EFFECTIVENESS OF PELTIER COOLING DEVICE IN REDUCING THE AIR TEMPERATURE OF ROOMS IN BUILDINGS

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EFFECTIVENESS OF PELTIER COOLING DEVICE IN REDUCING AIR TEMPERATURE OF ROOMS IN BUILDINGS

BY

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LIST OF ABBREVIATIONS

A/C	Air-conditioner
AC	Alternative Current
ACS	Air-Conditioning Systems
AS1	Application Strategy 1
AS2	Application Strategy 2
ASHRAE	American Society of Heating Refrigerating and Air-conditioning Engineers
BTU	British Thermal Unit
CETDEM	Center for Environment Technology and Development
CFC	Chlorofluorocarbon
Con.	Conductivity
Config.	Configuration
DC	Direct Current
EQ	Environmental Quality
GBI	Green Building Index

GHG	Green House Gases
HTV	Hybrid Turbine Ventilator
IS	Internal Space
ISO	International Standard Organization
LEED	Leadership in Energy and Environmental Design
N $_{Module}$	Number of Modules
PC	Peltier Cooler
PCD	Peltier Cooling Device
PD	Peltier Device
MCT	Malaysian Thermal Comfort
MMD	Malaysian Meteorological Department
MTC	Malaysian Thermal Comfort
ODP	Ozone Depletion Potential
PMV	Predicted Mean Vote
PPD	Percentage of People Dissatisfaction
PV	Photovoltaic

Pel. Peltier

SI International Unit System

TEC Thermoelectric Cooler

TECD Thermoelectric Cooling Device

VCS Vapor Compression System

LIST OF SYMBOLS AND NOMENCLATURE

GI(S) = Transfer function model of the thermoelectric cooler

I = Current (A)

K = Thermal conductivity

N = Number of thermocouple

Q_C = Cooling capacity (W)

Q_{Con} = Heat transfer by conduction (W)

Q_J = Joule heat generation rate (W)

Q_L= Cooling load of the thermoelectric cooler (W)

Q_{Pel} = Peltier effect (W)

RH % = Relative humidity

Ta= Ambient temperature (°C)

T_C = Cold side Temperature of PCD (°C)

TE = Temperature of enclosure (°C)

TE1= Temperature of enclosure in application strategy one (°C)

TE2= Temperature of enclosure in application strategy two (°C)

$TE_{net =}$ Temperature of enclosure without PCDs (°C)

T_H = Hot side temperature of PCD (K) (°C)

TH_{Start} = Hot side temperature of PCD in the beginning of PCD operation (°C)

TH_{End} = Hot side temperature of PCD at the end of PCD operation (°C)

T_{Imp} = Temperature improvement (°C)

TR = Temperature of room application strategy one (°C)

TR1 = Temperature of room in application strategy two (°C)

TR2 =Temperature of room (°C)

TR_{net} = Temperature if room with air-conditioning (°C)

TL= Temperature at the cold side of thermoelectric module (°C)

ρ = Electrical Resistivity (Ω cm)

ΔT = Temperature difference (°C)

α = Seebeck coefficient (VK^{-1})

