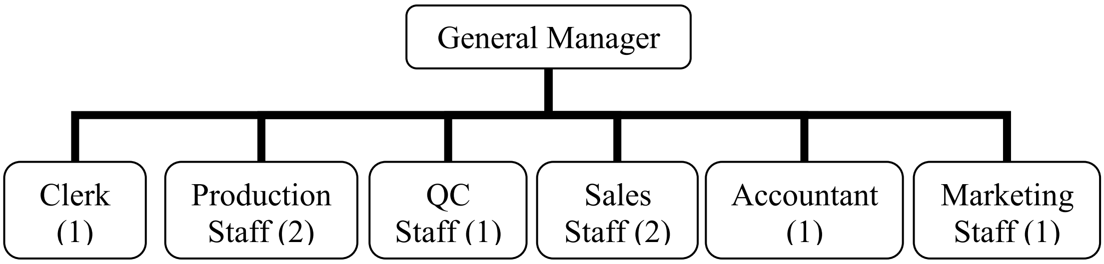


Figure 4.41 Organization chart for personnel in second phase of sales

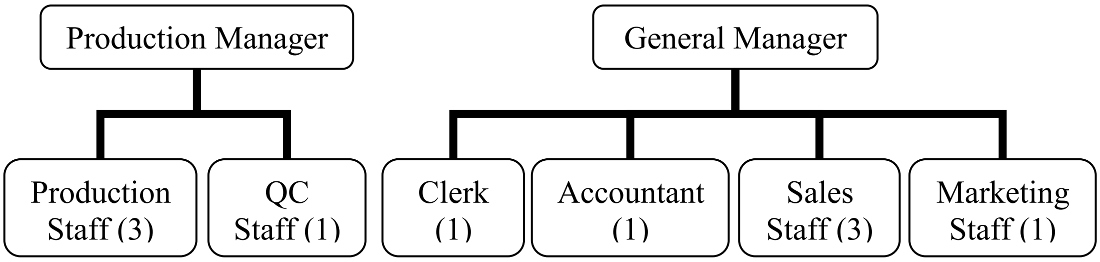


Figure 4.42 Organization chart for personnel in third phase of sales

4.5.5 Financial Plan

The projected financial plan is very sound. The one-time investment gives Thai TEG Company Limited the ability to achieve net profit (as percentage of sales) levels of over 10-15% the first five years of operations. The projected cash flow is outstanding and would enable TEG to pay handsome dividends to investors and have sufficient cash balance to consider alternate or ancillary product lines.

Thai TEG Company Limited may also enter into other joint ventures or partnerships to license other entities to manufacture and market their TEG product not only in the Thailand but also worldwide.

The last two possible sources of income are not included in the financial forecast and do not appear in the tables.

4.5.5.1 Important Assumptions

The financial plan based on important assumptions, detailed in the following statements:

a) Due to the initial limited production in comparison to the market size, Thai TEG Company Limited assumes that even a slow-growth economy, will not affect our plan for the next five years.

b) Thai TEG Company Limited forecasts that there would be no unforeseen changes in technology to make our products obsolete. Buyers are looking for cost effective solutions for replacing the high cost of back-up batteries and power reserve units, and offers the solution by providing a cost effective method for those without electricity to recharge their portable devices.

c) Cash flow is not expected to be a problem, with 100% of sales being sold on cash basis.

d) Thai TEG Company Limited assumes that their source(s) of components will not have any delivery related delays.

e) Thai TEG Company Limited assumes a short holding of inventory, with inventory never dropping below value of THB 1,700,000.

f) Thai TEG Company Limited assumes a 7% annual raise in personnel salary. This will be done to retained trained personnel and maintain employee morale.

g) Thai TEG Company Limited assumes no raise in our material costs, because the quantities we purchase will increase, and Thai TEG Company Limited anticipates discounts to offset any increased costs.

h) General assumptions of principal financial rate is defined for business context in Table 4.37.

Table 4.37 General assumptions of principal financial rate

General Assumptions	Year 1	Year 2	Year 3	Year 4	Year 5
Current Interest Rate	8.00%	8.00%	8.00%	8.00%	8.00%
Long-term Interest Rate	10.00%	10.00%	10.00%	10.00%	10.00%
Tax Rate	30.00%	30.00%	30.00%	30.00%	30.00%
Other	0	0	0	0	0

4.5.5.2 Startup Cost and Funding

Tables 4.38-4.39 shows the projected start-up costs during the two months needed to get into production. It includes the supply of specific machinery and equipment needed for the production lines. This includes THB 250,000 in long-term assets as follows:

1) Mould: THB 100,000
2) Punching Machine: THB 100,000
3) Air Compressor: THB: 50,000

Current assets will total THB 200,000 and be compromised entirely of furniture. Initial inventory of THB 1,500,000 plus THB 200,000 for other current assets to be used to produce 1,000 Units will be kept on hand and maintain at the level of THB 1,700,000 throughout the first five year of the project. Initial cash balance will be THB 640,000.

Table 4.38 Startup capital expenditure (asset) for the business

Startup capital expenditure (Asset)	Year 0
Cash Required	640,000
Startup Inventory	1,500,000
Other Current Assets	200,000
Long-term Assets	250,000
Total Assets	2,590,000
Total Startup capital expenditure (Asset)	**2,590,000**

Table 4.39 Startup expenses for the business

Startup expenses	Year 0
Consulting Fee	30,000
Legal Fee	12,000
Insurance	8,000
Recruitment Cost	10,000
Telephone/Computer System	50,000
Research and Development: Product Design	150,000
Research and Development: Packaging	50,000
Office Lease: 3 month deposit	75,000
Office Lease: 1st month rent	25,000
Total Start up expenses	**410,000**

According to Thai Civil and Commercial Code: 1097, any three or more persons may, by subscribing their names to a memorandum and otherwise complying with the provisions of this Code, promote and form a limited company. Upon completion of Registration with Department of Business Development, Thai TEG Company Limited will be owned 3 owners as shown in Table 4.40:

Table 4.40 Ownership breakdown for the company

Owners	**% Ownership**	**Investment (THB)**
Owner A (Co-Founder)	33.34%	1,000,000
Owner B (Co-Investor)	28.33%	850,000
Company C (Investor)	38.33%	1,150,000
Total	100%	3,000,000

The total capital injection from founders (owner) will be THB 1,000,000. Thai TEG Company Limited proposes participating shares for our external investors in exchange for THB 2,000,000 funding. Thai TEG Company Limited is willing to offer up to 66.66% of equity stake in Thai TEG Company Limited for the requested funding. Each shareholder will pay their percentage of capital as prescribed in Figure 4.43.

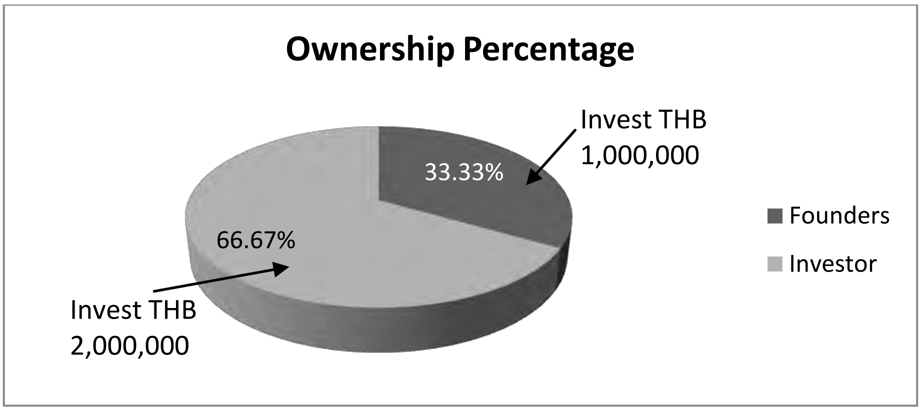


Figure 4.43 Percentage of ownership and startup cost funding portion

Thai TEG Company Limited's start-up funds are summarized in the following Table 4.41. The capital is enough to fund salaries, overhead, inventory lags and other costs during the first months of the business year.

Table 4.41 Startup cost funding detail for the business

Startup Cost used	Year 0
Total capital invested (Equity)	**3,000,000**
Cash balance	640,000
Other Current Asset	1,700,000
Total Current Asset	**2,340,000**
Total Long-term Asset	**250,000**
Depreciation 5 years/per month	50,000
Retained earning	(410,000)
Total Asset	**2,590,000**
Total Startup Cost Funding	**3,000,000**

4.5.5.3 Sales Forecast

Thai TEG Company Limited has conservatively calculated pro-forma projections for the first five years of operations. The projections are based on achieving sales to 30% of the market. The target market for the TEG product is 481,000 people, with a shrink rate of 4.5% per year.

Thai TEG Company Limited's sales forecast is shown in Table 4.42, based on the following assumptions:

a) Thai TEG Company Limited expects production to be ready within 60 days of funding.

b) Thai TEG Company Limited's product is not seasonal and will be continually manufactured throughout the year.

c) Thai TEG Company Limited's sales force will start taking orders thirty days prior to production.

d) Regarding the "direct cost of sales" (COG), Thai TEG Company Limited assumes the costs of materials will remain the same, due to discounts Thai TEG Company Limited will receive for the quantities of materials consumed which should offset rising costs.

Table 4.42 Sales forecast for the business

Sales Forecast	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Base Price & Sale Volume					
Product Price/ unit (baht)	2,500	2,500	2,500	2,500	2,500
Product Sales Volume (unit)	19240	27,540	30,730	29,260	24,006
Product Sales Revenue	**48,100,000**	**68,850,000**	**76,825,000**	**73,150,000**	**60,015,000**

4.5.5.4 Operational Costs and Expenses

Thai TEG Company Limited's operational costs and expenses i.e. material unit cost, direct cost of sales, personnel cost, and expenses are shown in Table 4.43-4.46, based on the following assumptions:

Table 4.43 Material unit cost for a TEG-based power supply product

Item	Unit	Amount	Cost of item per product
Material Cost (Baht/ unit)			
Raw Materials			
Aluminium plate	sq.m	0.0113	1.70
Heat absorber coated Aluminium Sheet	sq.m	0.0113	5.65
Consumables	A.U.	1	10.00
OEM Parts			
TE modules	item	3	1,100.00
Aluminium heat sink	item	1	50.00
Green house module body (Aluminium)	item	1	30.00
Acrylic plastic (PMMA) cover	item	1	20.00
Polypropylene frame for TEG part	item	1	15.00
Polypropylene case for charge controller	item	1	20.00
Silicone belt with stainless steel bucket	item	1	40.00
Butyl rubber O-ring	item	1	20.00
Charge Controller Curcuit	set	1	150.00
Rechargeable Battery	set	1	300.00
USB wiring reel	item	1	20.00
USB charger adapter set	set	1	30.00
Insulation material	set	1	20.00
Packaging / Bag	set	1	30.00
Total Material Cost (Baht/unit)	฿ / unit		**1,862.35**

Table 4.44 Yearly direct cost of sales for the business

Direct Cost	Year 1	Year 2	Year 3	Year 4	Year 5
Unit Sales					
TEG Product	19,240	27,540	30,730	29,260	24,006
Direct Unit Costs	1,862.35	1,862.35	1,862.35	1,862.35	1,862.35
Direct Cost of Sales	35,831,614	51,289,119	57,230,016	54,492,361	44,707,574

Table 4.45 Personnel plan and cost for the business

A. Manpower	Year 1	Year 2	Year 3	Year 4	Year 5
Production Personnel					
Production Staff	1	2	3	3	3
Quality control oficer	1	1	1	1	1
Production Manager	0	0	1	1	1
Sale & Marketing Personnel					
Sale	1	2	3	3	3
Marketing	0	1	1	1	1
General Admin. Personnel					
General Manager	1	1	1	1	1
Clerk	1	1	1	1	1
Accountant	0	1	1	1	1
Subtotal Manpower	5	9	12	12	12
B. Payroll	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Production Staff	78,130	146,298	197,433	250,797	268,353
Quality control oficer	85,460	91,442	97,843	104,692	112,020
Production Manager	-	-	160,000	256,800	274,776
Sale	150,000	337,050	513,600	577,800	618,246
Marketing	-	162,000	231,120	247,298	264,609
General Manager	200,000	256,800	274,776	294,010	314,591
Clerk	120,000	128,400	137,388	147,005	157,296
Accountant	-	180,000	256,800	274,776	294,010
Total Manpower	5	9	12	12	12
Total Payroll	633,590	1,301,990	1,868,960	2,153,178	2,303,901

Table 4.46 Yearly expenses for the business

Expenses	Year 1	Year 2	Year 3	Year 4	Year 5
Payroll	633,590	1,301,990	1,868,960	2,153,178	2,303,901
Sales and Marketing Expenses					
-Website online advertising	30,000	30,000	30,000	30,000	30,000
-Catalog sale cost	30,000	72,000	72,000	72,000	72,000
-Brochures	110,000	120,000	120,000	120,000	120,000
-Print Advertising	-	135,000	180,000	180,000	180,000
-Indirect Advertising (TV/Radio)	-	-	-	500,000	500,000
-Tourism trade show	-	-	-	500,000	500,000
Marketing Promotion	150,000	300,000	300,000	300,000	300,000
Electricity & Water	69,800	91,800	102,433	97,533	80,020
Insurance	8,000	8,000	8,000	8,000	8,000
Rent	350,000	1,200,000	1,200,000	1,200,000	1,200,000
Consultant	50,000	25,000	25,000	25,000	25,000
Other expenses	6,000	7,500	8,000	8,500	9,000

4.5.5.5 Pro Forma Profit and Loss

Table 4.47 shows Thai TEG Company Limited's expectations for profit and loss. The below assumptions are applied.

a) Sales Commission will apply to 75% of total sales, and be in the amount of 1%.

b) Electricity/Water will be determined by unit production. Five thousand Bahts will be billed for every 1,500 units produced.

Table 4.47 Profit and loss from the business

Pro Forma Profit and Loss	Year 1	Year 2	Year 3	Year 4	Year 5
Total Revenue	48,100,000	68,850,000	76,825,000	73,150,000	60,015,000
Direct Cost of Sales	35,831,614	51,289,119	57,230,016	54,492,361	44,707,574
Other	-	-	-	-	-
Total Cost of Sales	35,831,614	51,289,119	57,230,016	54,492,361	44,707,574
Gross Margin	12,268,386	17,560,881	19,594,985	18,657,639	15,307,426
Gross Margin %	25.51%	25.51%	25.51%	25.51%	25.51%
Expenses					
Payroll	633,590	1,301,990	1,868,960	2,153,178	2,303,901
Sales and Marketing Expenses					
-Website online advertising	30,000	30,000	30,000	30,000	30,000
-Catalog sale cost	30,000	72,000	72,000	72,000	72,000
-Brochures	110,000	120,000	120,000	120,000	120,000
-Print Advertising	-	135,000	180,000	180,000	180,000
-Indirect Advertising (TV/Radio)	-	-	-	500,000	500,000
-Tourism trade show	-	-	-	500,000	500,000
Marketing Promotion	150,000	300,000	300,000	300,000	300,000
Electricity & Water	69,800	91,800	102,433	97,533	80,020
Insurance	8,000	8,000	8,000	8,000	8,000
Rent	350,000	1,200,000	1,200,000	1,200,000	1,200,000
Consultant	50,000	25,000	25,000	25,000	25,000
Other expenses	6,000	7,500	8,000	8,500	9,000
Total Operating Expenses	1,437,390	3,291,290	3,914,393	5,194,211	5,327,921
Profit Before Interest and Taxes	10,830,996	14,269,591	15,680,592	13,463,428	9,979,505
EBITDA	10,830,996	14,269,591	15,680,592	13,463,428	9,979,505
Interest Expense	-	-	-	-	-
Taxes Incurred	3,249,299	4,280,877	4,704,177	4,039,028	2,993,851
Depreciation	50,000	50,000	50,000	50,000	50,000
Net Profit	7,531,697	9,938,714	10,926,414	9,374,400	6,935,653
Dividend paid	500,000	1,000,000	1,000,000	1,000,000	3,000,000
Net income	7,031,697	8,938,714	9,926,414	8,374,400	3,935,653
Net Profit/Sales	15.66%	14.44%	14.22%	12.82%	11.56%

4.5.5.6 Projected Balance Sheet

The projected annual financial balances are shown in Table 4.48.

Table 4.48 Balance sheet for the business

Pro Forma Balance Sheet	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Assets					
Current Assets					
Cash	7,721,697	16,710,411	26,686,825	35,111,225	39,096,878
Other Current Assets	1,700,000	1,700,000	1,700,000	1,700,000	1,700,000
Total Current Assets	9,421,697	18,410,411	28,386,825	36,811,225	40,796,878
Long-term Assets					
Long-term Assets (beginning)	250,000	154,167	104,167	54,167	4,167
Depreciation	50,000	50,000	50,000	50,000	50,000
Accumulated Depreciation	50,000	100,000	150,000	200,000	250,000
Total Long-term Assets	200,000	150,000	100,000	50,000	0
Total Assets	9,621,697	18,560,411	28,486,825	36,861,225	40,796,878
Liabilities and Capital					
Current Liabilities					
Accounts Payable	-	-	-	-	-
Current Borrowing	-	-	-	-	-
Other Current Liabilities	-	-	-	-	-
Subtotal Current Liabilities	-	-	-	-	-
Long-term Liabilities	-	-	-	-	-
Total Liabilities	-	-	-	-	-
Paid-in Capital	3,000,000	3,000,000	3,000,000	3,000,000	3,000,000
Retained Earnings	6,621,697	15,560,411	25,486,825	33,861,225	37,796,878
Total Equity	9,621,697	18,560,411	28,486,825	36,861,225	40,796,878
Total Liability & Equity	**9,621,697**	**18,560,411**	**28,486,825**	**36,861,225**	**40,796,878**

4.5.5.7 Projected Cash Flow

The cash flow projection in Table 4.49 shows that provisions for ongoing expenses are adequate to meet Thai TEG Company Limited's needs as the business generates cash flow sufficient to support operations. The first and second month decrease in cash flow reflects production not starting until 60 days post funding. As can be seen, Thai TEG Company Limited has anticipated such a decrease and has budgeted a sufficient amount of cash to cover losses.

Receivables will comprise 25% of total sales, with payment due in 30 days. A breakdown of receivables can be found directly below the cash flow table.

Table 4.49 Cash flow in the business

Pro Forma Cash Flow	Year 1	Year 2	Year 3	Year 4	Year 5
Cash Received					
Cash from Operations					
Cash Sales	48,100,000	68,850,000	76,825,000	73,150,000	60,015,000
Subtotal Cash from Operations	48,100,000	68,850,000	76,825,000	73,150,000	60,015,000
Additional Cash Received	-	-	-	-	-
New Current Borrowing	-	-	-	-	-
New Long-term Liabilities	-	-	-	-	-
Sales of Other Current Assets	-	-	-	-	-
Sales of Long-term Assets	-	-	-	-	-
New Investment Received	-	-	-	-	-
Subtotal Cash Received	48,100,000	68,850,000	76,825,000	73,150,000	60,015,000
Expenditures					
Expenditures from Operations					
Direct Cost of sale	35,831,614	51,289,119	57,230,016	54,492,361	44,707,574
Operating Cash Spending	1,437,390	3,291,290	3,914,393	5,194,211	5,327,921
Tax Payment	3,249,299	4,280,877	4,704,177	4,039,028	2,993,851
Subtotal Spent on Operations	40,518,303	58,861,286	65,848,586	63,725,600	53,029,347
Additional Cash Spent	-	-	-	-	-
Current Borrowing Repayment	-	-	-	-	-
Long-term Liabilities Principal Repayment	-	-	-	-	-
Purchase Other Current Assets	-	-	-	-	-
Purchase Long-term Assets	-	-	-	-	-
Dividends	500,000	1,000,000	1,000,000	1,000,000	3,000,000
Subtotal Cash Spent	41,018,303	59,861,286	66,848,586	64,725,600	56,029,347
Net Cash Flow	7,081,697	8,988,714	9,976,414	8,424,400	3,985,653
Cash Balance	7,081,697	8,988,714	9,976,414	8,424,400	3,985,653

4.5.5.8 Investment Analysis

The business anticipation of the ending total valuation of Thai TEG Company Limited at the exit year 5 will be THB 19,965,919.

The investment analysis in Table 4.50 shows the projected valuation of an investor's equity, with this in mind. For an initial outside investment of 3,000,000 Bahts, an investor will experience an IRR of 274.77%. Dividends are called for each fiscal year, and will be paid on a quarterly basis. The annual dividend amount is also shown in Table 4.50.

Table 4.50 Investment analysis

Investment Analysis	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Net Cash Flow after Dividend		7,081,697	8,988,714	9,976,414	8,424,400	3,985,653
Dividend		500,000	1,000,000	1,000,000	1,000,000	3,000,000
Total Cash Flow to Investor/Founder		7,581,697	9,988,714	10,976,414	9,424,400	6,985,653
Total Investment	**(3,000,000)**					
Founder	(1,000,000)					
Investor	(2,000,000)					
Free Cash Flow	(3,000,000)	7,581,697	9,988,714	10,976,414	9,424,400	6,985,653
Payback Period (Year)	1					
NPV @20%	**19,965,919**					
IRR	**274.77%**					

4.5.5.9 Break-even Analysis

The break-even analysis shows that Thai TEG Company Limited has sufficient sales strength to remain viable. Our break-even point is close to 119 units per month and our sales forecast for the first 9 month total is 19,240 units. Projections are detailed in the following Table 4.51.

Table 4.51 Break-even analysis for the business

Break-even Analysis	**Result**
Monthly Units Break-even	119
Monthly Revenue Break-even	฿297,622
Assumptions:	
Average Per-Unit Revenue	฿2,500.00
Average Per-Unit Variable Cost	฿1,580.35
Estimated Monthly Fixed Cost	฿109,483

4.5.5.10 Business Ratio

Business ratios for the years of this plan are shown in Table 4.52. Industry profile ratios based on the Standard Industrial Classification (SIC) code for "other electrical power generation", are shown for comparison.