KEBERKESANAN PERANTI PENYEJUKAN PELTIER DALAM PENGURANGAN SUHU UDARA BAGI BILIK DI DALAM BANGUNAN

ABSTRAK

Penggunaan berlebihan penyaman udara bagi menyejukkan bilik dalaman di dalam sebuah bangunan bagi keselesaan terma manusia boleh merosakan planet kita disebabkan oleh bahan penyejuk yang merbahaya dan penggunaan tenaga yang tinggi secara tabie untuk sistem penyejukan ini. Oleh itu penganti bagi sistem ini dengan Peranti Penyejukan Peltier (PCDs) yang lebih mesra alam adalah amat digalakkan. Tetapi, penggunaan PCDs di dalam bangunan masih lagi minimum yang mana kapasiti penyejuk terhad bagi mengurangkan kemampuan peranti dalam penjanaan kesan penyejukan dan menyebabkan penurunan suhu di dalam ruang tertutup. Oleh itu, kajian ini dijalankan untuk menambah-baik penurunan suhu bagi peranti penyejukan Peltier melalui strategi aplikasi yang sesuai supaya ianya boleh digunakan bagi mengurangkan suhu ruang dalaman bangunan. Analisis data bagi ekperimen fizik mendapati bahawa terdapat penambah-baikan penurunan suhu sebanyak 0.75-0.78 °C bagi setiap PCD beroperasi ke atas bilik dalaman apabila suhu bangunan keseluruhan menurun sebanyak 5 °C bagi aplikasi strategi dua (AS2). Oleh itu strategi ini adalah sesuai sekali untuk meningkatkan keupayaan peranti dalam menurunkan penurunan suhu bilik dalaman. Tambahan lagi, keselesaan terma Malaysia (MTC) untuk setiap meter isipadu ruang dalaman bangunan boleh dipenuhi dengan seunit hingga lima unit PCD bagi suhu normal sehingga 32 °C; sementara MTC boleh dicapai untuk julat suhu lebih tinggi bagi ruang dalaman 33-37 °C apabila suhu bilik keseluruhan menurun sebanyak 5 °C dengan bantuan sebarang jenis sistem penyejukan, seperti mana aplikasi strategi dua.

EFFECTIVENESS OF PELTIER COOLING DEVICE IN REDUCING THE AIR TEMPERATURE OF ROOMS IN BUILDINGS

ABSTRACT

The excessive usage of air-conditioning to cool internal room in a building for human thermal comfort is harming our planet due to their hazardous refrigerants and the high energy consumption nature of these cooling systems. Hence replacement of these systems with the Peltier Cooling Device (PCDs) which are more environmental friendly is highly encouraged. However, the application of PCDs in Buildings has remained minimal as they have limited cooling capacities that reduces the ability of the device in generating cooling effect and causing temperature reduction in enclosed spaces. Thus the present study seeks to improve the temperature reduction by the Peltier Cooling Device through an appropriate application strategy so that they can be used for reducing the temperature of buildings internal spaces. The data analysis of physical experiments revealed that there is a temperature reduction improvement of 0.75-0.78 °C by each PCD operating on the internal room when the overall building temperature is dropped by 5 °C in the application strategy two (AS2). Hence this strategy is the appropriate one to enhance the ability of the device in reducing the temperature reduction of the internal room. Moreover the Malaysian thermal comfort (MTC) for each cubic meter of the building internal spaces could be fulfilled with one to five modules of PCDs in normal room temperature up to 32 ° C; while the MTC can be achieved for internal spaces of higher temperature range 33 ° C – 37 ° C when the overall room temperature is dropped by 5 ° C with the assistance of any type of cooling system, likewise the application strategy two.

CHAPTER 1

INTRODUCTION

1.1 Background

Buildings are responsible for 40% of the world greenhouse gas emissions; which is certainly the main agent of the global warming (Snowdon, 2009) and with the rise in the average surface temperature of earth, dependence on the artificial cooling systems in buildings has drastically increased during past many decades. Initially the air- conditionings were envisaged to fulfill the occupant thermal comfort; but gradually with the rise in the living standards and the changes in the lifestyle of people, they have obtained more importance as a house gadget. However, after the energy crises of the early 70s, there is a need to cut down the excessive usage of the air conditioning systems (Priyadarsini et al., 2004); that holds the biggest share of the total energy consumption in building sector reaching to about 50% in South East Asian countries (Ahmed, 2008).

With regards to the high amount of energy consumption for building cooling, as seen in Figure 1.1; many researcher architects and engineers have aimed to replace the air conditioning fully or partially with an environmental friendly cooling method. These methods must be efficient and simultaneously able to maintain the indoor air temperature of the room within an acceptable range for occupants’ thermal comfort (Ismail, 2010). Moreover it has been dais that; the natural ventilation alone cannot achieve peoples thermal comfort in Malaysia especially in the urban area where lot of strategic planning in microclimate of buildings surrounding is required (Zain et al., 2007).