Table 4.52 Key business ratios

Ratio Analysis	TEG Business Plan					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Average**
Sales Growth	0	43.14%	11.58%	-4.78%	-17.96%	18.24%
Percent of Total Assets						
Cash	80.25%	90.03%	93.68%	95.25%	95.83%	95.25%
Total Current Assets	97.92%	99.19%	99.65%	99.86%	100.00%	99.86%
Long-term Assets	2.08%	0.81%	0.35%	0.14%	0.00%	0.14%
Total Assets	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Current Liabilities	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Long-term Liabilities	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total Liabilities	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total Equity	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Percent of Sales						
Sales	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Gross Margin	25.51%	25.51%	25.51%	25.51%	25.51%	25.51%
Ageneral Admin expenses	2.99%	4.78%	5.10%	7.10%	8.88%	7.10%
Marketing Promotion	0.31%	0.44%	0.39%	0.41%	0.50%	0.41%
EBITDA	22.52%	20.73%	20.41%	18.41%	16.63%	18.41%
Main Ratios						
Current	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Quick	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total Debt to Total Assets	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Pre-tax Return on Equity	112.57%	76.88%	55.05%	36.52%	24.46%	36.52%
Pre-tax Return on Assets	112.57%	76.88%	55.05%	36.52%	24.46%	36.52%
Additional Ratios	Year 1	Year 2	Year 3	Year 3	Year 3	
Net Profit Margin	15.66%	14.44%	14.22%	12.82%	11.56%	12.82%
Return on Equity	78.28%	53.55%	38.36%	25.43%	17.00%	25.43%
Activity Ratios						
Accounts Payable Turnover	0	0	0	0	0	0.00
Payment Days	0	0	0	0	0	0.00
Total Asset Turnover	5.00	3.71	2.70	1.98	1.47	1.98
Debt Ratios						
Debt to Net Worth	0	0	0	0	0	0.00
Current Liab. to Total Liab.	0	0	0	0	0	0.00
Liquidity Ratios						
Interest Coverage	0	0	0	0	0	0.00
Additional Ratios						
Assets to Sales	0.20	0.27	0.37	0.50	0.68	0.50
Current Debt/Total Assets	0%	0%	0%	0%	0%	0.00
Acid Test	0	0	0	0	0	0.00
Sales/Equity	5.00	3.71	2.70	1.98	1.47	1.98
Dividend Payout	7%	10%	9%	11%	43%	11%

4.5.5.11 Sensitivity Analysis

For sensitivity analysis, a change in price of product is the most sensitive factor. The maximum price reduction of up to 15 percent of the base price will be allowed. The project will still be generated the appropriate return and net present value when the increase of direct product cost is not more than 20 percent. The negative volume sale change is the least effect to the project. On the other hand, the positive volume sale change implies an impact from additional target penetration, and that will cause more satisfactory financial outcome. Detailed sensitivity analysis is shown below in Table 4.53.

Table 4.53 Investment-Sensitivity Analysis

Sensitivity Case	**Payback**	**NPV @20%**	**IRR**
1. Base case	1	19,965,919	274.77%
2. Change in sale volume			
+20%	1	25,671,831	335.18%
+10%	1	22,818,875	305.11%
-20%	1	14,260,007	212.85%
-40%	1	8,554,095	147.82%
-60%	2	2,848,183	73.64%
-75%	N.A.	-1,431,251	N.A.
3. Change in Sale Price (Baht/unit)			
-10%	1	8,780,488	150.50%
-15%	2	3,187,773	78.67%
-20%	N.A.	-2,404,943	N.A.
4. Change in Direct cost of product			
10%	1	11,633,444	183.47%
20%	2	3,300,969	80.31%
25%	N.A.	-865,268	N.A.

4.5.5.12 *Worst Case Scenario Exit Strategy*

(1) First Quarter Failure

If the Thai TEG Company Limited fails to sale more than 119 units after the first quarter of the project, the project should be stopped immediately. The company should use price reduction strategy to clear the remaining stocks. Additionally, the asset should also be sold to gain exit cash. After paying liabilities, the company should dissolve itself distributing cash balance as follows:

a) 66% of Cash to Investors
b) 34% of Cash to Founders

(2) Failure after First Quarter

Investors will be investing a total of THB 2,000,000. Thai TEG Company Limited projections show month 3, the first month of sales, as having 1,000 units sold. The resulting cash balance from the very first month of sales is sufficient to payback investors.

Thus, in the event of company not realizing expected projected growth patterns, and not meeting break even points, the company under this worst case scenario can dissolve itself distributing cash balance as follows:

a) Total of ฿2,000,000 to investors or 66.66%.

b) Total of ฿1,000,000 to founders or 33.34%.

c) Remaining sum to be distributed 66.66% to founders and 33.34% to investors.

Thai TEG Company Limited does not expect the worst case scenario to happen, based on the company showing very conservative projections in this plan.

4.5.5.13 Initial Public Offering

The investment of the project coming from founder and investors is THB 3,000,000. Company"s registered capital will be 3,000,000 share, valued at 1.00 baht per share. At the end of year 5, company plans to be listed on the MAI stock market. With earnings per share of 2.31 baht and market price earnings ratio of the current market of 10 times, estimated share price will be 23.10 baht per share.

For the investor, capital gain from initial public offering and five years dividend received from the investment will generate return on investment of 485.28% per year in investing in TEG Company as shown in Table 4.54.

Table 4.54 Initial Public Offering

Investment Offering	**Seed**	**Round 1**	**Round 2**	**Exit**
Proposed Year:	1	2	3	Year 5
Investment, Shares outstanding	3,000,000	0	0	3,000,000
Investment Amount	3,000,000	0	0	
Share Offering Percentage	66.66.%	0.00%	0.00%	
Earnings per share (Baht/share)				2.31
Book value (Baht/share)				13.6
Price/Earnings ratio				10
Expected share price				23.10
Plus 5 Year Dividend (6,500,000)				2.16
Total capital gain Plus dividend				25.26
Average return to investment				485.20%

4.6 Product and Technology Acceptance Evaluation

Qualitative in-depth interview was set up for evaluation via the guideline from TAM. Sample target users or customers were invited as interviewees and were asked for some questions relating to those focused contexts of the product exploitations as listed below.

- Primary market customers: secondary power supply for various electronic gadgets in case of people with high income and like to travel into places with limited or no electricity for more than 2 days in one trip, for several time a year, and usually use multiple PCEDs
- Secondary market customers: government officers whose job requires their position to be located in remote locations, with limited and inconsistent access to standard electrical sources, Border Patrol Police, Rangers, and many other government personnel who are required to patrol vast areas of Thailand, which do not always have reliable and convenient sources of electrical power.
- Additional market customers: upcountry household and community e.g. schools, health stations in off-grid rural areas including people who need a spare personal power supply for their emergencies and sudden needs.

Before evaluating the product and technology, the author had to reveal the information of the product and its contexts of use to clarify question in mind. The illustrating media included:

- A functional charger prototype
- 3D CAD modeling
- Principle schematic and explanation
- Scenario of product utilization
- Scenario for power saving contribution to the nation

The question outline prepared to ask the sample users or customers should be relevant to drill down the key point of each element of TAM as illustrated in Table 4.55. Sample consumers were selected using qualitative purposive sampling relying on people‟s specific favorite on the referred objectives of use. The ten samples were listed in Table 4.56.

Table 4.55 the list of question outlines for qualitative in-depth interview in TAM evaluation

No.	TAM elements	Question outlines
1.	External variables	• What are situations to urge you looking for a reliable secondary power supply to your portable electronic gadgets? • How do you prepare for spared power supply to ensure sufficiency while traveling in nowadays? • What is the impact while you face the problem of insufficient power supply for your necessary gadgets?
2.	Perceived ease of use	• How easy is the utilization of the proposed product? o The use for harvesting electrical charges o The convenience to bring the product for uses • What are your suggestions to improve the function of harvesting electrical charges? o Connectors / ports o Procedure to use o Safety from short circuit / over voltages o Interface / Signal
3.	Perceived usefulness	• How can the product be practically exploited if you owned it? And how necessary is it to use in any case? o Harvesting sufficient electrical charges / secondary power supply/ and others • How much does aesthetic and emotional design impact the value of product? And what is your key criteria for this product design to make it useful? • What is your opinion for supplementary functions e.g. MP3, radio, flashlight? Are they necessary? And what else of function should be added into the product to significantly enhance its value? • How many is your opportunities to harvest electrical charges from this product to your PCEDs? • What is your opinion for situations when the product will be the most useful and practical? Please consider electrical charges, and harvesting scenario.
4.	Attitude toward using	• If you have to decide to buy the product, what is your decision, buying or not? Or what are your specific conditions for the decision? • What is your attitude for this product? As a whole, is this product interesting to use? What are its advantages and disadvantages?
5.	Behavioral intention of use	• What will you bring the product to use in your life if you buy this product? What is your scenario of practical use in your way?

Table 4.56 the sample consumers" characteristics

Sample Consumers	Gender	Age	Preference of potential uses for the product	Market Category		
				primary	secondary	additional
A	Female	24	• Secondary portable power supply for outside applications	✓		
B	Male	20	• Secondary portable power supply for outside applications	✓		
C	Male	32	• Secondary portable power supply for outside applications	✓		
D	Female	45	• Secondary portable power supply for outside applications	✓		
E	Male	42	• Secondary portable power supply for outside applications	✓		
F	Male	50	• Secondary portable power supply for outside applications • Preparation for a power blackout	✓		✓
G	Male	25	• Secondary portable power supply for outside applications especially for duty/ occupation		✓	
H	Female	28	• Secondary portable power supply for outside applications	✓		
I	Female	33	• Secondary portable power supply for outside applications • Preparation for a power blackout	✓		✓
J	Male	36	• Secondary portable power supply for outside applications especially for duty/ occupation		✓	

The results from the in-depth interview were revealed by regarding each variable as follows.

4.6.1 External variables

Due to the fact that the proposed product was for secondary power supply function, this variable indicated the rational or basic mindset of consumers why they favor using this product. External variables that drive the desire of use occur in the specific group of consumers. The reason of use was to obtain the secondary power for their mobile electronic gadgets. The portable purpose was driven from personal character of trekking, occupations, the need of use for secondary power at a power lack condition. In addition, emergency preparation when encountering any disasters was a potential purpose for this category.

As analyzed, the motivation that drives utilization of battery charger stems from activities for consumers. The secondary power supply should fulfill their lives and make them easier for using with reasonable price.

The target customer as analyzed in market plan section identified the group of ecotourism or adventure travelers who love some activities along the trip e.g. photographing, geo-travel, eco-travel, adventure travel, sightseeing for nature, animals, botany etc. including people who work or live in remote areas with a scarcity of electricity to charge their necessary gadgets.

The samples have revealed some useful comment as follows.

- Some travelers or government offices have encountered the adversity to save their personal power for last the duration of availability for their important electronic gadgets e.g. compact cameras, D-SLR cameras, smart phones.
- The average duration for ecotourism spends around 3-5 days per trip (if the trip is needed to go by feet).
- Mostly, in case of 3-5 days trip, nature photographers need to bring secondary battery pack for D-SLR to spare the power supply for sufficient photography.
- Digital compact cameras tend to run out of electric power in shorter time than D-SLR cameras.
- Sometimes, there are some power supply by generators or solar cell panels from the owner of that place to provide wall sockets but mainly in the headquarter. Actually, there may be some further trips to go out of the source of electricity supply, and that is not convenient to recharge the battery for gadgets during trips.
- Smart phones in some areas of no signals are still advantageous for their convenience to use, many useful gadgets e.g. cameras, GPS, games application, media players, etc.
- Some model of mobile phones can transmit signals directly to a satellite especially for military uses. This is very useful if there are some reliable secondary battery and a charger.

- A threat for the researched product is that when a travel is mainly happen by car, the need for secondary power supply or charger is reduced because of 12 VDC power supply available in car.
- Going for a trip in rainy seasons, there may be a big obstacle to use solar charger application owing to cloudy sky.

4.6.2 Perceived ease of use

This variable indicated the attitude toward the product about how easy it is when consumers desire to use it. The product was proposed to bring out flexibility for charging battery by capability to adapt with various sources of heat or coldness e.g. flame, candle, portable stove, food, cooking device, sunlight. There were still some concerns and suggestions for improvements as shown in Table 4.57.

To summarize, 6 out of 10 sample consumers agreed with the judgment of ease of use for this product. It needed the consideration of its portable package, durability for field uses in tough conditions, and flexible for various types of heat power sources.

Table 4.57 the consumers‟ opinions for perceived ease of use

Sample Consumers	Judgments for ease of use	Additional opinions
A	Agree	• It will be more attractive if the fully-charged battery can be brought for portable uses.
B	Agree	• Applicable in urban outdoor application and camping
C	Agree	• Sources of heat are various when going camping e.g. fire from wood and natural solid fuel, and gas lantern. The feature of this product is flexible for those, so it is practical to be applicable for uses in that situation.
D	Disagree	• More than one piece of components to assembly.
E	Disagree	• Still have a solar charger and additional battery pack.
F	Agree	• It can be applicable to use for other urban application as well in the situation of inconvenience to recharge battery from a plug.
G	Agree	• There is a power indicator and charging indicator to inform the power bank status
H	Disagree	• Too many accessories in using for each application; It may be developed for more attraction to minimize their size for portability compared with other products and to add up aesthetic design as well.
I	Agree	• Flexible for uses in many situations and adaptable for various conditions of uses
J	Disagree	• Inconvenient to install and uninstall the required components for each applications

4.6.3 Perceived usefulness

This variable indicated the attitude toward the product about how practical or applicable it is when consumers desire to use it. The sample consumers will be asked if they agreed with the usefulness of the product. There were also some opinions and suggestions for improvements as shown in Table 4.58.

To summarize, 5 out of 10 sample consumers agreed with the judgment of usefulness for this product.

Table 4.58 the consumers‟ opinions for perceived usefulness

Sample Consumers	Judgments for usefulness	Additional opinions
A	Disagree	• Personally, consumer A is not addicted to smart gadgets, social network and sometimes go camping with friends, not a very favorite hobby, so there is no need for secondary power supply, and considering for its high price.
B	Agree	• It is practical for outdoor applications. • Multipurpose gadget products
C	Agree	• It is a useful alternative for charging batteries of all gadgets when camping with various thermal power sources. • There are some gadgets consuming electrical power that have to use during the trip e.g. smart phone, portable GPS, wireless communication equipments, D-SLR camera, compact camera, and so on. Therefore, the product from the research is desired especially by the condition as stated.
D	Disagree	• Mostly going with husband by car, so all PCEDs can be charged from 12 VDC power supply. • High price compared with secondary battery
E	Disagree	• He suggested that foreign market in some countries with more disasters or emergency events in Thailand e.g. the USA, Japan, Philippines, Africa, may be more potential and wider than Thailand, and people tend to perceive more usefulness of this product.
F	Agree	• Very useful to generate secondary power supply during a power blackout situation. • Secondary power supply for charging some daily-used gadgets instead of wall chargers.
G	Agree	• Very useful, especially for some gadgets e.g. a digital compact camera, a camcorder, a GPS when taking a long trip with a scarcity of electricity
H	Disagree	• Higher price compared with some substituting products and no need to use it to produce electricity. • There are currently various capacities of electric power bank to be selected.
I	Agree	• Flexible and adaptable product using with various situations • Maybe not only suitable for those who go out to remote area but also for those who want to collect power anywhere as another spared power bank. It can be used in any inconvenient situations of inaccessibility to a wall socket.
J	Disagree	• Normally, a few spare batteries can be used instead of this equipment. • Maybe it works for the approach to tap energy from surrounding to keep as a personal spare power when necessary to use.

4.6.4 Attitude towards using

This variable indicated the attitude about the overall product and that leaded to an interest and a decision making to buy the product or not. There were also some opinions and conditions for buying by the sample consumers as shown in Table 4.59.

To summarize, 6 out of 10 sample consumers decided to buy this product but with some conditions of further improvements. The reasons about ease of use, charging function (perceived usefulness), and reasonable price were the fundamental criteria for consumers to decide to buy or not.

Table 4.59 the consumers‟ decision for buying the product

Sample Consumers	Decision for buying	Reasons for buying decision			Conditions of improvements for buying decision
		Charger function	Ease of use	Reasonable Price	
A	Do not buy				• Should reduce the cost for production
B	Buy	✓	✓		• Reliable and various applications
C	Buy	✓	✓		• Good to respond a need for secondary power supply
D	Do not buy				• Prefer more ease of use when bring out the portable power supply parts to use
E	Do not buy				• Prefer more compact design for portable applications • Prefer cheaper price
F	Buy	✓	✓	✓	• Alternative for emergency case • Various applications
G	Buy	✓	✓		• Prefer more efficiency for low-temperature energy harvest
H	Do not buy				• Prefer cheaper price, • Prefer smaller size
I	Buy	✓	✓	✓	• Respond a need for secondary power supply while trekking or inconvenience to access a wall socket
J	Buy	✓	✓		• Environmental-friendly product used as a spare power bank for some necessary situations

4.6.5 Consumer‟s buying behavior analysis

From Table 4.59, buying behavior was traced back to some potential groups in consumer classification. Gender of the samples revealed the distinction between male or female‟s buying decision as shown in Figure 4.44. There were 83.33% of male samples who decided to buy the product, whereas only 25% of female samples decided to buy it. This implied more attractiveness for male than for female consumers.

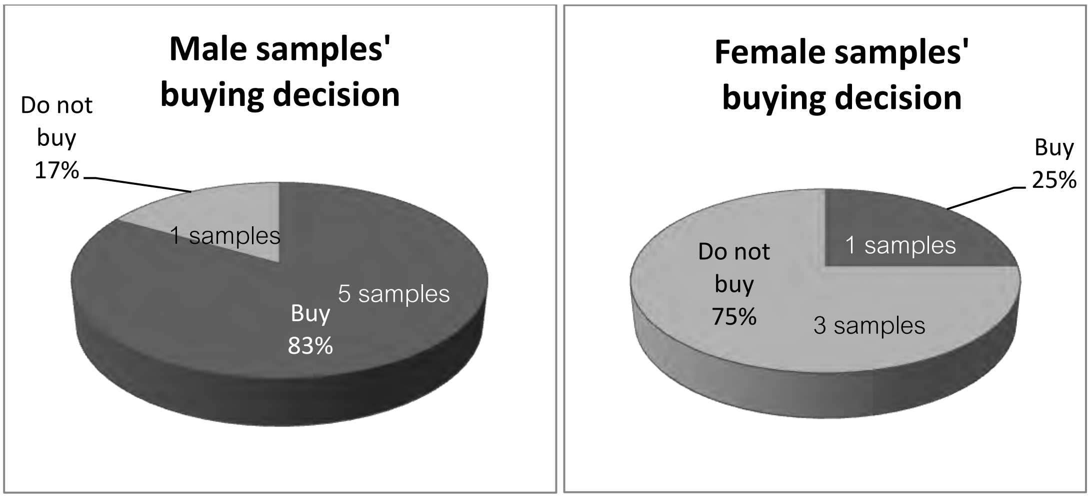


Figure 4.44 Samples‟ buying decision for the research product classified by gender

Table 4.60 rearranged the overall factors relating to buying decision as shown. Regarding the target groups from the 10 samples, there were 6 and 2 samples that were purely categorized in the primary and secondary market customers, whereas the rest 2 samples were both categorized in both the primary and addition market customers. Of the 8 samples of the primary target customers, there were 4 samples (50%) decided to buy the product, but all samples of secondary and additional target customers decided to buy it. This implied a dropping number of the primary market size to be considered in project valuation, and the disadvantages were mainly revealed for their more expensive price compared with other substitutions, the need for more compact design, and fewer compositions to be connected. Fortunately, due to the distinctive feature of the product in low starting temperature difference for battery charging, the samples of additional market customers were interested to buy the product to serve their additional need of a spare power supply for PCEDs especially in case of emergencies or inconvenience, with reasonable price for its value. This implied the potential market to boost sales and revenue from the product, and further product development was needed to respond customers with more attractive features of uses. In addition, the samples of secondary market customers decided to buy the product as a spare power supply to serve some necessary situations but to be procured by their original affiliations.

Table 4.60 The overall factors relating to buying decision for all samples

Sample Consumers	Gender	Age	Market Category			Buying Decision	Reasons of buying			Concerns
			Primary	Secondary	Additional		function	Ease	Price	
B	Male	20	✓			Buy	✓	✓		Reliable and various applications
C	Male	32	✓			Buy	✓	✓		Good to respond a need for secondary power supply
F	Male	50	✓		✓	Buy	✓	✓	✓	• Alternative for emergency case • Various applications
G	Male	25		✓		Buy	✓	✓		Prefer more efficiency for low- temperature energy harvest
J	Male	36		✓		Buy	✓	✓		Environmental-friendly product used as a spare power bank for some necessary situations
I	Female	33	✓		✓	Buy	✓	✓	✓	Respond a need for secondary power supply while trekking or inconvenience to access a wall socket
E	Male	42	✓			Do not buy				• Prefer more compact design for portable applications • Prefer cheaper price
A	Female	24	✓			Do not buy				Should reduce the cost for production
H	Female	28	✓			Do not buy				• Prefer cheaper price, • Prefer smaller size
D	Female	45	✓			Do not buy				Prefer more ease of use when bringing out the portable power supply parts to use

Chapter V
Conclusion and Future Works

5.1 Comprehensive Conclusion Remarks

Due to global contexts and consumer‟s trend in Thailand for TEG technology, this research, primarily focusing on the metropolitan market in Thailand, aimed at the insight of thermoelectric generators" (TEGs‟) potential commercialization as PCED‟s power supply. The research was composed of 3 phases i.e. (1) feasibility study phase; (2) new product development phase; and (3) commercialization phase.

5.1.1 Feasibility Study Phase

In the initial phase, the author has studied technical feasibility of its applications for PCED power supply, and market attractiveness in Thailand as a guideline to design the product further.

Technical assessment revealed output ranges, opportunities, and limitations of TEG for focused applications. Four TE modules from Ferrotech corporation with all 508 couples and 63.04-sq.cm surface area per a side were used as TEG applications. Technically, the outputs from the experiments ranged from 2.1 mW to 100.8 mW and from 0.16 V to 1.08 V for the maximum electrical power outputs and the most practical operating voltage respectively, based on various actual situations of daily lives with highest temperature differential of 95°C. The Seebeck coefficient (α) was calculated for the number of all 508 couples of TE elements in 4 TE modules, to be 46 ±1 μV/°C for each couple. The average effective figure of merit of 0.40 and 0.32 of TE module with cold-side temperature of 0 and 27 ◦C respectively are still significantly lower than the predicted value of around 0.66. However, the thermal-to-electric efficiencies and the figures of merit from the experiments remained lower than those of the predicted state-of-the-art value. All passive losses and heat transfer qualification are main considerations for commercial product design with better qualifications.

For the market attractiveness, based on the secondary data analysis from literature and the National Statistical Office of Thailand, quantitative analysis was applied using the cluster probability sampling methodology, statistically, with the sample size of 400 at 0.05 level of significance. The market study recommended 12 target applications of PCEDs e.g. smart phones, mobile phones, digital cameras, D-SLR cameras, and so on, which had market potentials and were adaptable by current TEG technology. The power recovery resulted from 11 potential heat sources or sinks such as direct sunlight, laptop computers, hot / cold beverage cup, and so on, was significantly related to the population. From the correlations analysis, two correlating factors were implied to find out some categories that were favourable or the most related ones to focus on the further product design, whereas those without correlation expressed no differences in all categories.

As the problems of power supply lacking were analyzed, inconvenience to find a power source to recharge PCEDs, inflexibility to prepare various chargers while travelling, inflexibility to manage power for gadgets, deterioration of a battery, and inconvenience to wire an electrical cable plug „often" impact on users statistically in descending order, and needed to be served to satisfy those PCEDs" users by a novel universal power supply. Those 5 items with impact level of "often impact" would be a recommendation for further product conceptual design. The customer response for serving requirement implied the intention to buy innovative power supply product with the portion of 86.3% of all the sample, but to consider the purchasing decision factor with „the most important" level from the results.

In addition, the qualitative analysis was conducted to emphasize the rationale of consumer's behaviour using in-depth qualitative interview for their PCED utilization patterns, power supply lacking problems, and encountering heat sources or sinks. Due to the limitations of power outputs and energy conversion efficiencies for current TEG-based technology as shown in the research, a fully-charging process is not applicable, but the optimal TEG application is to enhance battery power or to last battery"s operating period longer depending on convenient surrounding heat and temperature differentials.

5.1.2 New Product Development Phase

In the second phase, product and production design was done to compile all backgrounds from feasibility studies to exploit. QFD was used to transfer the information about customer requirements of a desired product or "voices of customers" from the market attractiveness study into technical requirements for the product design. Six criteria of the first-half ranking technical requirements for the product design were sorted by their weight of importance as follows: (1) the number of power input sources; (2) satisfactory power output and efficiency; (3) a battery capacity (4) illuminated charging status signal; (5) sufficient indicator of power level; and (6) equipment weight. TRIZ physical contradiction principle was used to solve the contradiction problem of relating 4 factors i.e. equipment weight, surface area, satisfactory output power & efficiency, and materials & process unit cost. Separation principle was applied to those contradictions and composed of 4 approach i.e. area separation, time separation, parts-and-the-whole separation, and conditional separation. Therefore, the design was guided to separately analyze for each case of usage context.

Prior to DFMA execution, other substituted products were analyzed for their pros and cons compared with TEG based power supply to focus the gap to develop the product into the right way. An option for commercialization was designed and proposed based on those product development guidelines and included a TEG-based power supply product. Materials and processing for each project were defined matching each product design concept.

TEG-based power supply prototype was evaluated for its characteristics via 5 conditions of uses and obtained the maximum power of 4.82 W (charging by the heat source of hot pan burned by LPG stove). The result also revealed the capability to charge with low temperature differences as for the lowest minimum starting temperature differential of 26°C. From the study of the research prototype characteristics and those of other example competitive product, two competitive potential products of TEG-based chargers were selected to test and compare functional characteristics with the research prototype i.e. the PowerPot V and tPOD5. The specification comparison was summarized as follows in Table 5.1. As the same condition of charging was defined, the research prototype finished charging Li-ion Battery faster than the competitive product of about 15.8-25.4% with 30.3-41.4% higher maximum power, but with 5.7-13.2% lower maximum power per unit area.

Table 5.1 A summary of product specification comparison for TEG-based power supply

No.	Criteria	TEG Commercial Product		
		The PowerPot V	tPOD5	IndyPoww
1	Maximum Regulator Voltage (nominal/actual)	5 VDC / 4.89 VDC	5 VDC/ 5.30 VDC	5 VDC/ 5.02 VDC
2	Maximum Regulator Current	1A	1A	1A
3	Maximum Power	5W	5W	5W / 4.82W
4	Weight	PowerPot: 343g Regulator: 71g Total Weight with Lid & Regulator: 516 g	1304.1 g	500g (Total weight)
5	Size /Dimension	1.4 litre, ϕ4.5” x 5.5” or ϕ4.5” x 8” with lid	ϕ7” x 3-3/4”	140.0 × 80.0 × 5.0 mm for TEG module and 75.0 × 60.0 × 24.0 mm for Charge Controller Box, Connected by USB wiring integrated in a reel
6	Generator Type	2 TE Modules Bi_2Te_3 (40.0x40.0x4.0 mm, 127 couples)	2 TE Modules Bi_2Te_3 (40.0x40.0x4.0 mm, 127 couples)	3 TE Modules Bi_2Te_3 (40.0x40.0x4.0 mm, 127 couples)
	Cooling Type	Water	Fan-cooled	Water / Air
7	Heat / Coldness Source	Fire/ Stove	Fire/ Stove	Fire/ Stove/ Cooking Devices / Direct Sunlight / Hot or Cold Beverage Cup / Food Container
8	Highest Operating Temperature	250 °C	250 °C	250 °C
9	Lowest Starting Temperature Differential to enable charging	120 °C (approx.)	170 °C (approx.)	26 °C (approx.)
10	Charging Output	5V USB 2.0 Connector	5V USB 2.0 Connector	5V USB 2.0 Connector
11	Current Price	US$ 172.50 (Shipping included)	US$ 192.45 (Shipping included)	THB 2,500.00 (Shipping included)
11	Accessories	Bowl Lid / 5V Power Regulator with 3" Fire-Resistant Cable and USB Plug	5V Power Regulator with 3" Fire-Resistant Cable and USB Plug	Heat Sink Module / Green House Module / Waste Heat Trap Module/ Regulator Module

5.1.3 Commercialization Phase

In the last phase, the business plan for the most attractive project was conducted using the past information from the research. Marketing plan, manufacturing and operational plan, and financial plan were proposed for direction of commercialization.

Potential customers to buy the product were categorized into 3 groups i.e. (1) primary target for the people who like travelling into places with a scarcity of electrical power supply; (2) secondary target for government officers whose job requires their position to be located in remote locations, with limited and inconsistent access to standard electrical sources; and (3) additional target for upcountry household and community in off-grid rural areas including people who need a spare personal power supply for their emergencies and sudden needs.

Financial plan was conducted for its feasibility to invest the project using discounted cash flow (DCF) method. As a result, the project was attractive for NPV of THB 19,965,919, IRR of 274.77% with the most rapid payback period of 1 year. Sensitivity analysis revealed that a change in price of product (not allowed for more than a -15% reduction of the base price) and direct product cost (not allowed for more than a +20% increase) are the most two sensitive factors in descending order. The negative volume sale change is the least effect to the project (acceptable down to a -60% reduction). In contrast, the positive volume sale change implies an impact from additional target penetration, and that will cause more satisfactory financial outcome.

To ensure that the product was practical for consumers, to verify potential commercialization, and to explore additional improvement aspects, TAM was applied via qualitative in-depth interview with purposive sampling for 10 sample target consumers with different backgrounds. The purposes of uses for the product could be verified for portable power supply. The result revealed that 6 out of 10 sample consumers agreed with the judgment of ease of use for this product, 5 out of 10 sample consumers agreed with the judgment of usefulness for this product, and 6 out of 10 sample consumers decided to buy this product but with some conditions of further improvements. The reasons about ease of use and reasonable price were the fundamental criteria for consumers to decide to buy or not. The attractive features and suggestions for further improvements were summarized in Table 5.2.

Table 5.2 A summary of attractive features of the product and suggestions for further improvements considered by the sample users

Attractive features from the product	Suggestions for further improvements
1) Environmentally-friendly concept for a power bank 2) New experience to harvest energy 3) Reliability for power source in outdoor applications 4) Flexibility to charge from various heat source and temperature differences 5) Alternative for emergency cases 6) Able to use in the concept of accumulating energy collection in daily life as a spare electrical power supply	1) Reducing price 2) More compact and smaller size compared with other competitive product 3) Reducing the number of part compositions 4) Enhancing efficiency for low-temperature energy harvest 5) Expanding into more general PCED market for those who needed spare power bank for any situations with inconvenience to access electrical power

In conclusion, there was consideration to address the target market groups of which customers tend to buy the research product as follows.

1.) Male customers are aimed to address more than females by 83% and 25% of the number of target group for males and females respectively.

2.) The samples of primary market customers decided not to buy the product mainly because they thought it is too expensive for their necessities and compared with other substituting products.

3.) The samples of additional market customers felt it was worth buying to serve their needs, especially for emergencies or inconvenience of power supply lack.

4.) The samples of secondary market customers felt it necessary to obtain the product but the price is not attractive for a personal purchase. They wished their original affiliations to buy for them, so the salespersons will have to negotiate with purchasing departments for market penetration further.

5.) To address the primary market customers especially for women, the more compact size and the various features but easy to use are to be considered.

6.) By generating needs for the customers in the primary target market or even general PCED users to be risen in the additional target group, the product will be more attractive in the marketplace.

5.2 Innovation Outcome from the Research

The innovation synthesized from this research was TEG-based power supply for PCEDs which is mainly used waste heat sources from surroundings. The type of innovation could be defined as "architectural innovation" because the modules or elements of the product came from existing technology with some improvements, but were linked for a new configuration or system to support a new marketplace. Regarding substituting products, there are some current commercial products sold in marketplace e.g. solar chargers, electric external batteries or power banks, motion chargers, and TEG-based power supply. A distinctive advantage for the researched product compared with the other substitutions is reliability of power supply for portable uses especially in the condition of no electricity supply and inconsistent sunlight.

To commercialize the product, the potential product concepts for commercialization were the portable and flexible purpose. The commercialized product for PCED market consisted of 8 components as follows: (1) TE modules, (2) solar thermal power input, (3) waste-heat trap module, (4) heat sink module, (5) charge controller circuit, (6) battery module, (7) adapter set, and (8) packaging. The product was intended to support the various approach to harvest heat from consumers" daily life i.e. (1) waste heat from surroundings; (2) heat from direct sunlight; and (3) deliberate heat sources. The product was mainly defined to serve the primary and secondary market of travellers and government officers in remote area respectively. Owing to the outstanding feature in lower temperature difference and the suggestions from sample users in TAM verification, target market would be expanded to cover PCED users with the problem of inconvenience to access electrical power in daily life, the need for spare power collection and harvesting free energy from surrounding waste heat, or even people living in the area with a scarcity of electricity as well.

In summary, although TEG-based power supply products were available in the world market and not widely diffused in Thailand, the product innovation from this research provided new features that fitted the niche to serve target customer needs in Thailand. The research prototype outperformed the other competitive products with attractive features as follows.

1.) The power transformation capability in the range of uses
2.) Quicker time for charging electricity compared with direct competitors
3.) Lighter weight and compact for portable
4.) Various application heat / coldness sources, even passive ones, and flexible to obtain power
5.) Enable to collect power from passive low-power sources of heat / coldness down to starting temperature difference of 26°C.
6.) Battery provided with the product concept of harvesting and collecting energy as much and often as possible to be ready to use
7.) More waste heat recovered thus able to claimed of environmentally-friendly product to save the world

5.3 Future Works of Product Developments

The future researches will be recommended for some TEG applications especially in the near future which TE materials have been continuously improved for their thermal-to-electric efficiency, their form, and cost reduction for more competitive. The design optimization for commercialized products is more useful to drive this technology and is the gap to improve TEG-based power supply product further. This research demonstrated application guidelines of commercialized TEG-based power supply for PCEDs in Thailand"s metropolitan market. Therefore, it is applicable for other geographical areas but with thorough and specific market consideration including financial feasibility in order to serve consumer requirements effectively and ensure a successful green energy innovation as well.

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Appendices

Appendix A

The Questionnaire form for the Business Research in Metropolitan Market in Thailand

แบบสอบถามเพื่อการพัฒนาผลิตภัณฑ์ใหม่ที่เป็นมิตรกับสิ่งแวดล้อม

เรื่อง ความต้องการใช้แหล่งจ่ายพลังงานไฟฟ้าสำรองซึ่งชาร์จไฟด้วยเทคโนโลยีเทอร์โมอิเล็กทริก สำหรับอุปกรณ์อิเล็กทรอนิกส์แบบพกพา

บทนำ

ปัจจุบัน วัฒนธรรมด้านการสื่อสารที่ก่อเกิดกระแสนิยมของสังคมออนไลน์อย่างแพร่หลาย เป็นผลให้อุปกรณ์อิเล็กทรอนิกส์แบบพกพามีการขยายตัวอย่างรวดเร็วในตลาดของผลิตภัณฑ์ผู้บริโภค (Consumer Products) อย่างไรก็ดี แบตเตอรี่ซึ่งถือเป็น แหล่งพลังงานหลักนั้นยังมีข้อจำกัดในการใช้งานและสร้างผลกระทบต่อสิ่งแวดล้อมอย่างหลีกเลี่ยงมิได้ ***เทอร์โมอิเล็กทริก*** เป็นอีกหนึ่งเทคโนโลยีพลังงานทดแทนที่สามารถแปลงพลังงานความร้อนเหลือทิ้งให้กลายเป็นพลังงานไฟฟ้าได้ จึงสามารถช่วยเสริมศักยภาพของแบตเตอรี่ให้ดียิ่งขึ้น แต่ยังจำเป็นต้องมีการออกแบบให้เหมาะกับสภาวะ รูปแบบ และข้อจำกัดในการใช้งานของผู้บริโภคเป็นสำคัญ ฉะนั้น แบบสอบถามฉบับนี้ จึงช่วยวิเคราะห์ประเด็นการใช้งานที่เกี่ยวข้องกับผู้บริโภค เพื่อนำไปพัฒนาผลิตภัณฑ์ที่เป็นประโยชน์และตรงตามความต้องการต่อไป โดยถือเป็นส่วนหนึ่งของการทำวิจัยระดับปริญญาเอก หลักสูตรธุรกิจเทคโนโลยีและการจัดการนวัตกรรม จุฬาลงกรณ์มหาวิทยาลัย ทั้งนี้ผู้จัดทำขอรับรองว่าจะไม่นำข้อมูลที่ท่านไว้วางใจตอบเราไปเผยแพร่ไม่ว่ากรณีใดทั้งสิ้น

นอกจากนี้ แบบสอบถามที่ท่านได้กรอกทุกฉบับถือเป็นการร่วมบริจาคเงินทำบุญกุศลอีกด้วย ***โดยแบบสอบถามทุกฉบับ จะสมทบทุนบริจาคเงินทำบุญ 5 บาทต่อฉบับ เข้าไปที่มูลนิธิช่วยเหลือสังคมตามที่ท่านประสงค์*** จึงขอความกรุณาทุกท่านโปรดเสียสละเวลาอันมีค่าเพื่อตอบแบบสอบถามตามความเป็นจริงให้ครบถ้วนต่อไป

ด้วยความขอบพระคุณเป็นอย่างสูง และขออนุโมทนาในผลบุญที่ท่านได้มีส่วนร่วมในครั้งนี้

วัตถุประสงค์ของการสำรวจ

1. เพื่อระบุแนวทางความต้องการใช้งานอุปกรณ์อิเล็กทรอนิกส์แบบพกพาของผู้บริโภคในกลุ่มย่อยต่างๆ และปัญหาปัจจุบันที่เกี่ยวกับพลังงานจากแบตเตอรี่
2. เพื่อระบุความต้องการที่จะทำให้เกิดการพัฒนาแหล่งจ่ายพลังงานรูปแบบใหม่ที่ตอบสนองรูปแบบการใช้ชีวิตของผู้บริโภคในกลุ่มย่อยต่างๆ ได้ดียิ่งขึ้น
3. เพื่อพิจารณาสภาวะ รูปแบบการใช้ชีวิตของผู้บริโภค ที่เกี่ยวข้องกับสิ่งรอบตัวซึ่งมีผลต่างของอุณหภูมิ ที่ส่งผลถึงศักยภาพของการนำเทคโนโลยีเทอร์โมอิเล็กทริก ซึ่งทำให้เกิดกระแสไฟฟ้าด้วยผลต่างของอุณหภูมิ มาใช้ให้เกิดประโยชน์สูงสุดในการผลิตไฟฟ้าสำรองให้แก่อุปกรณ์อิเล็กทรอนิกส์เหล่านั้น
4. เพื่อวิเคราะห์ความสัมพันธ์เกี่ยวกับปัจจัยด้านลักษณะเฉพาะตัวของผู้บริโภคในแต่ละกลุ่ม ที่มีผลต่อความจำเป็นหรือความต้องการในการเลือกซื้อแหล่งจ่ายพลังงานไฟฟ้าสำรอง
5. เพื่อประเมินตลาดเฉพาะด้าน (Niche) ที่มีศักยภาพสำหรับการพัฒนาผลิตภัณฑ์แหล่งจ่ายพลังงานไฟฟ้าสำรองที่ชาร์จไฟฟ้าด้วยเทคโนโลยีเทอร์โมอิเล็กทริก นำไปสู่การสร้างนวัตกรรมผลิตภัณฑ์

ความประสงค์ของท่านในการสมทบทุนร่วมบริจาคไปยังมูลนิธิช่วยเหลือสังคม

<u>**คำอธิบาย**</u> โปรดระบุชื่อมูลนิธิ ที่ท่านประสงค์จะบริจาคเงิน โดยทำเครื่องหมาย √ ลงในช่อง ☐ ด้านหน้าข้อที่ท่านต้องการเพียงข้อเดียว โดย<u>***แบบสอบถามที่ท่านกรอกอย่างบริบูรณ์จะสมทบทุนบริจาค 5 บาทต่อฉบับ แก่มูลนิธิที่ท่านเลือก***</u>

☐ มูลนิธิชัยพัฒนา (ช่วยเหลือประเทศชาติและสังคม) ☐ มูลนิธิสงเคราะห์เด็กอ่อนพิการทางสมองและปัญญา

☐ สภากาชาดไทย (ช่วยเหลือเพื่อนมนุษย์) ☐ มูลนิธิบ้านสงเคราะห์สัตว์พิการ

ส่วนที่ 1: ข้อมูลเกี่ยวกับผู้ตอบแบบสอบถาม

<u>**คำอธิบาย:**</u> กรุณากรอกรายละเอียดให้ครบถ้วน โดย<u>ทำเครื่องหมาย √</u> หรือ<u>ใส่หมายเลข (เฉพาะข้อ 6)</u> ลงในช่อง ☐

1. **เพศ**: ☐ ชาย ☐ หญิง

2. **อายุ**: ☐ ต่ำกว่า 20 ปี ☐ 20-39 ปี ☐ 40-59 ปี ☐ 60 ปีขึ้นไป

3. **รายได้เฉลี่ยต่อเดือน**: ☐ ไม่มีรายได้ ☐ มีรายได้ไม่เกิน 5,000 บาท/เดือน ☐ 5,001 – 10,000 บาท / เดือน ☐ 10,001-30,000 บาท / เดือน ☐ 30,001-50,000 บาท / เดือน ☐ 50,001-100,000 บาท / เดือน ☐ มากกว่า 100,000 บาท / เดือน

4. **อาชีพหลักหรือลักษณะงานหลักที่ทำอยู่** (เลือกตอบเพียง 1 ข้อที่ตรงกับตัวท่านมากที่สุด)

☐ นักเรียน / นักศึกษา ☐ ข้าราชการตำรวจ / ทหาร ☐ ข้าราชการทั่วไป / พนักงานรัฐวิสาหกิจ / ลูกจ้าง ☐ ครูอาจารย์สอนในโรงเรียน ☐ อาจารย์มหาวิทยาลัย ☐ บุคลากรด้านการแพทย์
☐ วิศวกร/สถาปนิก ☐ ผู้ปฏิบัติงานโครงการ/ งานนอกสถานที่ ☐ ผู้ปฏิบัติงานภายในโรงงานอุตสาหกรรม
☐ สื่อสารมวลชน ☐ บุคลากรด้านการบินและอากาศยาน ☐ เลขานุการ ☐ ผู้เกษียณอายุราชการ
☐ ผู้บริหารทั่วไป ☐ พนักงานบริษัท/ลูกจ้าง ☐ ค้าขาย ☐ เกษตรกร
☐ ศิลปิน ☐ เจ้าของกิจการ ☐ รับจ้าง / Freelance / อาชีพอิสระ ☐ อื่นๆ ระบุ
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5. **กิจกรรมยามว่างหรืองานอดิเรกที่โปรดปราน** (เลือกตอบได้มากกว่า 1 ข้อที่ท่านชอบ และ<u>***โปรดเรียงลำดับ***</u>ตามความชอบโดย<u>***ใส่ตัวเลขอันดับ*** ตั้งแต่ 1 เป็นต้นไป ลงในช่อง ☐ จนครบตามที่ชอบ</u>)

☐ ออกกำลังกาย / เล่นกีฬา ☐ ท่องเที่ยว ☐ เดินป่า / พักแรม ☐ ถ่ายภาพ / วาดรูป
☐ หาของอร่อยทาน ☐ ทำอาหาร ☐ เข้าวัด / ปฏิบัติธรรม ☐ สังสรรค์ในหมู่เพื่อน
☐ ช้อปปิ้ง ☐ ท่องอินเตอร์เน็ต / สังคมออนไลน์ ☐ เล่นเกม ☐ ชมภาพยนตร์ / มหรสพ / ฟังเพลง
☐ ร้องเพลง / เล่นดนตรี ☐ ปลูกต้นไม้ / เลี้ยงสัตว์ ☐ อ่านหนังสือ ☐ นวด / สปา (Spa)
☐ อื่นๆ ระบุ...