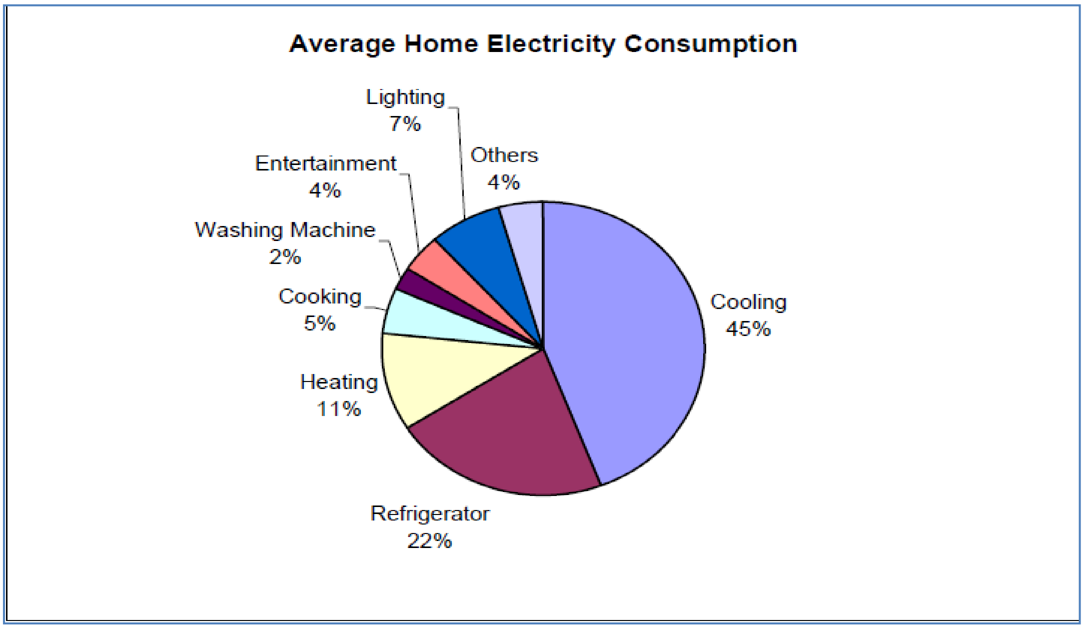


Figure 1.1: Year 2006 study of household energy use by CETDEM – Center for Environment, Technology and Development, Malaysia (Aun, 2009).

Moreover, it has been said that the use of all mechanical cooling systems in buildings is a necessity for the hot and humid climatic condition (Abdul Rahman, 1994). Therefore the cooling device adopted to maintain the indoor temperature is preferred to have a similar functioning of the air conditioning system and also it must be an eco-friendly one.

One of the existing system with all the above mentioned qualities is the thermo-electric cooler (TEC) or the Peltier Cooling Device (PCD). This devise is suitable for the present time to deal with the environmental regulations and CFC release (Riffat & Ma, 2003). As compared to vapor compression air-conditioner which has ozone layer depletion potential and expensive absorption air-conditioner with sophistications and bulkiness, is more eco-friendly due to the absence of refrigerants and reliable, with lesser noise (Riffat & Qiu, 2004); light weight with no mechanical moving parts which saves on the maintenance, making a suitable alternative to the present air conditioning systems.

In spite of the low cooling capacity of the Peltier Device, the research shows that the performance of Peltier devices are better when functioned as air conditioners rather than a refrigerant as they demand smaller temperature differences (Bansal & Martin, 2000). Yet the application of PCD in various fields such as military and aerospace, industrial temperature control, electronic cooling and restaurant equipments are more as compare to building space cooling usage. The single reason for that is the low cooling capacity of the device (Riffat & Ma, 2004) making it suitable only for small scale air conditioning.

According to Neufert "Air conditioning and ventilation systems should be considered during preliminary planning, as they have a major influence on building design and construction" (Neufert & Peter, 2000). Hence to make the PCDs applicable for indoor space air cooling, it's the role of architects to plan the building zones in accordance with the air reduction ability of the device. This could be done by dividing them into smaller zones; at the same time look for the possibilities to increase the cooling generation of the system through appropriate architectural strategies.

According to the reliability studies of the thermo-electric devices, it is known that the cooling effect of PCDs will decrease when operated above room temperature (Rowe & Min, 1998)**;** which was based on the comparative analysis of temperature data; the final results showed that cooling effectiveness of the Peltier cooler is more when the environment is cooler. Hence considering the ambient temperature as a major factor to influence the performance of the device is an area of research for architects without handling the technical and engineering aspect of the device.