ส่วนที่ 2: ข้อมูลการใช้งานอุปกรณ์อิเล็กทรอนิกส์แบบพกพา ปัญหาที่พบด้านพลังงานไฟฟ้า และวิถีชีวิตของท่านที่เกี่ยวข้อง

6. ลักษณะการใช้งานอุปกรณ์อิเล็กทรอนิกส์แบบพกพา

คำอธิบาย เลือกตอบได้มากกว่า 1 ข้อเฉพาะอุปกรณ์ที่ท่านใช้งานอยู่จริง และ***โปรดเรียงลำดับ***ตาม***ความถี่หรือความบ่อยครั้ง*** โดย***ใส่หมายเลขอันดับ*** ลงในช่อง ☐ หน้าหัวข้ออุปกรณ์ ตั้งแต่หมายเลข 1 สำหรับอุปกรณ์ที่ใช้งานบ่อยครั้งที่สุด ไล่หมายเลขอันดับไปจนครบตามที่ท่านมีใช้งานจริง

- ☐ สมาร์ทโฟน เช่น I-Phone, BB, Android
- ☐ โทรศัพท์มือถือทั่วไป
- ☐ Tablet PC เช่น I-Pad, Galaxy Tab
- ☐ GPS พกพา
- ☐ คอมพิวเตอร์โน้ตบุ๊ค / Laptop
- ☐ คอมพิวเตอร์พกพาขนาดเล็ก / PDA / Pocket PC
- ☐ ชุดหูฟังบลูทูธ
- ☐ เกมส์พกพา
- ☐ กล้องถ่าย รูปดิจิตอลทั่วไป(ชนิด Compact)
- ☐ กล้องถ่ายรูป D-SLR (เปลี่ยนเลนส์ได้)
- ☐ เครื่องเล่น CD/MP3/ IPOD แบบไม่มีจอภาพ
- ☐ เครื่องบันทึกเสียง/อัดเสียงพกพา
- ☐ เครื่องเล่น Video /DVD/ IPOD มีจอภาพ/ MP4 / TV พกพา
- ☐ กล้องถ่ายวีดีโอ (Camcorder)
- ☐ ไฟฉายขนาดเล็ก
- ☐ อื่นๆระบุ…..

7. ปัญหาด้านแหล่งจ่ายพลังงานไฟฟ้าสำหรับอุปกรณ์อิเล็กทรอนิกส์เคลื่อนที่

7.1 **คำอธิบาย** กรุณาระบุผลกระทบจากปัญหาที่ประสบเกี่ยวกับกรณีแหล่งจ่ายไฟฟ้าไม่เพียงพอสำหรับการใช้งานอุปกรณ์อิเล็กทรอนิกส์แบบพกพาเหล่านั้น โดย***ทำเครื่องหมายวงกลมล้อมรอบระดับคะแนน***ตามความคิดเห็นของท่าน (แนะนำให้พิจารณาผลกระทบต่อตัวท่านด้าน*ความถี่ของปัญหา* ว่าปัญหาเกิดบ่อยเพียงใดและด้าน*ความยุ่งยากของปัญหา* ว่าทำให้เกิดความยุ่งยากมากน้อยเพียงใดประกอบกัน เมื่อกำหนดให้ระดับ 5 คือมากที่สุด และระดับ 1 คือ น้อยที่สุด)

No.	ปัญหาที่พบ	ผลกระทบจากปัญหาต่อตัวท่าน				
		5 มากที่สุด	4 มาก	3 บางครั้ง	2 น้อย	1 น้อยที่สุด
7.1.1	ความไม่สะดวกในการพกพาที่ชาร์จแบตเตอรี่หลายๆ อย่าง ขณะเดินทาง	5	4	3	2	1
7.1.2	ความไม่สะดวกในการหาปลั๊กไฟฟ้าเพื่อใช้หรือชาร์จไฟในบางแห่ง	5	4	3	2	1
7.1.3	ปัญหาในการเตรียม Adapter แปลงแรงดันและหัวปลั๊กไฟฟ้าในการนำอุปกรณ์ไปใช้งานต่างประเทศ	5	4	3	2	1
7.1.4	คาดการณ์เวลาใช้งานที่เหลืออยู่ของแบตเตอรี่ได้ยากจากภาระและรูปแบบการใช้งานที่ไม่แน่นอน	5	4	3	2	1
7.1.5	แบตเตอรี่หรืออุปกรณ์ชาร์จเสื่อมสภาพ ทำให้ชาร์จไฟไม่เข้า หรือแบตเตอรี่ไฟหมดเร็ว	5	4	3	2	1
7.1.6	แบตเตอรี่หรืออุปกรณ์ชาร์จแพง หากเสื่อมสภาพแล้วต้องเปลี่ยนใหม่อาจพิจารณาซื้อเครื่องใหม่จะคุ้มค่ากว่า ดังนั้น ถ้าแบตเตอรี่มีอายุการใช้งานยาวนานขึ้นก็จะช่วยลดค่าใช้จ่ายในการเปลี่ยนอุปกรณ์ได้	5	4	3	2	1

No.	ปัญหาที่พบ	ผลกระทบจากปัญหาต่อตัวท่าน				
		5 มากที่สุด	4 มาก	3 บางครั้ง	2 น้อย	1 น้อยที่สุด
7.1.7	ความไม่สะดวกในการลากสายไฟเสียบปลั๊กเพื่อใช้ไฟฟ้าหรือชาร์จแบตเตอรี่ในบางสถานการณ์ เช่น การประชุม การทำกิจกรรมที่ต้องย้ายที่บ่อยๆ เป็นต้น	5	4	3	2	1
7.1.8	ความกังวลในการประหยัดไฟฟ้าในแบตเตอรี่สำหรับอุปกรณ์ไฟฟ้าในกรณีที่ต้องเดินทางนอกสถานที่	5	4	3	2	1

7.1.9 โปรดระบุปัญหาอื่นๆที่พบ ความถี่ของปัญหา และความยุ่งยากที่เกิดขึ้นจากปัญหานั้นๆ หรือหากท่าน เคยใช้งาน / กำลังใช้งานแบตเตอรี่สำรองใดๆ อยู่ โปรดระบุปัญหาหรือความลำบากใจของท่านในการใช้งานแบตเตอรี่เหล่านั้น (*ถ้ามี*)

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7.2 **<u>คำอธิบาย</u>** โปรดเรียงลำดับอุปกรณ์อิเล็กทรอนิกส์แบบพกพา ตาม***<u>ระดับปัญหาด้านแหล่งจ่ายไฟฟ้าสำรองที่ท่านพบ</u>*** (เลือกใส่ตัวเลขลำดับเฉพาะที่เกี่ยวข้องกับท่าน และโดย***<u>ใส่ตัวเลขอันดับตั้งแต่ 1 เป็นต้นไป</u>*** ลงในช่อง ☐ <u>สำหรับอุปกรณ์ที่พบปัญหามากที่สุด ตามความรู้สึกของท่าน ไล่ลำดับไปจนครบจำนวนอุปกรณ์ที่ท่านเกี่ยวข้องและรู้สึกว่าพบปัญหา</u>)

☐ สมาร์ทโฟน เช่น I-Phone, BB, Android
☐ โทรศัพท์มือถือทั่วไป
☐ Tablet PC เช่น I-Pad, Galaxy Tab
☐ GPS พกพา
☐ คอมพิวเตอร์โน้ตบุ๊ค / Laptop
☐ คอมพิวเตอร์พกพาขนาดเล็ก / PDA / Pocket PC
☐ ชุดหูฟังบลูทูธ
☐ เกมส์พกพา
☐ กล้องถ่าย รูปดิจิตอลทั่วไป(ชนิด Compact)
☐ กล้องถ่ายรูป D-SLR (เปลี่ยนเลนส์ได้)
☐ เครื่องเล่น CD/MP3/ IPOD แบบไม่มีจอภาพ
☐ เครื่องบันทึกเสียง/อัดเสียงพกพา
☐ เครื่องเล่น Video /DVD/ IPOD มีจอภาพ/ MP4 / TV พกพา
☐ กล้องถ่ายวีดีโอ (Camcorder)
☐ ไฟฉายขนาดเล็ก
☐ อื่นๆระบุ…..

7.3 อุปกรณ์อิเล็กทรอนิกส์ชนิดพกพาอื่นๆใด ที่ท่านใช้งานอยู่บ้าง และปรารถนาให้แบตเตอรี่สามารถจ่ายพลังงานได้ยาวนาน หรือมีสภาวะ / รูปแบบการใช้งานพิเศษของท่านอย่างไรบ้าง (ถ้ามีความเห็นเพิ่มเติม)

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8. แหล่งความร้อนและความเย็นรอบตัวที่มีศักยภาพในการผลิตกระแสไฟฟ้าด้วยเทคโนโลยีเทอร์โมอิเล็กทริก

คำอธิบาย โปรดพิจารณาแหล่งความร้อน / ความเย็นรอบตัวท่านที่ต้องเผชิญ หรือเกี่ยวข้อง หรือใช้งานตามรายการต่อไปนี้ กรุณาระบุระดับความเกี่ยวข้องกับสิ่งเหล่านั้น โดยทำเครื่องหมาย √ หรือ ลงในช่อง ☐ ตามระดับที่เป็นจริงสำหรับท่าน ***แนะนำให้พิจารณาจากเวลาในการใช้ชีวิตที่ท่านต้องเข้าไปเกี่ยวข้องกับสิ่งต่างๆเหล่านี้***

No.	แหล่งความร้อน / ความเย็นรอบตัวท่าน ที่ต้องเผชิญ หรือเกี่ยวข้อง หรือใช้งาน	ระดับการประเมินความเกี่ยวข้องกับตัวท่าน / การใช้ชีวิต				
		เกี่ยวข้อง/ ใช้เป็นประจำ [สัปดาห์ละ 6-7 วัน]	เกี่ยวข้อง/ ใช้อยู่บ่อยๆ [สัปดาห์ละ 3-5 วัน]	เกี่ยวข้อง/ ใช้บ้างเป็นครั้งคราว [สัปดาห์ละ 1-2 วัน]	เกี่ยวข้อง/ ใช้นานๆครั้ง [เดือนละ 1-3 วัน]	ไม่เกี่ยวข้อง/ ไม่เคยใช้
8.1	เครื่องครัว (ขณะทำอาหาร) เช่น กระทะ หม้อ เตา	☐	☐	☐	☐	☐
8.2	ถ้วยบะหมี่กึ่งสำเร็จรูป/ อาหารกล่อง (ที่อาหารสุกแล้ว)	☐	☐	☐	☐	☐
8.3	ถุงใส่อาหารสำเร็จรูป (ร้อน/เย็น)	☐	☐	☐	☐	☐
8.4	ภาชนะร้อน เช่น หม้อสุกี้ ชาบู บาร์บีคิว กระทะร้อน	☐	☐	☐	☐	☐
8.5	ถ้วยไอศกรีม/ ขนมหวาน(เย็น)	☐	☐	☐	☐	☐
8.6	ถ้วย/แก้วเครื่องดื่ม*ร้อน* เช่น ชาร้อน กาแฟร้อน	☐	☐	☐	☐	☐
8.7	จานรองแก้วพกพา (เสียบปลั๊กอุ่นน้ำให้ร้อนเสมอ)	☐	☐	☐	☐	☐
8.8	ถ้วย/แก้วเครื่องดื่ม*เย็น*เช่น น้ำเย็น กาแฟเย็น	☐	☐	☐	☐	☐
8.9	เครื่องปรับอากาศ	☐	☐	☐	☐	☐
8.10	ตู้เย็น	☐	☐	☐	☐	☐
8.11	เครื่องทำน้ำร้อน/ น้ำเย็น	☐	☐	☐	☐	☐
8.12	คอมพิวเตอร์โน้ตบุ๊ค (ความร้อนที่พบจากใต้เครื่อง)	☐	☐	☐	☐	☐
8.13	คอมพิวเตอร์ PC (ความร้อนที่พบจากตัวเครื่อง)	☐	☐	☐	☐	☐
8.14	โทรศัพท์มือถือต่างๆ (ความร้อนสะสมจากตัวเครื่อง)	☐	☐	☐	☐	☐
8.15	เครื่องฉาย LCD Projector (ความร้อนสะสมที่เครื่อง)	☐	☐	☐	☐	☐
8.16	รถยนต์ (ความร้อน/เย็นจากภายใน/นอกรถยนต์)	☐	☐	☐	☐	☐
8.17	ไฟแช็ค (กรณีที่ท่านพกติดตัว)	☐	☐	☐	☐	☐
8.18	บุหรี่ (ความร้อนจากก้นบุหรี่ที่ท่านสูบเอง)	☐	☐	☐	☐	☐
8.19	ความร้อนจากแสงอาทิตย์	☐	☐	☐	☐	☐
8.20	เทียน / ธูป (กรณีที่มีการจุด)	☐	☐	☐	☐	☐
8.21	กระเป๋าน้ำร้อนแก้ปวดหลัง/ ปวดประจำเดือน	☐	☐	☐	☐	☐
8.22	อื่นๆ ระบุ	☐	☐	☐	☐	☐

8.23 โปรดระบุแหล่งความร้อน / ความเย็นรอบตัวอื่นๆที่พบ ความถี่ และรูปแบบชีวิตที่ท่านประสบพบเจอ (*ถ้ามีเพิ่มเติม*)

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.ส่วนที่ 3: ข้อมูลเกี่ยวกับรูปแบบผลิตภัณฑ์จ่ายไฟฟ้าสำรองแบบพกพาซึ่งเป็นที่ต้องการของท่าน

9. ความสนใจเลือกซื้อแหล่งจ่ายไฟฟ้าสำรองสำหรับอุปกรณ์อิเล็กทรอนิกส์แบบพกพา

หากมีอุปกรณ์จำพวกแหล่งจ่ายไฟฟ้าสำรองสำหรับอุปกรณ์อิเล็กทรอนิกส์แบบพกพา ยกตัวอย่างเช่น *แหล่งจ่ายไฟฟ้าพกพาที่มีหัวต่อใช้งานได้กับอุปกรณ์อิเล็กทรอนิกส์หลายๆ รูปแบบ อาจอยู่ในรูปของพวงกุญแจ หรือของสะสม* เป็นต้น ท่านจะพิจารณาเลือกซื้อมาใช้งานหรือไม่

- ☐ ซื้อ โดยพิจารณาปัจจัย หรือเงื่อนไข หรือเหตุผลต่างๆ ประกอบกัน
- ☐ ไม่ต้องการซื้อ ไม่สนใจผลิตภัณฑ์

10. ปัจจัยหลักที่คำนึงถึงในการเลือกซื้อ ตามข้อ 9 (กรณีไม่ต้องการซื้อ หรือไม่สนใจผลิตภัณฑ์ ไม่จำเป็นต้องตอบข้อนี้) หากท่านต้องการเลือกซื้อผลิตภัณฑ์จ่ายไฟฟ้าสำรองแบบพกพา เช่น แบตเตอรี่สำรอง ท่านคิดว่ามีปัจจัยสำคัญใดบ้างที่ท่านต้องคำนึงถึงในการเลือกซื้อ กรุณา***ทำเครื่องหมายวงกลมล้อมรอบระดับคะแนน***ตามความคิดเห็นของท่าน

No.	ปัจจัยในการเลือกซื้อ	ระดับการประเมินความสำคัญ			
		4 สำคัญมาก	3 สำคัญอยู่บ้าง	2 สำคัญน้อย	1 ไม่สำคัญเลย
10.1	ราคาขายย่อมเยา สมเหตุสมผล	4	3	2	1
10.2	ความน่าเชื่อถือของยี่ห้อ แบรนด์ ประเทศที่ผลิต	4	3	2	1
10.3	ความหลากหลายในการใช้งานกับอุปกรณ์ต่างๆ	4	3	2	1
10.4	ใช้งานง่าย สะดวก ไม่จุกจิก	4	3	2	1
10.5	เก็บประจุไฟฟ้าได้มาก จ่ายไฟสำรองได้เพียงพอกับอุปกรณ์อิเล็กทรอนิกส์พกพาที่จำเป็นต้องใช้ทั้งหมด	4	3	2	1
10.6	น้ำหนักเบา ขนาดกะทัดรัด พกพาสะดวก	4	3	2	1
10.7	ปลอดภัยต่อผู้ใช้ และไม่ทำให้อุปกรณ์อิเล็กทรอนิกส์ที่ใช้งานเกิดปัญหาหรือเสียหาย	4	3	2	1
10.8	ความทนทาน สมบุกสมบัน ในการใช้งาน	4	3	2	1
10.9	รูปลักษณ์ที่สวยงาม ดีไซน์ทันสมัย โดนใจ	4	3	2	1
10.10	มีฟังก์ชั่นเสริม เช่น มีไฟฉาย/ เล่น MP3/ Flash Drive	4	3	2	1
10.11	ความแปลกใหม่ ประสบการณ์ใช้งานผลิตภัณฑ์แบบใหม่ๆ ความน่าทดลองใช้งาน	4	3	2	1
10.12	เป็นผลิตภัณฑ์ลดโลกร้อน ช่วยประหยัดพลังงาน	4	3	2	1
10.13	มีการรับประกันและบริการหลังการขายที่ดี	4	3	2	1
10.14	ไม่ทำลายสิ่งแวดล้อมเมื่อแบตเตอรี่เสื่อมสภาพ	4	3	2	1

10.15 ข้อคิดเห็นอื่นๆ เกี่ยวกับผลิตภัณฑ์สำหรับจ่ายไฟฟ้าสำรองเพื่อใช้งานกับอุปกรณ์อิเล็กทรอนิกส์แบบพกพา เช่น ปัจจัยอื่นๆ ที่พิจารณาเลือกซื้อ ฟังก์ชันหรือความสามารถอื่นๆ ที่ท่านปรารถนาเพิ่มเติม คำอธิบายตัวอย่างรูปแบบการใช้งานเฉพาะด้านของท่าน เงื่อนไขพิเศษที่ท่านต้องใช้งาน เป็นต้น (ถ้ามี)

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ขอขอบพระคุณเป็นอย่างสูงที่กรุณาเสียสละเวลาเพื่อตอบแบบสอบถาม

ทางผู้จัดทำจะขอน้อมรับความคิดเห็นอันมีค่าและเป็นประโยชน์จากท่าน

เพื่อนำไปพัฒนาผลิตภัณฑ์ที่มีคุณภาพตรงตามความต้องการของท่าน

และจะได้บริจาคเงินทำบุญตามความประสงค์ของท่านต่อไป

Appendix B

Reliability Test (Printout Data) of the Research Questionnaire by SPSS Statistics Software Version 17.0

Reliability test: printout data from SPSS program

Test for questionnaire in the topic 7.1

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	439	100.0
	Excluded[a]	0	.0
	Total	439	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.808	8

Item Statistics

	Mean	Std. Deviation	N
ความไม่สะดวกในการพกพาที่ชาร์จแบตเตอรี่หลายๆ อย่าง ขณะเดินทาง	3.71	1.048	439
ความไม่สะดวกในการหาปลั๊กไฟฟ้าเพื่อใช้หรือชาร์จไฟในบางแห่ง	3.81	.969	439
ปัญหาในการเตรียม Adapter แปลงแรงดันและหัวปลั๊กไฟฟ้าในการนำอุปกรณ์ไปใช้ ตปท.	3.15	1.289	439
คาดการณ์เวลาใช้งานที่เหลืออยู่ของแบตเตอรี่ได้ยาก	3.38	1.064	439
แบตเตอรี่หรืออุปกรณ์ชาร์จเสื่อมสภาพ ทำให้ชาร์จไฟไม่เข้า หรือแบตเตอรี่ไฟหมดเร็ว	3.31	1.148	439
แบตเตอรี่หรืออุปกรณ์ชาร์จแพง หากเสื่อมสภาพแล้วต้องเปลี่ยนใหม่	3.62	1.171	439
ความไม่สะดวกในการลากสายไฟเสียบปลั๊กเพื่อใช้ไฟฟ้าหรือชาร์จแบตเตอรี่ในบางสถานการณ์	3.57	1.038	439
ความกังวลในการประหยัดไฟฟ้าในแบตเตอรี่สำหรับอุปกรณ์ไฟฟ้าในกรณีที่ต้องเดินทางนอก	3.69	1.058	439

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
ความไม่สะดวกในการพกพาที่ชาร์จแบตเตอรี่หลายๆ อย่าง ขณะเดินทาง	24.54	26.934	.471	.793
ความไม่สะดวกในการหาปลั๊กไฟฟ้าเพื่อใช้หรือชาร์จไฟในบางแห่ง	24.43	26.511	.571	.780
ปัญหาในการเตรียม Adapter แปลงแรงดันและหัวปลั๊กไฟฟ้าในการนำอุปกรณ์ไปใช้ ตปท.	25.09	25.628	.449	.800
คาดการณ์เวลาใช้งานที่เหลืออยู่ของแบตเตอรี่ได้ยาก	24.86	25.852	.570	.779
แบตเตอรี่หรืออุปกรณ์ชาร์จเสื่อมสภาพ ทำให้ชาร์จไฟไม่เข้า หรือแบตเตอรี่ไฟหมดเร็ว	24.94	25.939	.504	.789
แบตเตอรี่หรืออุปกรณ์ชาร์จแพง หากเสื่อมสภาพแล้วต้องเปลี่ยนใหม่	24.62	25.734	.508	.788
ความไม่สะดวกในการลากสายไฟเสียบปลั๊กเพื่อใช้ไฟฟ้าหรือชาร์จแบตเตอรี่ในบางสถานการณ์	24.67	26.066	.567	.780
ความกังวลในการประหยัดไฟฟ้าในแบตเตอรี่สำหรับอุปกรณ์ไฟฟ้าในกรณีที่ต้องเดินทางนอก	24.56	25.942	.565	.780

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
28.24	33.148	5.757	8

Reliability test: Test for questionnaire in the topic 10

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	384	87.5
	Excluded[a]	55	12.5
	Total	439	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.820	14

Item Statistics

	Mean	Std. Deviation	N
ราคาขายย่อมเยา สมเหตุสมผล	3.62	.609	384
ความน่าเชื่อถือของยี่ห้อ แบรนด์ ประเทศที่ผลิต	3.47	.616	384
ความหลากหลายในการใช้งานกับอุปกรณ์ต่างๆ	3.54	.653	384
ใช้งานง่าย สะดวก ไม่จุกจิก	3.72	.508	384
เก็บประจุไฟฟ้าได้มาก จ่ายไฟสำรองได้เพียงพอกับอุปกรณ์อิเล็กทรอนิกส์พกพาที่จำเป็น	3.78	.474	384
น้ำหนักเบา ขนาดกะทัดรัด พกพาสะดวก	3.73	.512	384
ปลอดภัยต่อผู้ใช้ และไม่ทำให้อุปกรณ์อิเล็กทรอนิกส์ที่ใช้งานเกิดปัญหาหรือเสียหาย	3.88	.382	384
ความทนทาน สมบุกสมบัน ในการใช้งาน	3.61	.590	384
รูปลักษณ์ที่สวยงาม ดีไซน์ทันสมัย โดนใจ	2.94	.876	384
มีฟังก์ชั่นเสริม เช่น มีไฟฉาย/ เล่น MP3/ Flash Drive	2.33	.990	384
ความแปลกใหม่ ประสบการณ์ใช้งานผลิตภัณฑ์แบบใหม่ๆ ความน่าทดลองใช้งาน	2.78	.942	384
เป็นผลิตภัณฑ์ลดโลกร้อน ช่วยประหยัดพลังงาน	3.21	.852	384
มีการรับประกันและบริการหลังการขายที่ดี	3.62	.623	384
ไม่ทำลายสิ่งแวดล้อมเมื่อแบตเตอรี่เสื่อมสภาพ	3.44	.776	384

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
ราคาขายย่อมเยา สมเหตุสมผล	44.05	26.282	.269	.820
ความน่าเชื่อถือของยี่ห้อ แบรนด์ ประเทศที่ผลิต	44.21	26.153	.286	.819
ความหลากหลายในการใช้งานกับอุปกรณ์ต่างๆ	44.13	24.801	.478	.806
ใช้งานง่าย สะดวก ไม่จุกจิก	43.95	25.616	.479	.808
เก็บประจุไฟฟ้าได้มาก จ่ายไฟสำรองได้เพียงพอกับอุปกรณ์อิเล็กทรอนิกส์พกพาที่จำเป็น	43.89	26.038	.428	.811
น้ำหนักเบา ขนาดกะทัดรัด พกพาสะดวก	43.95	25.739	.450	.810
ปลอดภัยต่อผู้ใช้ และไม่ทำให้อุปกรณ์อิเล็กทรอนิกส์ที่ใช้งานเกิดปัญหาหรือเสียหาย	43.80	26.627	.396	.814
ความทนทาน สมบุกสมบัน ในการใช้งาน	44.06	24.631	.574	.801
รูปลักษณ์ที่สวยงาม ดีไซน์ทันสมัย โดนใจ	44.73	23.544	.474	.807
มีฟังก์ชั่นเสริม เช่น มีไฟฉาย/ เล่น MP3/ Flash Drive	45.34	23.185	.437	.813
ความแปลกใหม่ ประสบการณ์ใช้งานผลิตภัณฑ์แบบใหม่ๆ ความน่าทดลองใช้งาน	44.89	22.834	.513	.804
เป็นผลิตภัณฑ์ลดโลกร้อน ช่วยประหยัดพลังงาน	44.46	22.933	.573	.798
มีการรับประกันและบริการหลังการขายที่ดี	44.05	24.772	.512	.804
ไม่ทำลายสิ่งแวดล้อมเมื่อแบตเตอรี่เสื่อมสภาพ	44.23	23.641	.542	.801

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
47.67	28.336	5.323	14

Appendix C

Cross Tabulation (Crosstab) Results of the Correlation Analysis by SPSS Statistics Software Version 17.0

Table C.1 Crosstab results of the correlation between occupations and selected ranks of the power supply problem for portable GPS

			Occupation													
			Student	Mass media officer	General executive	Employee	Merchant	Business owner	Police / military officer	Freelance	Others	Government officer	Professor / Instructor	Engineer/ architect	Industrial worker	Total
Portable GPS	1	Count	0	0	0	0	0	0	0	1	1	1	0	0	0	3
		% within Occupation	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	33.3%	14.3%	.0%	.0%	.0%	7.5%
	2	Count	0	0	0	3	0	0	0	1	1	1	1	1	0	8
		% within Occupation	.0%	.0%	.0%	27.3%	.0%	.0%	.0%	25.0%	33.3%	14.3%	25.0%	50.0%	.0%	20.0%
	3	Count	0	1	0	3	0	0	0	1	1	2	0	0	0	8
		% within Occupation	.0%	100.0%	.0%	27.3%	.0%	.0%	.0%	25.0%	33.3%	28.6%	.0%	.0%	.0%	20.0%
	4	Count	0	0	1	3	1	0	0	1	0	2	0	0	0	8
		% within Occupation	.0%	.0%	100.0%	27.3%	100.0%	.0%	.0%	25.0%	.0%	28.6%	.0%	.0%	.0%	20.0%
	5	Count	1	0	0	1	0	0	1	0	0	0	2	0	0	5
		% within Occupation	33.3%	.0%	.0%	9.1%	.0%	.0%	100.0%	.0%	.0%	.0%	50.0%	.0%	.0%	12.5%
	6	Count	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		% within Occupation	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	.0%	.0%	2.5%
	7	Count	0	0	0	1	0	0	0	0	0	0	0	0	0	1
		% within Occupation	.0%	.0%	.0%	9.1%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	2.5%
	8	Count	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Occupation	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	2.5%
	9	Count	1	0	0	0	0	0	0	0	0	0	0	1	0	2
		% within Occupation	33.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	5.0%
	10	Count	1	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Occupation	33.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	2.5%
	11	Count	0	0	0	0	0	0	0	0	0	1	0	0	0	1
		% within Occupation	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	14.3%	.0%	.0%	.0%	2.5%
	15	Count	0	0	0	0	0	1	0	0	0	0	0	0	0	1
		% within Occupation	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	2.5%
Total		Count	3	1	1	11	1	1	1	4	3	7	4	2	1	40
		% within Occupation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.2 Crosstab results of the correlation between occupations and selected ranks of the power supply problem for voice recorder

			Occupation									
			Student	Employee	Business owner	Police / military officer	Freelance	Government officer	Professor / instructor	Engineer / architect	Industrial worker	Total
Voice recorder	1	Count	0	0	0	0	0	1	1	0	0	2
		% within Occupation	.0%	.0%	.0%	.0%	.0%	25.0%	25.0%	.0%	.0%	8.3%
	3	Count	0	2	0	1	0	0	0	0	0	3
		% within Occupation	.0%	33.3%	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	12.5%
	4	Count	0	2	1	0	0	2	2	0	0	7
		% within Occupation	.0%	33.3%	25.0%	.0%	.0%	50.0%	50.0%	.0%	.0%	29.2%
	5	Count	1	0	0	0	0	1	1	0	0	3
		% within Occupation	50.0%	.0%	.0%	.0%	.0%	25.0%	25.0%	.0%	.0%	12.5%
	6	Count	1	1	2	0	0	0	0	1	0	5
		% within Occupation	50.0%	16.7%	50.0%	.0%	.0%	.0%	.0%	100.0%	.0%	20.8%
	8	Count	0	0	0	0	1	0	0	0	0	1
		% within Occupation	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	4.2%
	9	Count	0	1	0	0	0	0	0	0	0	1
		% within Occupation	.0%	16.7%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	4.2%
	11	Count	0	0	0	0	0	0	0	0	1	1
		% within Occupation	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	4.2%
	13	Count	0	0	1	0	0	0	0	0	0	1
		% within Occupation	.0%	.0%	25.0%	.0%	.0%	.0%	.0%	.0%	.0%	4.2%
Total		Count	2	6	4	1	1	4	4	1	1	24
		% within Occupation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.3 Crosstab results of the correlation between selected ranks of sports as a favourite hobby and selected ranks of the power supply problem for smart phone

			Sports														
			1	2	3	4	5	6	7	8	9	10	11	12	14	15	Total
Smart phone	1	Count	20	8	4	10	9	5	10	0	3	3	1	0	1	0	74
		% within Sports	74.1%	66.7%	36.4%	58.8%	56.3%	71.4%	76.9%	.0%	75.0%	60.0%	100.0%	.0%	100.0%	.0%	61.2%
	2	Count	2	3	2	5	2	1	1	3	0	2	0	0	0	0	21
		% within Sports	7.4%	25.0%	18.2%	29.4%	12.5%	14.3%	7.7%	100.0%	.0%	40.0%	.0%	.0%	.0%	.0%	17.4%
	3	Count	2	0	4	1	3	0	1	0	0	0	0	0	0	1	12
		% within Sports	7.4%	.0%	36.4%	5.9%	18.8%	.0%	7.7%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	9.9%
	4	Count	1	1	1	1	1	0	1	0	0	0	0	0	0	0	6
		% within Sports	3.7%	8.3%	9.1%	5.9%	6.3%	.0%	7.7%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	5.0%
	5	Count	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2
		% within Sports	3.7%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	1.7%
	6	Count	1	0	0	0	0	1	0	0	0	0	0	0	0	0	2
		% within Sports	3.7%	.0%	.0%	.0%	.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.7%
	8	Count	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
		% within Sports	.0%	.0%	.0%	.0%	6.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.8%
	9	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Sports	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.8%
	13	Count	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
		% within Sports	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	.0%	.0%	.0%	.0%	.0%	.8%
	15	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Sports	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.8%
Total		Count	27	12	11	17	16	7	13	3	4	5	1	1	1	3	121
		% within Sports	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.4 Crosstab results of the correlation between selected ranks of photographing as a favourite hobby and selected ranks of the power supply problem for digital compact camera

			Photographing															Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	
Digital compact camera	1	Count	0	1	1	1	0	3	1	1	0	0	0	0	0	0	0	8
		% within Photographing	.0%	7.7%	8.3%	11.1%	.0%	50.0%	14.3%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	9.8%
	2	Count	1	4	1	3	3	2	2	1	0	1	0	2	0	0	1	21
		% within Photographing	50.0%	30.8%	8.3%	33.3%	42.9%	33.3%	28.6%	14.3%	.0%	16.7%	.0%	50.0%	.0%	.0%	100.0%	25.6%
	3	Count	0	5	1	1	3	0	2	3	1	2	0	1	0	0	0	19
		% within Photographing	.0%	38.5%	8.3%	11.1%	42.9%	.0%	28.6%	42.9%	33.3%	33.3%	.0%	25.0%	.0%	.0%	.0%	23.2%
	4	Count	1	1	5	4	1	0	0	2	1	1	0	0	1	0	0	17
		% within Photographing	50.0%	7.7%	41.7%	44.4%	14.3%	.0%	.0%	28.6%	33.3%	16.7%	.0%	.0%	33.3%	.0%	.0%	20.7%
	5	Count	0	0	2	0	0	0	0	0	0	2	0	0	0	1	0	5
		% within Photographing	.0%	.0%	16.7%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	.0%	100.0%	.0%	6.1%
	6	Count	0	2	0	0	0	1	2	0	0	0	0	0	1	0	0	6
		% within Photographing	.0%	15.4%	.0%	.0%	.0%	16.7%	28.6%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	7.3%
	7	Count	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
		% within Photographing	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	1.2%
	11	Count	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
		% within Photographing	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	.0%	.0%	.0%	1.2%
	12	Count	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	3
		% within Photographing	.0%	.0%	16.7%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	3.7%
	14	Count	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
		% within Photographing	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	.0%	.0%	.0%	.0%	1.2%
Total		Count	2	13	12	9	7	6	7	7	3	6	1	4	3	1	1	82
		% within Photographing	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.5 Crosstab results of the correlation between selected ranks of photographing as a favourite hobby and selected ranks of the power supply problem for D-SLR camera

			Photographing													
			1	2	3	4	5	6	7	8	9	11	12	13	15	Total
D-SLR camera	1	Count	1	0	2	2	0	0	0	0	0	0	0	0	0	5
		% within Photographing	16.7%	.0%	16.7%	20.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	8.1%
	2	Count	2	5	3	1	1	1	0	1	1	0	0	0	0	15
		% within Photographing	33.3%	41.7%	25.0%	10.0%	20.0%	50.0%	.0%	33.3%	33.3%	.0%	.0%	.0%	.0%	24.2%
	3	Count	2	4	1	5	3	0	3	0	1	0	0	0	0	19
		% within Photographing	33.3%	33.3%	8.3%	50.0%	60.0%	.0%	60.0%	.0%	33.3%	.0%	.0%	.0%	.0%	30.6%
	4	Count	1	1	1	2	0	0	1	0	0	0	0	0	0	6
		% within Photographing	16.7%	8.3%	8.3%	20.0%	.0%	.0%	20.0%	.0%	.0%	.0%	.0%	.0%	.0%	9.7%
	5	Count	0	1	3	0	1	1	0	2	0	1	0	0	0	9
		% within Photographing	.0%	8.3%	25.0%	.0%	20.0%	50.0%	.0%	66.7%	.0%	100.0%	.0%	.0%	.0%	14.5%
	6	Count	0	0	1	0	0	0	0	0	0	0	0	0	0	1
		% within Photographing	.0%	.0%	8.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.6%
	7	Count	0	1	0	0	0	0	0	0	1	0	0	1	0	3
		% within Photographing	.0%	8.3%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	100.0%	.0%	4.8%
	8	Count	0	0	0	0	0	0	1	0	0	0	0	0	0	1
		% within Photographing	.0%	.0%	.0%	.0%	.0%	.0%	20.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.6%
	10	Count	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Photographing	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	1.6%
	12	Count	0	0	1	0	0	0	0	0	0	0	0	0	0	1
		% within Photographing	.0%	.0%	8.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.6%
	15	Count	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		% within Photographing	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	1.6%
Total		Count	6	12	12	10	5	2	5	3	3	1	1	1	1	62
		% within Photographing	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.6 Crosstab results of the correlation between selected ranks of eating as a favourite hobby and selected ranks of the power supply problem for smart phone

			Eating														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Smart phone	1	Count	5	15	13	13	9	8	4	4	4	2	2	0	1	0	80
		% within Eating	45.5%	60.0%	81.3%	61.9%	64.3%	66.7%	50.0%	57.1%	100.0%	50.0%	100.0%	.0%	100.0%	.0%	63.0%
	2	Count	3	6	1	2	3	1	2	1	0	0	0	0	0	0	19
		% within Eating	27.3%	24.0%	6.3%	9.5%	21.4%	8.3%	25.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	15.0%
	3	Count	1	4	1	3	1	1	2	1	0	1	0	0	0	0	15
		% within Eating	9.1%	16.0%	6.3%	14.3%	7.1%	8.3%	25.0%	14.3%	.0%	25.0%	.0%	.0%	.0%	.0%	11.8%
	4	Count	1	0	1	2	0	2	0	1	0	0	0	0	0	0	7
		% within Eating	9.1%	.0%	6.3%	9.5%	.0%	16.7%	.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	5.5%
	5	Count	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2
		% within Eating	.0%	.0%	.0%	.0%	7.1%	.0%	.0%	.0%	.0%	25.0%	.0%	.0%	.0%	.0%	1.6%
	8	Count	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.8%
	9	Count	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
		% within Eating	.0%	.0%	.0%	4.8%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.8%
	13	Count	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Eating	9.1%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.8%
	15	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.8%
Total		Count	11	25	16	21	14	12	8	7	4	4	2	1	1	1	127
		% within Eating	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.7 Crosstab results of the correlation between selected ranks of eating as a favourite hobby and selected ranks of the power supply problem for mobile phone

			Eating															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Mobile phone	1	Count	8	6	6	7	11	5	6	4	0	1	0	1	0	0	1	56
		% within Eating	53.3%	31.6%	35.3%	33.3%	61.1%	31.3%	66.7%	50.0%	.0%	16.7%	.0%	100.0%	.0%	.0%	100.0%	41.5%
	2	Count	4	5	5	9	3	2	2	2	1	1	0	0	0	0	0	34
		% within Eating	26.7%	26.3%	29.4%	42.9%	16.7%	12.5%	22.2%	25.0%	100.0%	16.7%	.0%	.0%	.0%	.0%	.0%	25.2%
	3	Count	2	5	2	2	3	4	1	0	0	3	0	0	0	0	0	22
		% within Eating	13.3%	26.3%	11.8%	9.5%	16.7%	25.0%	11.1%	.0%	.0%	50.0%	.0%	.0%	.0%	.0%	.0%	16.3%
	4	Count	0	3	2	1	1	3	0	0	0	0	0	0	1	0	0	11
		% within Eating	.0%	15.8%	11.8%	4.8%	5.6%	18.8%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	8.1%
	5	Count	0	0	2	1	0	2	0	0	0	0	0	0	0	1	0	6
		% within Eating	.0%	.0%	11.8%	4.8%	.0%	12.5%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	4.4%
	6	Count	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	12.5%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.7%
	7	Count	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	.7%
	8	Count	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
		% within Eating	.0%	.0%	.0%	4.8%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.7%
	10	Count	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	16.7%	.0%	.0%	.0%	.0%	.0%	.7%
	11	Count	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	12.5%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.7%
	12	Count	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Eating	6.7%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.7%
Total		Count	15	19	17	21	18	16	9	8	1	6	1	1	1	1	1	135
		% within Eating	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.8 Crosstab results of the correlation between selected ranks of eating as a favourite hobby and selected ranks of the power supply problem for tablet PC

			Eating												Total
			1	2	3	4	5	6	7	8	10	11	12	14	
Tablet PC	1	Count	1	0	0	1	0	0	0	0	0	0	0	0	2
		% within Eating	33.3%	.0%	.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	5.3%
	2	Count	1	1	1	1	2	0	1	0	0	1	0	0	8
		% within Eating	33.3%	20.0%	50.0%	14.3%	28.6%	.0%	20.0%	.0%	.0%	100.0%	.0%	.0%	21.1%
	3	Count	0	2	1	2	3	1	3	1	0	0	0	0	13
		% within Eating	.0%	40.0%	50.0%	28.6%	42.9%	100.0%	60.0%	33.3%	.0%	.0%	.0%	.0%	34.2%
	4	Count	1	0	0	1	2	0	0	1	1	0	0	0	6
		% within Eating	33.3%	.0%	.0%	14.3%	28.6%	.0%	.0%	33.3%	50.0%	.0%	.0%	.0%	15.8%
	5	Count	0	1	0	1	0	0	0	1	0	0	0	0	3
		% within Eating	.0%	20.0%	.0%	14.3%	.0%	.0%	.0%	33.3%	.0%	.0%	.0%	.0%	7.9%
	6	Count	0	1	0	0	0	0	1	0	1	0	0	0	3
		% within Eating	.0%	20.0%	.0%	.0%	.0%	.0%	20.0%	.0%	50.0%	.0%	.0%	.0%	7.9%
	9	Count	0	0	0	0	0	0	0	0	0	0	1	0	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	2.6%
	10	Count	0	0	0	1	0	0	0	0	0	0	0	0	1
		% within Eating	.0%	.0%	.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	2.6%
	14	Count	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Eating	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	2.6%
Total		Count	3	5	2	7	7	1	5	3	2	1	1	1	38
		% within Eating	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.9 Crosstab results of the correlation between selected ranks of cooking as a favourite hobby and selected ranks of the power supply problem for mobile phone

			Cooking															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Mobile phone	1	Count	1	4	4	1	3	4	2	0	3	3	3	1	0	2	0	31
		% within Cooking	11.1%	44.4%	40.0%	50.0%	37.5%	44.4%	40.0%	.0%	60.0%	100.0%	60.0%	20.0%	.0%	40.0%	.0%	38.3%
	2	Count	2	0	1	0	5	0	2	1	0	0	0	2	0	0	0	13
		% within Cooking	22.2%	.0%	10.0%	.0%	62.5%	.0%	40.0%	33.3%	.0%	.0%	.0%	40.0%	.0%	.0%	.0%	16.0%
	3	Count	5	3	2	0	0	3	0	1	1	0	0	2	0	2	0	19
		% within Cooking	55.6%	33.3%	20.0%	.0%	.0%	33.3%	.0%	33.3%	20.0%	.0%	.0%	40.0%	.0%	40.0%	.0%	23.5%
	4	Count	0	1	3	0	0	1	0	0	1	0	1	0	0	0	0	7
		% within Cooking	.0%	11.1%	30.0%	.0%	.0%	11.1%	.0%	.0%	20.0%	.0%	20.0%	.0%	.0%	.0%	.0%	8.6%
	5	Count	1	0	0	0	0	1	1	1	0	0	0	0	0	1	0	5
		% within Cooking	11.1%	.0%	.0%	.0%	.0%	11.1%	20.0%	33.3%	.0%	.0%	.0%	.0%	.0%	20.0%	.0%	6.2%
	6	Count	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	20.0%	.0%	.0%	.0%	.0%	1.2%
	7	Count	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Cooking	.0%	11.1%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.2%
	8	Count	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	1.2%
	10	Count	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	1.2%
	11	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	1.2%
	12	Count	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
		% within Cooking	.0%	.0%	.0%	50.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.2%
Total		Count	9	9	10	2	8	9	5	3	5	3	5	5	2	5	1	81
		% within Cooking	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.10 Crosstab results of the correlation between selected ranks of cooking as a favourite hobby and selected ranks of the power supply problem for digital compact camera

			Cooking																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Digital compact camera	1	Count	1	0	2	0	0	0	0	0	1	0	0	1	0	0	0	0	5
		% within Cooking	16.7%	.0%	20.0%	.0%	.0%	.0%	.0%	.0%	16.7%	.0%	.0%	20.0%	.0%	.0%	.0%	.0%	7.2%
	2	Count	1	2	3	1	2	3	2	0	2	1	0	0	0	1	0	0	18
		% within Cooking	16.7%	33.3%	30.0%	33.3%	40.0%	37.5%	50.0%	.0%	33.3%	50.0%	.0%	.0%	.0%	25.0%	.0%	.0%	26.1%
	3	Count	2	1	5	1	2	1	1	0	2	0	1	2	0	2	0	0	20
		% within Cooking	33.3%	16.7%	50.0%	33.3%	40.0%	12.5%	25.0%	.0%	33.3%	.0%	33.3%	40.0%	.0%	50.0%	.0%	.0%	29.0%
	4	Count	2	1	0	0	0	3	0	1	0	1	0	0	1	0	0	2	11
		% within Cooking	33.3%	16.7%	.0%	.0%	.0%	37.5%	.0%	50.0%	.0%	50.0%	.0%	.0%	50.0%	.0%	.0%	100.0%	15.9%
	5	Count	0	2	0	0	1	1	0	0	0	0	0	1	0	0	0	0	5
		% within Cooking	.0%	33.3%	.0%	.0%	20.0%	12.5%	.0%	.0%	.0%	.0%	.0%	20.0%	.0%	.0%	.0%	.0%	7.2%
	6	Count	0	0	0	0	0	0	0	0	1	0	2	1	0	1	0	0	5
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	16.7%	.0%	66.7%	20.0%	.0%	25.0%	.0%	.0%	7.2%
	7	Count	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Cooking	.0%	.0%	.0%	33.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.4%
	11	Count	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	.0%	1.4%
	12	Count	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	50.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	2.9%
	14	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	1.4%
Total		Count	6	6	10	3	5	8	4	2	6	2	3	5	2	4	1	2	69
		% within Cooking	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.11 Crosstab results of the correlation between selected ranks of cooking as a favourite hobby and selected ranks of the power supply problem for tablet PC

			Cooking															Total
			2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Tablet PC	1	Count	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Cooking	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	3.4%
	2	Count	2	0	2	0	1	1	0	1	0	1	0	0	1	0	0	9
		% within Cooking	50.0%	.0%	100.0%	.0%	33.3%	50.0%	.0%	100.0%	.0%	50.0%	.0%	.0%	100.0%	.0%	.0%	31.0%
	3	Count	1	0	0	2	1	0	0	0	0	1	0	0	0	0	1	6
		% within Cooking	25.0%	.0%	.0%	50.0%	33.3%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	.0%	.0%	100.0%	20.7%
	4	Count	1	0	0	1	0	0	0	0	0	0	2	0	0	1	0	5
		% within Cooking	25.0%	.0%	.0%	25.0%	.0%	.0%	.0%	.0%	.0%	.0%	66.7%	.0%	.0%	100.0%	.0%	17.2%
	5	Count	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	3
		% within Cooking	.0%	.0%	.0%	25.0%	33.3%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	.0%	10.3%
	6	Count	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	3
		% within Cooking	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	.0%	.0%	33.3%	50.0%	.0%	.0%	.0%	10.3%
	10	Count	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	.0%	3.4%
	14	Count	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
		% within Cooking	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	3.4%
Total		Count	4	1	2	4	3	2	1	1	1	2	3	2	1	1	1	29
		% within Cooking	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.12 Crosstab results of the correlation between selected ranks of playing game as a favourite hobby and selected ranks of the power supply problem for smart phone

			Playing game															Total
			1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	
Smart phone	1	Count	5	13	11	5	6	6	4	3	4	0	2	2	0	1	2	64
		% within Playing game	71.4%	68.4%	57.9%	55.6%	50.0%	85.7%	80.0%	100.0%	80.0%	.0%	66.7%	50.0%	.0%	33.3%	50.0%	61.5%
	2	Count	2	3	4	4	4	1	1	0	1	1	1	1	0	0	0	23
		% within Playing game	28.6%	15.8%	21.1%	44.4%	33.3%	14.3%	20.0%	.0%	20.0%	33.3%	33.3%	25.0%	.0%	.0%	.0%	22.1%
	3	Count	0	2	3	0	2	0	0	0	0	1	0	0	1	2	0	11
		% within Playing game	.0%	10.5%	15.8%	.0%	16.7%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	100.0%	66.7%	.0%	10.6%
	4	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Playing game	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	1.0%
	5	Count	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Playing game	.0%	.0%	5.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.0%
	8	Count	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
		% within Playing game	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	.0%	.0%	.0%	1.0%
	9	Count	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Playing game	.0%	5.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.0%
	13	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Playing game	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	1.0%
	15	Count	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
		% within Playing game	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	.0%	.0%	.0%	1.0%
Total		Count	7	19	19	9	12	7	5	3	5	3	3	4	1	3	4	104
		% within Playing game	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.13 Crosstab results of the correlation between selected ranks of playing game as a favourite hobby and selected ranks of the power supply problem for digital compact camera

			Playing game															Total
			1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	
Digital compact camera	1	Count	0	2	1	0	3	0	0	1	0	0	0	0	0	0	0	7
		% within Playing game	.0%	14.3%	7.1%	.0%	33.3%	.0%	.0%	20.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	9.0%
	2	Count	1	3	5	0	1	2	2	2	0	0	1	0	0	1	0	18
		% within Playing game	33.3%	21.4%	35.7%	.0%	11.1%	33.3%	66.7%	40.0%	.0%	.0%	33.3%	.0%	.0%	25.0%	.0%	23.1%
	3	Count	0	2	5	3	3	4	1	1	0	0	1	1	0	2	0	23
		% within Playing game	.0%	14.3%	35.7%	50.0%	33.3%	66.7%	33.3%	20.0%	.0%	.0%	33.3%	20.0%	.0%	50.0%	.0%	29.5%
	4	Count	1	3	1	3	1	0	0	0	0	1	0	3	0	0	1	14
		% within Playing game	33.3%	21.4%	7.1%	50.0%	11.1%	.0%	.0%	.0%	.0%	50.0%	.0%	60.0%	.0%	.0%	50.0%	17.9%
	5	Count	0	0	2	0	0	0	0	1	0	0	1	0	1	0	0	5
		% within Playing game	.0%	.0%	14.3%	.0%	.0%	.0%	.0%	20.0%	.0%	.0%	33.3%	.0%	100.0%	.0%	.0%	6.4%
	6	Count	0	3	0	0	0	0	0	0	1	0	0	0	0	1	0	5
		% within Playing game	.0%	21.4%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	25.0%	.0%	6.4%
	7	Count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		% within Playing game	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	1.3%
	11	Count	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Playing game	.0%	7.1%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.3%
	12	Count	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	3
		% within Playing game	33.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	20.0%	.0%	.0%	.0%	3.8%
	14	Count	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
		% within Playing game	.0%	.0%	.0%	.0%	11.1%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.3%
Total		Count	3	14	14	6	9	6	3	5	1	2	3	5	1	4	2	78
		% within Playing game	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.14 Crosstab results of the correlation between selected ranks of movie / music as a favourite hobby and selected ranks of the power supply problem for tablet PC

			Movie/ Music												
			1	2	3	4	5	6	7	8	9	11	14	16	Total
Tablet PC	1	Count	0	0	1	0	0	1	0	0	1	0	0	0	3
		% within Movie/ Music	.0%	.0%	11.1%	.0%	.0%	16.7%	.0%	.0%	25.0%	.0%	.0%	.0%	6.1%
	2	Count	2	0	0	1	2	3	1	0	1	0	2	0	12
		% within Movie/ Music	25.0%	.0%	.0%	14.3%	50.0%	50.0%	50.0%	.0%	25.0%	.0%	66.7%	.0%	24.5%
	3	Count	5	1	5	4	1	0	0	0	0	1	0	0	17
		% within Movie/ Music	62.5%	50.0%	55.6%	57.1%	25.0%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	34.7%
	4	Count	1	0	1	0	0	1	1	0	1	0	0	1	6
		% within Movie/ Music	12.5%	.0%	11.1%	.0%	.0%	16.7%	50.0%	.0%	25.0%	.0%	.0%	100.0%	12.2%
	5	Count	0	0	2	0	1	0	0	0	0	0	1	0	4
		% within Movie/ Music	.0%	.0%	22.2%	.0%	25.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	8.2%
	6	Count	0	1	0	2	0	1	0	0	0	0	0	0	4
		% within Movie/ Music	.0%	50.0%	.0%	28.6%	.0%	16.7%	.0%	.0%	.0%	.0%	.0%	.0%	8.2%
	9	Count	0	0	0	0	0	0	0	0	1	0	0	0	1
		% within Movie/ Music	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	25.0%	.0%	.0%	.0%	2.0%
	10	Count	0	0	0	0	0	0	0	1	0	0	0	0	1
		% within Movie/ Music	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	.0%	.0%	.0%	.0%	2.0%
	14	Count	0	0	0	0	0	0	0	0	0	1	0	0	1
		% within Movie/ Music	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	50.0%	.0%	.0%	2.0%
Total		Count	8	2	9	7	4	6	2	1	4	2	3	1	49
		% within Movie/ Music	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.15 Crosstab results of the correlation between selected ranks of singing / playing music as a favourite hobby and selected ranks of the power supply problem for digital compact camera

			Singing/ Playing Music															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Digital compact camera	1	Count	0	2	0	1	1	0	0	0	1	1	0	0	1	0	0	7
		% within Singing/ Playing Music	.0%	28.6%	.0%	20.0%	11.1%	.0%	.0%	.0%	33.3%	50.0%	.0%	.0%	20.0%	.0%	.0%	9.7%
	2	Count	2	1	4	1	5	1	1	2	0	0	0	0	1	1	0	19
		% within Singing/ Playing Music	20.0%	14.3%	57.1%	20.0%	55.6%	12.5%	20.0%	66.7%	.0%	.0%	.0%	.0%	20.0%	33.3%	.0%	26.4%
	3	Count	5	2	1	1	1	2	1	1	1	1	0	0	1	1	0	18
		% within Singing/ Playing Music	50.0%	28.6%	14.3%	20.0%	11.1%	25.0%	20.0%	33.3%	33.3%	50.0%	.0%	.0%	20.0%	33.3%	.0%	25.0%
	4	Count	2	2	1	1	1	5	1	0	0	0	0	1	0	1	0	15
		% within Singing/ Playing Music	20.0%	28.6%	14.3%	20.0%	11.1%	62.5%	20.0%	.0%	.0%	.0%	.0%	33.3%	.0%	33.3%	.0%	20.8%
	5	Count	0	0	0	1	0	0	1	0	1	0	0	0	2	0	0	5
		% within Singing/ Playing Music	.0%	.0%	.0%	20.0%	.0%	.0%	20.0%	.0%	33.3%	.0%	.0%	.0%	40.0%	.0%	.0%	6.9%
	6	Count	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	3
		% within Singing/ Playing Music	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	33.3%	.0%	.0%	100.0%	4.2%
	7	Count	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Singing/ Playing Music	.0%	.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.4%
	11	Count	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
		% within Singing/ Playing Music	.0%	.0%	.0%	.0%	.0%	.0%	20.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.4%
	12	Count	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2
		% within Singing/ Playing Music	.0%	.0%	.0%	.0%	11.1%	.0%	.0%	.0%	.0%	.0%	.0%	33.3%	.0%	.0%	.0%	2.8%
	14	Count	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		% within Singing/ Playing Music	10.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.4%
Total		Count	10	7	7	5	9	8	5	3	3	2	1	3	5	3	1	72
		% within Singing/ Playing Music	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.16 Crosstab results of the correlation between selected ranks of sports as a favourite hobby and frequency levels of the samples' encounter with heat from food packaging

			Sports																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Food package	1	Count	6	4	2	3	2	0	0	0	0	1	0	0	0	0	0	0	18
		% within Reading	11.1%	16.7%	13.3%	10.3%	8.7%	.0%	.0%	.0%	.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	8.4%
	2	Count	15	6	3	5	1	1	3	4	3	0	1	0	0	1	0	0	43
		% within Reading	27.8%	25.0%	20.0%	17.2%	4.3%	8.3%	16.7%	66.7%	42.9%	.0%	16.7%	.0%	.0%	50.0%	.0%	.0%	20.0%
	3	Count	17	3	4	6	5	2	8	0	3	3	1	2	0	0	1	1	56
		% within Reading	31.5%	12.5%	26.7%	20.7%	21.7%	16.7%	44.4%	.0%	42.9%	42.9%	16.7%	100.0%	.0%	.0%	25.0%	100.0%	26.0%
	4	Count	11	8	2	11	6	6	4	2	0	2	2	0	1	0	3	0	58
		% within Reading	20.4%	33.3%	13.3%	37.9%	26.1%	50.0%	22.2%	33.3%	.0%	28.6%	33.3%	.0%	20.0%	.0%	75.0%	.0%	27.0%
	5	Count	5	3	4	4	9	3	3	0	1	1	2	0	4	1	0	0	40
		% within Reading	9.3%	12.5%	26.7%	13.8%	39.1%	25.0%	16.7%	.0%	14.3%	14.3%	33.3%	.0%	80.0%	50.0%	.0%	.0%	18.6%
Total		Count	54	24	15	29	23	12	18	6	7	7	6	2	5	2	4	1	215
		% within Reading	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.17 Crosstab results of the correlation between selected ranks of photographing as a favourite hobby and frequency levels of the samples' encounter with heat from laptop computer

			Photographing															
			1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	Total
Laptop Compu-ter	1	Count	0	2	1	3	0	1	0	1	0	0	0	0	0	0	1	9
		% within Reading	.0%	8.7%	3.6%	13.6%	.0%	12.5%	.0%	8.3%	.0%	.0%	.0%	.0%	.0%	.0%	100.0%	5.3%
	2	Count	0	0	1	1	0	2	2	1	1	0	0	0	0	0	0	8
		% within Reading	.0%	.0%	3.6%	4.5%	.0%	25.0%	15.4%	8.3%	11.1%	.0%	.0%	.0%	.0%	.0%	.0%	4.7%
	3	Count	0	3	1	3	1	0	0	1	0	1	0	0	3	0	0	13
		% within Reading	.0%	13.0%	3.6%	13.6%	5.6%	.0%	.0%	8.3%	.0%	12.5%	.0%	.0%	50.0%	.0%	.0%	7.7%
	4	Count	3	5	9	3	5	1	1	2	0	1	2	3	0	1	0	36
		% within Reading	33.3%	21.7%	32.1%	13.6%	27.8%	12.5%	7.7%	16.7%	.0%	12.5%	66.7%	42.9%	.0%	50.0%	.0%	21.3%
	5	Count	6	13	16	12	12	4	10	7	8	6	1	4	3	1	0	103
		% within Reading	66.7%	56.5%	57.1%	54.5%	66.7%	50.0%	76.9%	58.3%	88.9%	75.0%	33.3%	57.1%	50.0%	50.0%	.0%	60.9%
Total		Count	9	23	28	22	18	8	13	12	9	8	3	7	6	2	1	169
		% within Reading	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.18 Crosstab results of the correlation between selected ranks of eating as a favourite hobby and frequency levels of the samples' encounter with heat from cooking devices

			Eating															Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Cooking device	1	Count	3	2	2	2	1	2	2	1	0	0	1	0	0	0	0	16
		% within Eating	12.0%	5.7%	6.5%	5.4%	3.4%	8.0%	11.1%	7.7%	.0%	.0%	33.3%	.0%	.0%	.0%	.0%	6.8%
	2	Count	6	8	8	9	5	13	2	2	3	1	0	0	0	0	0	57
		% within Eating	24.0%	22.9%	25.8%	24.3%	17.2%	52.0%	11.1%	15.4%	60.0%	11.1%	.0%	.0%	.0%	.0%	.0%	24.4%
	3	Count	7	9	5	10	12	6	5	8	2	1	0	0	0	0	0	65
		% within Eating	28.0%	25.7%	16.1%	27.0%	41.4%	24.0%	27.8%	61.5%	40.0%	11.1%	.0%	.0%	.0%	.0%	.0%	27.8%
	4	Count	2	9	14	5	5	3	6	1	0	4	0	0	1	1	1	52
		% within Eating	8.0%	25.7%	45.2%	13.5%	17.2%	12.0%	33.3%	7.7%	.0%	44.4%	.0%	.0%	100.0%	100.0%	100.0%	22.2%
	5	Count	7	7	2	11	6	1	3	1	0	3	2	1	0	0	0	44
		% within Eating	28.0%	20.0%	6.5%	29.7%	20.7%	4.0%	16.7%	7.7%	.0%	33.3%	66.7%	100.0%	.0%	.0%	.0%	18.8%
Total		Count	25	35	31	37	29	25	18	13	5	9	3	1	1	1	1	234
		% within Eating	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.19 Crosstab results of the correlation between selected ranks of praying as a favourite hobby and frequency levels of the samples' encounter with coldness from cold-beverage cup

			Praying																Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Cold-Beverage Cup	1	Count	0	1	1	0	0	0	0	0	0	0	1	0	1	0	2	0	6
		% within Reading	.0%	16.7%	9.1%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	10.0%	.0%	100.0%	.0%	33.3%	.0%	4.8%
	2	Count	1	2	2	7	0	1	2	1	0	0	1	0	0	0	0	0	17
		% within Reading	8.3%	33.3%	18.2%	41.2%	.0%	10.0%	50.0%	10.0%	.0%	.0%	10.0%	.0%	.0%	.0%	.0%	.0%	13.7%
	3	Count	4	1	0	2	2	2	0	3	2	0	1	1	0	1	0	1	20
		% within Reading	33.3%	16.7%	.0%	11.8%	20.0%	20.0%	.0%	30.0%	40.0%	.0%	10.0%	14.3%	.0%	16.7%	.0%	20.0%	16.1%
	4	Count	4	1	4	5	3	4	1	1	2	4	4	4	0	2	0	4	43
		% within Reading	33.3%	16.7%	36.4%	29.4%	30.0%	40.0%	25.0%	10.0%	40.0%	100.0%	40.0%	57.1%	.0%	33.3%	.0%	80.0%	34.7%
	5	Count	3	1	4	3	5	3	1	5	1	0	3	2	0	3	4	0	38
		% within Reading	25.0%	16.7%	36.4%	17.6%	50.0%	30.0%	25.0%	50.0%	20.0%	.0%	30.0%	28.6%	.0%	50.0%	66.7%	.0%	30.6%
Total		Count	12	6	11	17	10	10	4	10	5	4	10	7	1	6	6	5	124
		% within Reading	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.20 Crosstab results of the correlation between selected ranks of praying as a favourite hobby and frequency levels of the samples' encounter with heat from food package

			Praying																Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Food Package	1	Count	1	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	4
		% within Reading	8.3%	.0%	.0%	.0%	.0%	10.0%	.0%	10.0%	.0%	.0%	.0%	14.3%	.0%	.0%	.0%	.0%	3.2%
	2	Count	2	1	0	3	1	0	0	3	5	0	2	0	0	1	2	0	20
		% within Reading	16.7%	16.7%	.0%	17.6%	10.0%	.0%	.0%	30.0%	100.0%	.0%	20.0%	.0%	.0%	16.7%	33.3%	.0%	16.1%
	3	Count	3	3	5	9	2	5	0	3	0	0	2	3	0	2	1	1	39
		% within Reading	25.0%	50.0%	45.5%	52.9%	20.0%	50.0%	.0%	30.0%	.0%	.0%	20.0%	42.9%	.0%	33.3%	16.7%	20.0%	31.5%
	4	Count	4	1	3	2	5	3	4	2	0	2	2	1	0	1	1	3	34
		% within Reading	33.3%	16.7%	27.3%	11.8%	50.0%	30.0%	100.0%	20.0%	.0%	50.0%	20.0%	14.3%	.0%	16.7%	16.7%	60.0%	27.4%
	5	Count	2	1	3	3	2	1	0	1	0	2	4	2	1	2	2	1	27
		% within Reading	16.7%	16.7%	27.3%	17.6%	20.0%	10.0%	.0%	10.0%	.0%	50.0%	40.0%	28.6%	100.0%	33.3%	33.3%	20.0%	21.8%
Total		Count	12	6	11	17	10	10	4	10	5	4	10	7	1	6	6	5	124
		% within Reading	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.21 Crosstab results of the correlation between selected ranks of party as a favourite hobby and frequency levels of the samples' encounter with heat from hot-beverage cup

			Party																Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Hot-Beverage Cup	1	Count	1	1	2	1	2	1	1	2	0	0	1	3	0	0	0	0	15
		% within Reading	7.7%	7.1%	6.5%	3.8%	10.5%	5.9%	6.3%	33.3%	.0%	.0%	16.7%	37.5%	.0%	.0%	.0%	.0%	8.1%
	2	Count	2	3	10	2	7	1	0	0	1	2	1	1	1	2	1	0	34
		% within Reading	15.4%	21.4%	32.3%	7.7%	36.8%	5.9%	.0%	.0%	10.0%	20.0%	16.7%	12.5%	20.0%	100.0%	100.0%	.0%	18.3%
	3	Count	3	2	9	7	4	0	6	0	0	1	0	2	1	0	0	2	37
		% within Reading	23.1%	14.3%	29.0%	26.9%	21.1%	.0%	37.5%	.0%	.0%	10.0%	.0%	25.0%	20.0%	.0%	.0%	100.0%	19.9%
	4	Count	1	3	6	11	3	8	3	2	3	3	1	1	1	0	0	0	46
		% within Reading	7.7%	21.4%	19.4%	42.3%	15.8%	47.1%	18.8%	33.3%	30.0%	30.0%	16.7%	12.5%	20.0%	.0%	.0%	.0%	24.7%
	5	Count	6	5	4	5	3	7	6	2	6	4	3	1	2	0	0	0	54
		% within Reading	46.2%	35.7%	12.9%	19.2%	15.8%	41.2%	37.5%	33.3%	60.0%	40.0%	50.0%	12.5%	40.0%	.0%	.0%	.0%	29.0%
Total		Count	13	14	31	26	19	17	16	6	10	10	6	8	5	2	1	2	186
		% within Reading	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.22 Crosstab results of the correlation between selected ranks of party as a favourite hobby and frequency levels of the samples' encounter with heat from cooking device

			Party																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Cooking Device	1	Count	0	2	1	1	5	1	2	0	0	1	1	2	0	0	0	0	16
		% within Reading	.0%	14.3%	3.2%	3.8%	26.3%	5.9%	12.5%	.0%	.0%	10.0%	16.7%	25.0%	.0%	.0%	.0%	.0%	8.6%
	2	Count	3	5	6	7	9	3	0	2	2	2	2	1	0	2	1	0	45
		% within Reading	23.1%	35.7%	19.4%	26.9%	47.4%	17.6%	.0%	33.3%	20.0%	20.0%	33.3%	12.5%	.0%	100.0%	100.0%	.0%	24.2%
	3	Count	5	3	13	6	2	3	7	1	4	3	1	0	1	0	0	0	49
		% within Reading	38.5%	21.4%	41.9%	23.1%	10.5%	17.6%	43.8%	16.7%	40.0%	30.0%	16.7%	.0%	20.0%	.0%	.0%	.0%	26.3%
	4	Count	4	3	7	8	2	8	4	1	2	1	1	4	0	0	0	1	46
		% within Reading	30.8%	21.4%	22.6%	30.8%	10.5%	47.1%	25.0%	16.7%	20.0%	10.0%	16.7%	50.0%	.0%	.0%	.0%	50.0%	24.7%
	5	Count	1	1	4	4	1	2	3	2	2	3	1	1	4	0	0	1	30
		% within Reading	7.7%	7.1%	12.9%	15.4%	5.3%	11.8%	18.8%	33.3%	20.0%	30.0%	16.7%	12.5%	80.0%	.0%	.0%	50.0%	16.1%
Total		Count	13	14	31	26	19	17	16	6	10	10	6	8	5	2	1	2	186
		% within Reading	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.23 Crosstab results of the correlation between selected ranks of shopping as a favourite hobby and frequency levels of the samples' encounter with heat from mobile phone

			Shopping																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Mobile Phone	1	Count	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	2
		% within Reading	.0%	.0%	.0%	4.2%	.0%	6.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.1%
	2	Count	3	4	3	0	3	1	0	1	0	0	0	0	0	0	0	0	15
		% within Reading	15.0%	16.0%	10.7%	.0%	15.0%	6.3%	.0%	8.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	8.0%
	3	Count	1	3	1	0	0	0	1	0	2	1	0	2	0	0	0	0	11
		% within Reading	5.0%	12.0%	3.6%	.0%	.0%	.0%	8.3%	.0%	28.6%	14.3%	.0%	66.7%	.0%	.0%	.0%	.0%	5.9%
	4	Count	2	4	2	3	2	6	1	0	3	3	1	0	0	1	1	1	30
		% within Reading	10.0%	16.0%	7.1%	12.5%	10.0%	37.5%	8.3%	.0%	42.9%	42.9%	25.0%	.0%	.0%	25.0%	50.0%	100.0%	16.0%
	5	Count	14	14	22	20	15	8	10	11	2	3	3	1	3	3	1	0	130
		% within Reading	70.0%	56.0%	78.6%	83.3%	75.0%	50.0%	83.3%	91.7%	28.6%	42.9%	75.0%	33.3%	100.0%	75.0%	50.0%	.0%	69.1%
Total		Count	20	25	28	24	20	16	12	12	7	7	4	3	3	4	2	1	188
		% within Reading	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.24 Crosstab results of the correlation between selected ranks of singing or playing music as a favourite hobby and frequency levels of the samples' encounter with heat from mobile phone

			Singing/ Playing Music																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Mobile phone (heat source)	1	Count	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		% within Singing/ Playing Music	.0%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	1.3%
	2	Count	2	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0	7
		% within Singing/ Playing Music	11.8%	7.1%	5.9%	.0%	3.8%	.0%	9.1%	14.3%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	.0%	4.6%
	3	Count	3	0	0	0	4	3	1	0	0	0	0	0	3	1	0	0	15
		% within Singing/ Playing Music	17.6%	.0%	.0%	.0%	15.4%	25.0%	9.1%	.0%	.0%	.0%	.0%	.0%	42.9%	14.3%	.0%	.0%	9.9%
	4	Count	4	2	1	3	3	0	1	0	0	1	1	2	3	3	1	1	26
		% within Singing/ Playing Music	23.5%	14.3%	5.9%	25.0%	11.5%	.0%	9.1%	.0%	.0%	25.0%	50.0%	66.7%	42.9%	42.9%	50.0%	100.0%	17.2%
	5	Count	8	9	15	9	18	9	8	6	9	3	1	1	1	3	1	0	101
		% within Singing/ Playing Music	47.1%	64.3%	88.2%	75.0%	69.2%	75.0%	72.7%	85.7%	100.0%	75.0%	50.0%	33.3%	14.3%	42.9%	50.0%	.0%	66.9%
Total		Count	17	14	17	12	26	12	11	7	9	4	2	3	7	7	2	1	151
		% within Singing/ Playing Music	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.25 Crosstab results of the correlation between selected ranks of planting or animal feeding as a favourite hobby and frequency levels of the samples' encounter with direct sunlight

			Plant / Animal Feeding																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Direct sunlight	1	Count	0	0	0	1	2	1	0	0	0	0	1	1	0	0	0	0	6
		% within Plant / Animal Feeding	.0%	.0%	.0%	7.7%	18.2%	7.7%	.0%	.0%	.0%	.0%	20.0%	25.0%	.0%	.0%	.0%	.0%	4.4%
	2	Count	0	0	0	2	0	3	0	0	1	1	0	0	0	0	0	1	8
		% within Plant / Animal Feeding	.0%	.0%	.0%	15.4%	.0%	23.1%	.0%	.0%	50.0%	10.0%	.0%	.0%	.0%	.0%	.0%	50.0%	5.9%
	3	Count	0	2	2	2	3	3	4	3	0	0	1	0	0	4	1	0	25
		% within Plant / Animal Feeding	.0%	14.3%	10.5%	15.4%	27.3%	23.1%	40.0%	50.0%	.0%	.0%	20.0%	.0%	.0%	40.0%	12.5%	.0%	18.5%
	4	Count	0	3	2	3	0	3	2	2	0	2	0	0	2	1	4	1	25
		% within Plant / Animal Feeding	.0%	21.4%	10.5%	23.1%	.0%	23.1%	20.0%	33.3%	.0%	20.0%	.0%	.0%	66.7%	10.0%	50.0%	50.0%	18.5%
	5	Count	5	9	15	5	6	3	4	1	1	7	3	3	1	5	3	0	71
		% within Plant / Animal Feeding	100.0%	64.3%	78.9%	38.5%	54.5%	23.1%	40.0%	16.7%	50.0%	70.0%	60.0%	75.0%	33.3%	50.0%	37.5%	.0%	52.6%
Total		Count	5	14	19	13	11	13	10	6	2	10	5	4	3	10	8	2	135
		% within Plant / Animal Feeding	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table C.26 Crosstab results of the correlation between selected ranks of planting or animal feeding as a favourite hobby and frequency levels of the samples' encounter with hot beverage container

			Plant / Animal Feeding																Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Hot beverage container	1	Count	1	0	2	3	2	1	0	0	0	0	2	0	0	0	0	0	11
		% within Plant / Animal Feeding	20.0%	.0%	10.5%	23.1%	18.2%	7.7%	.0%	.0%	.0%	.0%	40.0%	.0%	.0%	.0%	.0%	.0%	8.1%
	2	Count	0	3	3	1	1	4	2	2	1	2	1	0	1	1	1	1	24
		% within Plant / Animal Feeding	.0%	21.4%	15.8%	7.7%	9.1%	30.8%	20.0%	33.3%	50.0%	20.0%	20.0%	.0%	33.3%	10.0%	12.5%	50.0%	17.8%
	3	Count	0	1	3	2	0	2	2	1	0	7	0	1	1	3	2	0	25
		% within Plant / Animal Feeding	.0%	7.1%	15.8%	15.4%	.0%	15.4%	20.0%	16.7%	.0%	70.0%	.0%	25.0%	33.3%	30.0%	25.0%	.0%	18.5%
	4	Count	3	3	10	5	2	4	3	0	0	0	0	0	1	3	2	1	37
		% within Plant / Animal Feeding	60.0%	21.4%	52.6%	38.5%	18.2%	30.8%	30.0%	.0%	.0%	.0%	.0%	.0%	33.3%	30.0%	25.0%	50.0%	27.4%
	5	Count	1	7	1	2	6	2	3	3	1	1	2	3	0	3	3	0	38
		% within Plant / Animal Feeding	20.0%	50.0%	5.3%	15.4%	54.5%	15.4%	30.0%	50.0%	50.0%	10.0%	40.0%	75.0%	.0%	30.0%	37.5%	.0%	28.1%
Total		Count	5	14	19	13	11	13	10	6	2	10	5	4	3	10	8	2	135
		% within Plant / Animal Feeding	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Appendix D

Product's Parts, Assembly, and Applications Drawings

Product Parts and Assembly

1. <u>TEG and Waste-heat Trap Module</u>

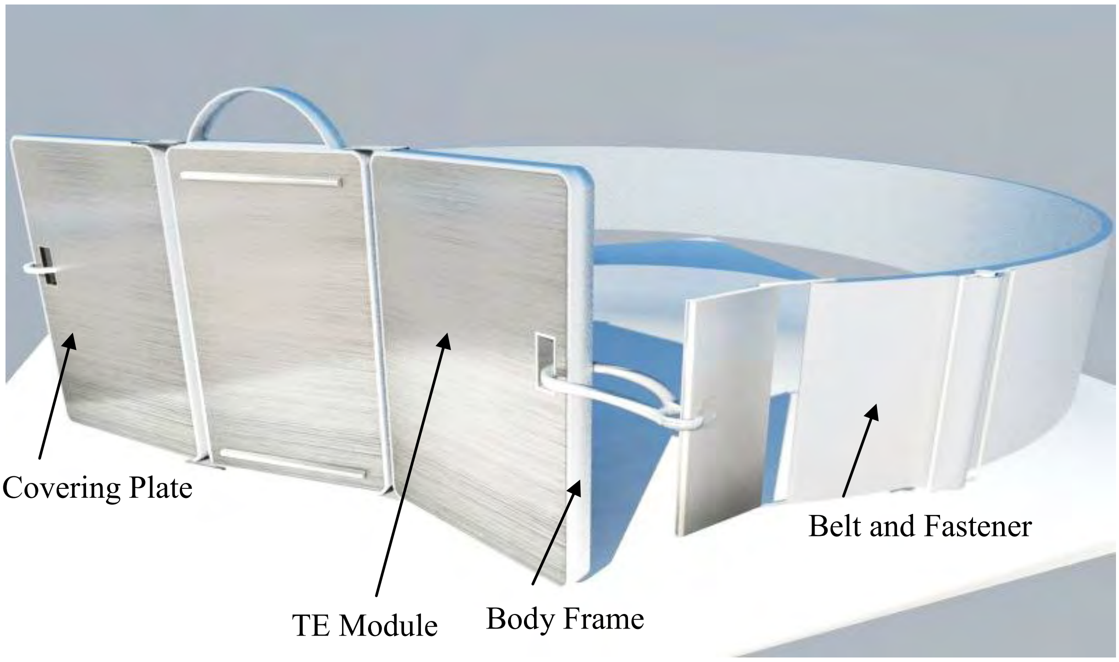

Figure D.1 TEG and waste-heat trap module part

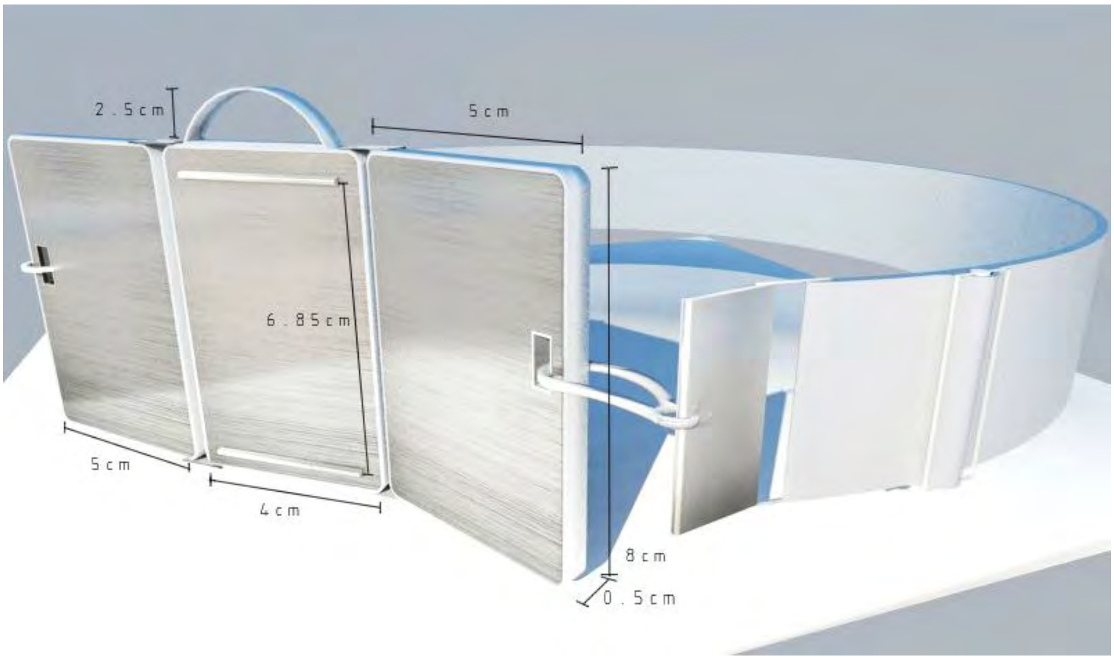

Figure D.2 TEG and waste-heat trap module part with dimensions

2. Solar Thermal Power Input

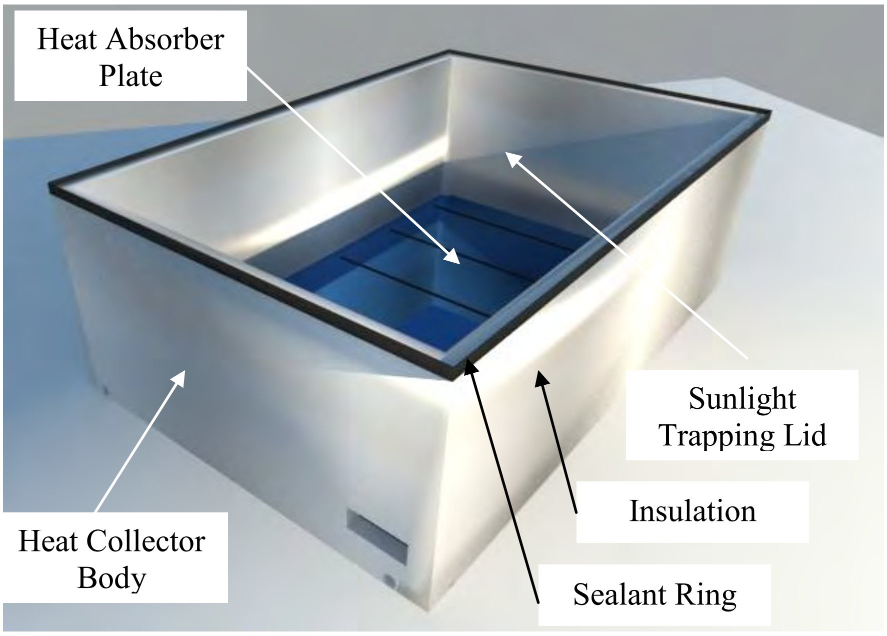

Figure D.3 Solar thermal power input module part

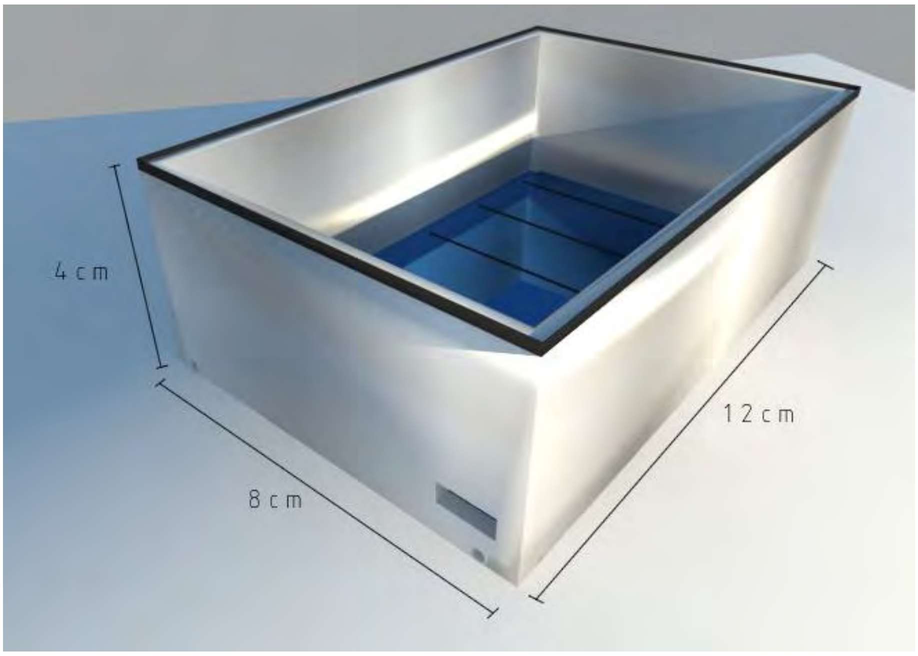

Figure D.4 Solar thermal power input module part with dimensions

3. Heat Sink Module

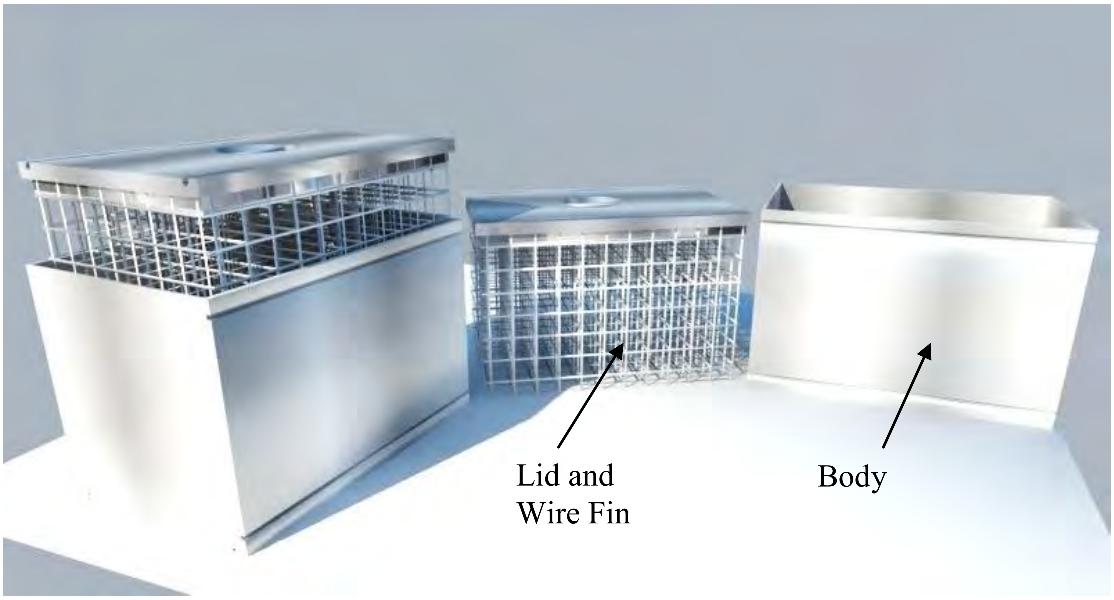

Figure D.5 Heat sink module part

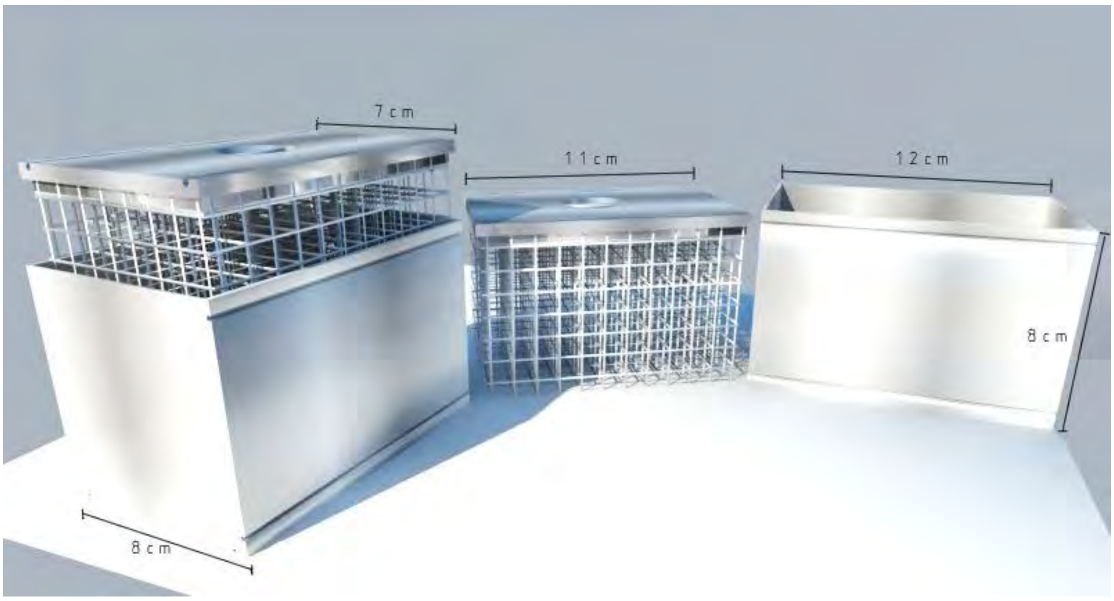

Figure D.6 Heat sink module part with dimensions

4. Charge Controller Case and Battery Module

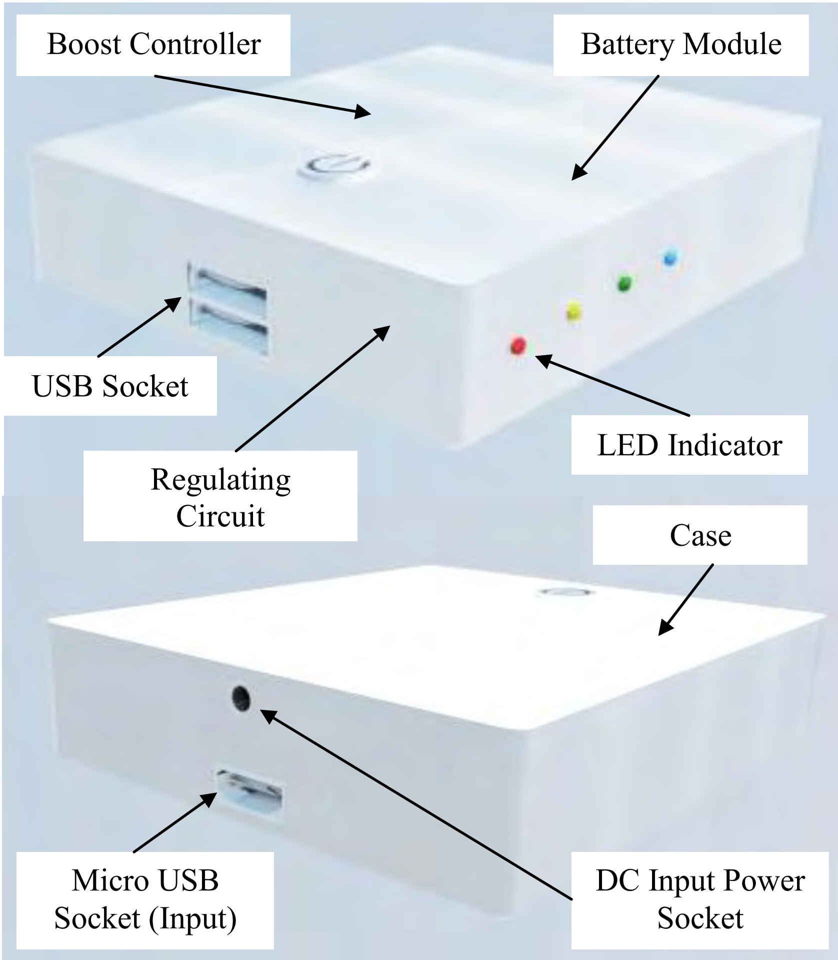

Figure D.7 Charge controller case and battery module part

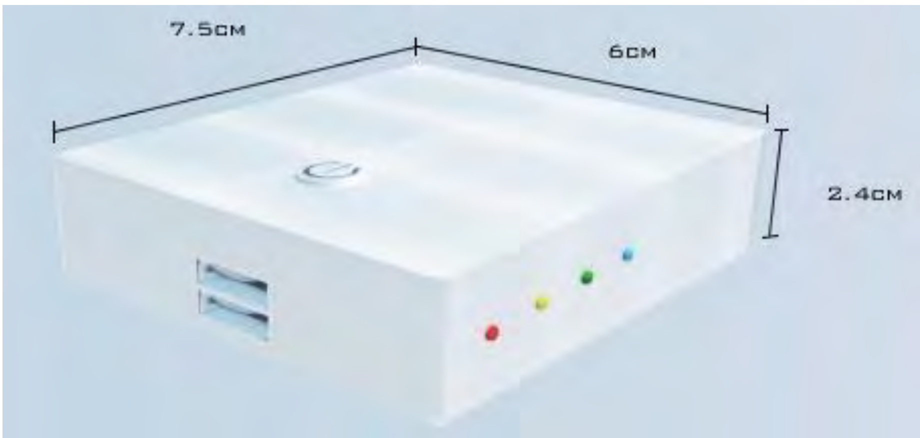

Figure D.8 Charge controller case and battery module part with dimensions

5. Charge Controller Circuit (Boost Converter)

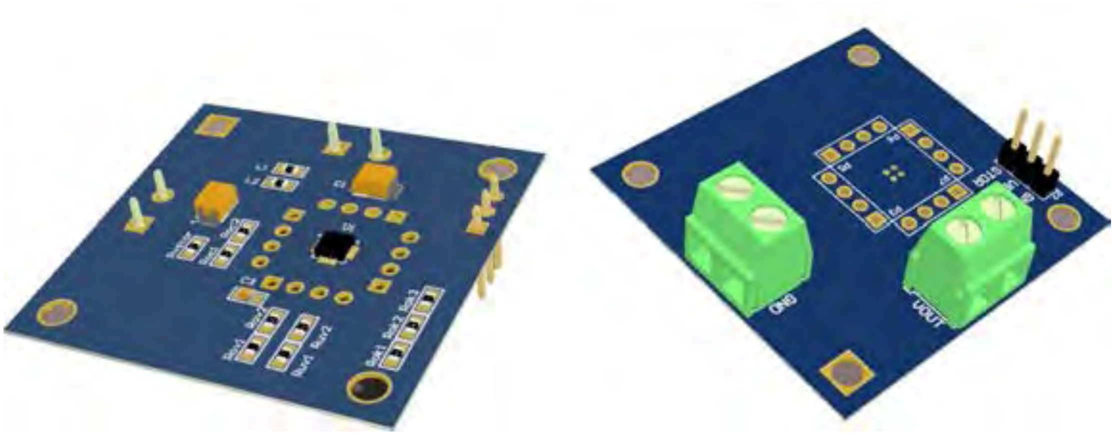

Figure D.9 Charge controller circuit (ultra low power boost converter) prototype

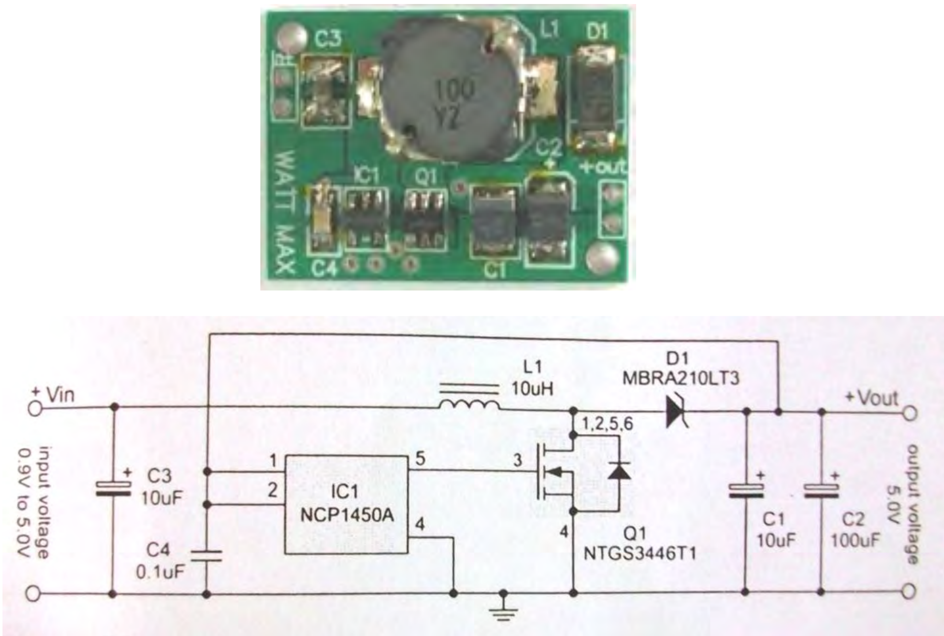

Figure D.10 A commercial 1.5-to-5.0V/1A boost converter “Smart Kit” ™ for boosting power from internal battery toward 5.0-V USB Port

Sample Product Applications for Heat Sources and Sinks

1. Using Heat from Sunlight

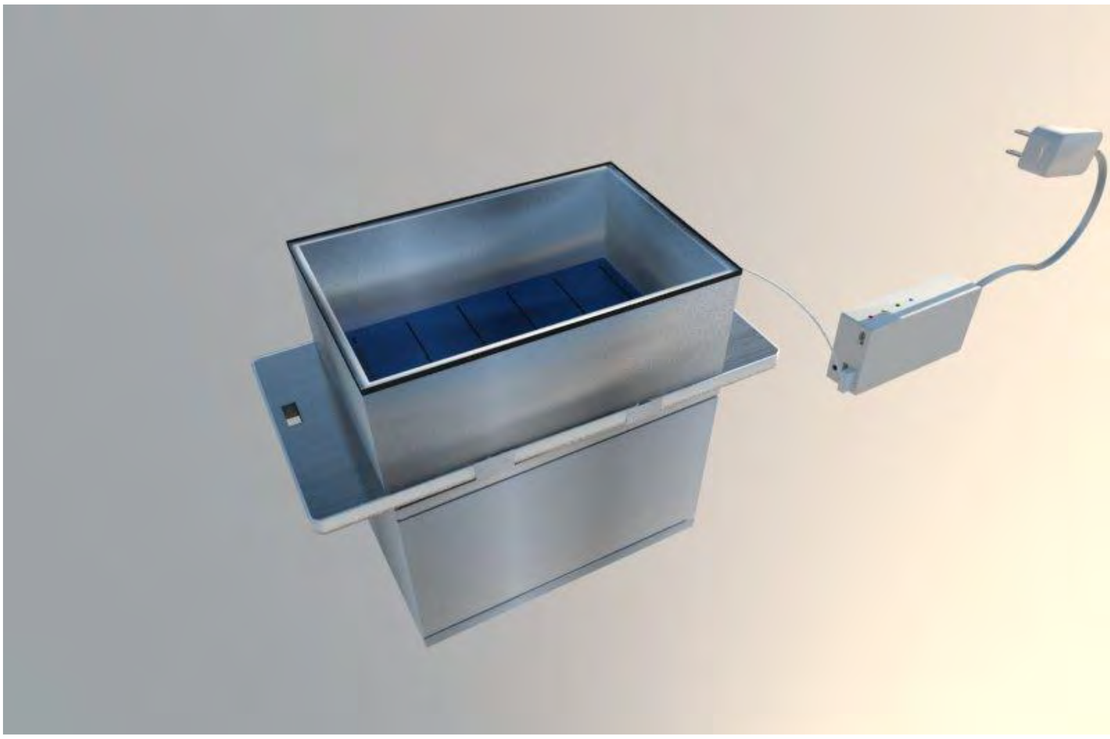

Figure D.11 Product components applied with heat from sunlight

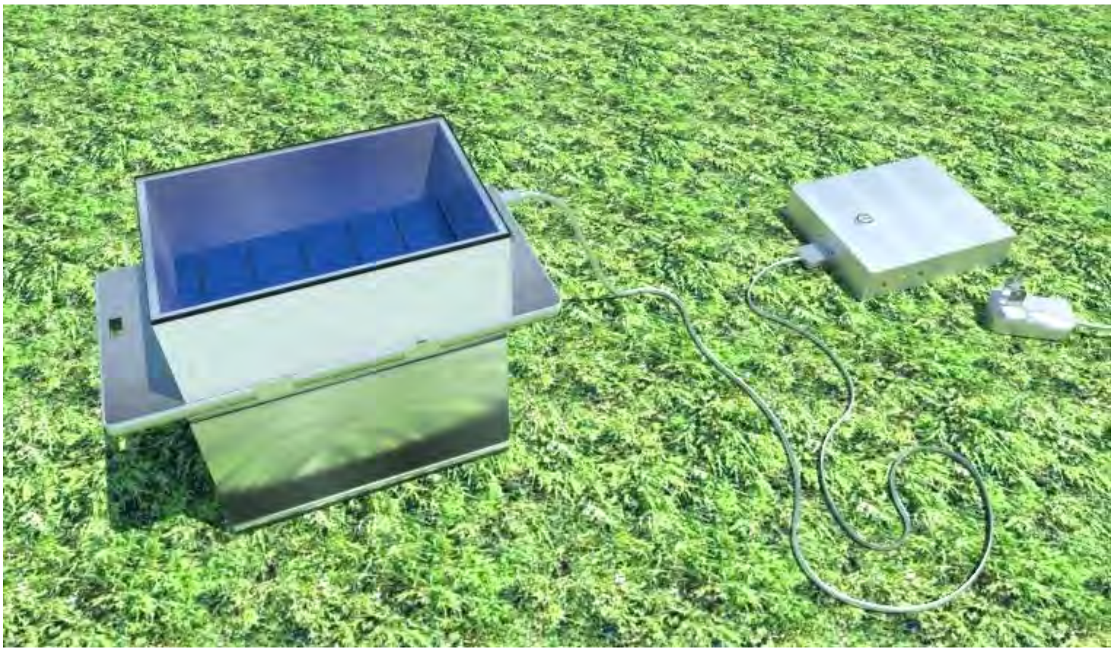

Figure D.12 Product application with heat from sunlight

2. <u>Using with Hot Container / Cooking Device</u>

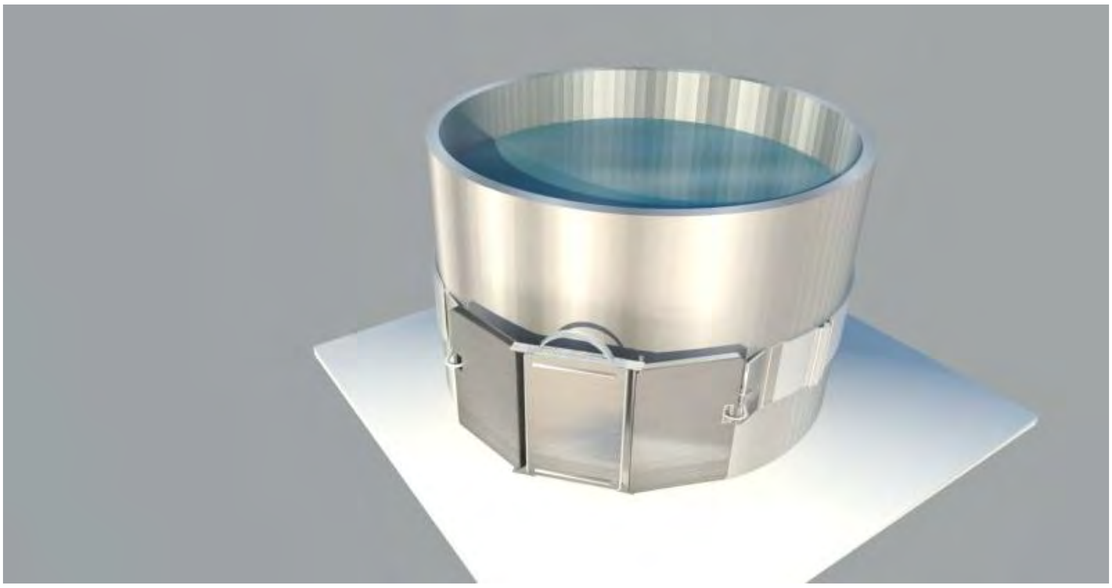

Figure D.13 Product components applied with heat from a hot container / cooking device

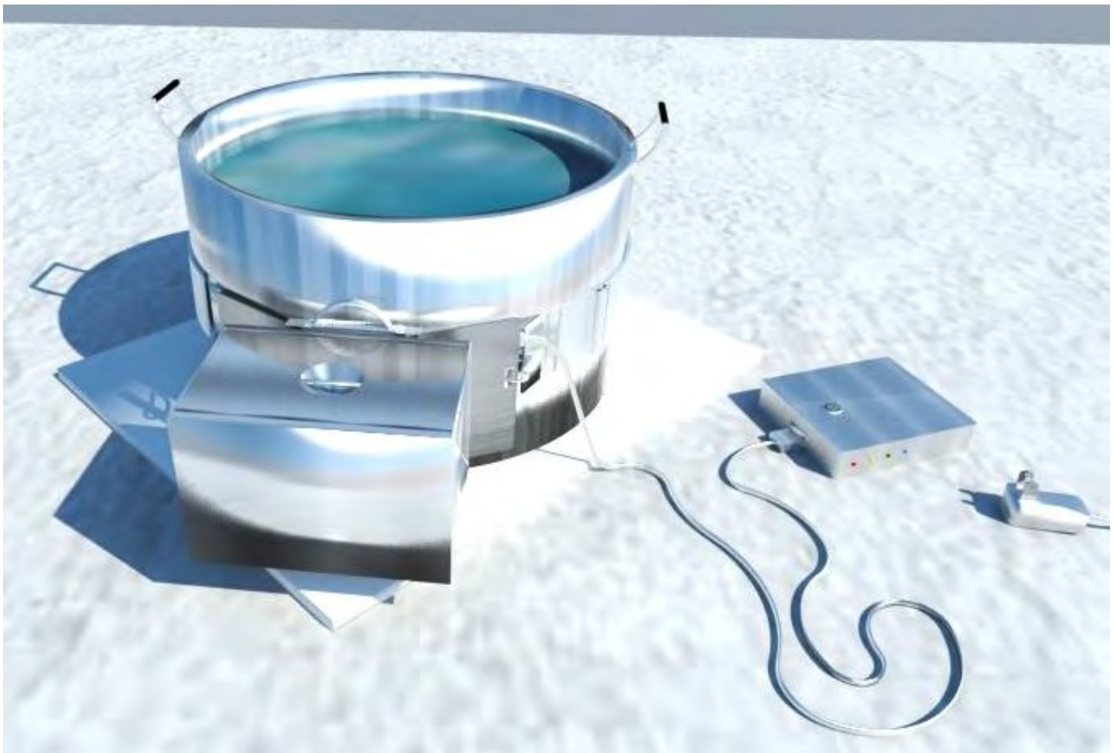

Figure D.14 Product application with heat from a hot container/ cooking device

3. Using with Hot / Cold Container

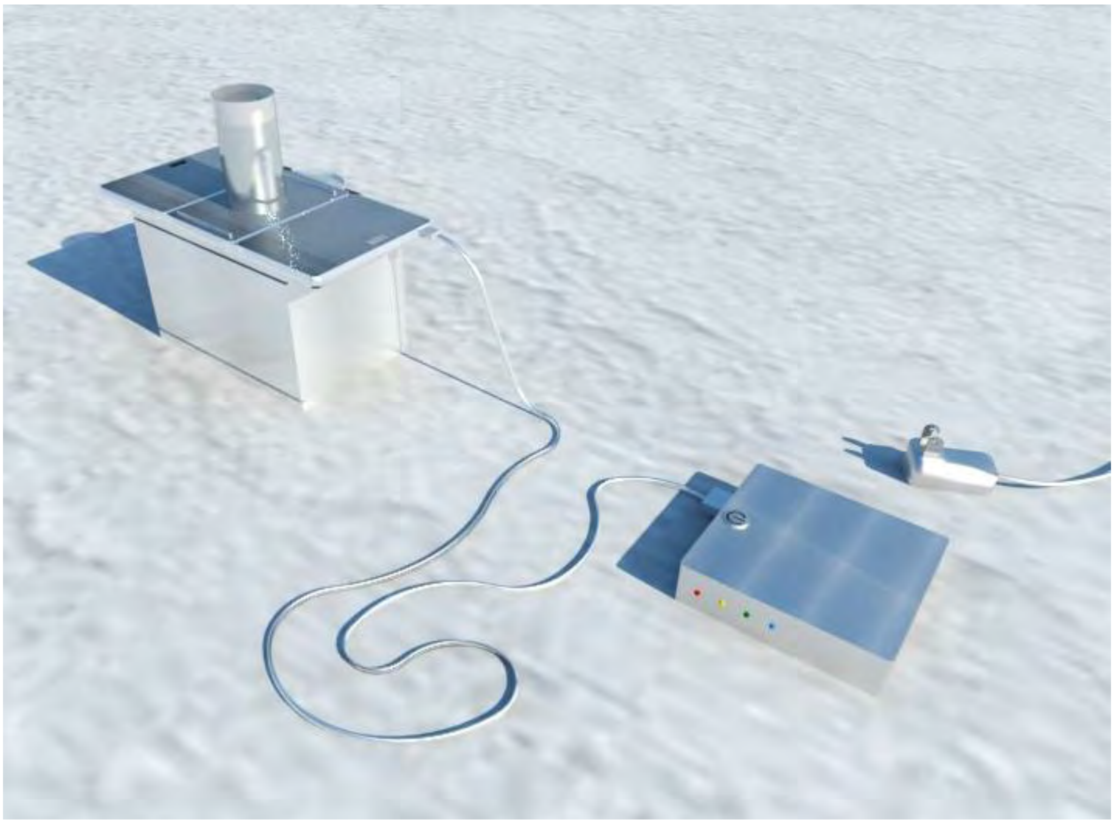

Figure D.15 Product application with heat from a hot/cold beverage container

Biography

Mr. Surapree Maolikul was born on Thursday 22nd May, 1980 in Bangkok, Thailand. The author graduated for a bachelor’s degree of engineering (mechanical engineering) from Chulalonkorn University in 2001, and for a master’s degree of engineering (industrial engineering) from Chulalonkorn University in 2004. The author used to work as a lecturer for the department of industrial engineering, Dhurakij Pundit University from 2005 to 2006. The author has been working as an analyst for commercial and international marketing for oil business unit in PTT public company limited, Thailand since 2006.