In the final analysis of the device workability it is realized that, the system might have the possibility to reduce the excessive usage of air conditioning by maintaining the temperature of the individual zones within the building on a lower range while the other zones are cooled by the means of air conditioning on a higher temperature range. Nevertheless, the reduction in air temperature of the room even by 1°C not only makes a significant difference in the comfort level of the occupants, but the acclimatization of Malaysian people allows a higher range of thermal comfort band 25.5-28.8°C (Abdul Shukor, 1993) which can criticize the unnecessary low temperature in the internal spaces of buildings that is not required.

In addition, setting the same on higher temperature range can save on the monthly electricity bill (Abdul Rahman *et al*., 2011). The overall energy use in buildings will decrease by a reduction in overall usage of cooling energy, especially in hot and humid regions. On the other hand, when the temperature is set at a low temperature, the air conditioning unit has to consume more energy to function (Ismail, 2000). Rather, there can be a big save on each building expense and the amount of CO_2 emissions over a year, by simply setting the air conditioning thermostat to just one degree higher (Quisenberry & DeVilbiss, 1996).

The entire studies demonstrate that the cooling capacity of the PCDs is likely to be increased**;** while operating in relatively cooler ambient that leads to the improvement of the cooling generation of the device. However the quantitative data are required for the architectural understanding with the real building situation (Wouters et al., 1998) and in spite of the experimental work that has been done for small scale conditioning in buildings by Gillot et al. (2010) still there is a need to investigate the cooling effectiveness of this device regarding the indoor air temperature reduction in internal spaces of buildings. Therefore the capability of the device has to be confirmed before it is accepted as an appropriate cooling means in buildings, through comprehensive empirical studies.

1.2 Problem Statement

The cooling system for the present time must deal with the environmental regulations and CFC release like the thermoelectric cooling device (Riffat and ma 2003) As compared to vapor compression air-conditioner which has ozone layer depletion potential and expensive absorption air-conditioner with sophistications and bulkiness, these cooling devices are more Eco friendly due to the absence of refrigerants and more reliable, with less noise, vibration (Riffat & Qiu, 2004) and many more merits over the air conditioning systems such as their light weight and no mechanical moving parts which saves on the maintenance cost. These devices are widely known for their industrial and other small scale air conditioning applications; however their application in buildings has remained minimal; however there is only a single report to describe the devise behavior in space cooling with building qualities (Kim et al., 2001). The single issue of low heat transfer (Rowe & Min, 1998) or the low cooling capacity of the TEC (Riffat & Ma, 2004) that results in limited temperature reduction.

Even though the cooling effect generated by the PCDs are tested and their abilities as a cooler is proven under laboratories controlled environmental conditions but due to their only drawback which is the cooling load constraints or the low cooling capacity that makes it impossible for the device to handle large heat loads (Riffat & Ma, 2003). Hence the temperature reduction of the indoor space which is cooled by the PCD is less and at last the temperature reduction by the peltier cooling devices for internal spaces of buildings needs to be improved.

1.3 Research Questions

Deployment of the Peltier cooling Devices are considered to be one of the most environmental friendly cooling method, however the low cooling capacity of the device demands for further investigations. Hence, with regards to the ability of the PCDs in reducing the indoor temperature; the following questions of the research have been formulated.

1. What is the range of air temperature reduction by the PCDs in a specific volume?
2. What is the appropriate application strategy to improve the temperature reduction by PCDs?
3. What is the range of further temperature reduction by PCD in the specific volume?

All the above mentioned questions will lead to the main question of:

What is the extent of PCDs effectiveness in reducing temperature of rooms with different ambient temperature?

1.4 Research Objectives

1. To find the exact range of temperature reduction by the PCDs in a specific volume.
2. To improve the temperature reduction of the rooms by the PCDs through an appropriate application strategy.

3. To attain the extent of temperature reduction improvement of building rooms by the PCDs.

And all of these are to fulfill the main objectives of the thesis which is "to determine the effectiveness of the PCD in reducing the temperature of rooms in different ambient temperature".

1.5 Research Approach and Methods

At the outset of the research after finding the low cooling capacity as the main issue of the Peltier cooling device, resulting in limited temperature reduction of buildings indoor spaces; all the related literatures in the field of study was reviewed to find various configurations of the PCD and also the possible application strategies which can enhance the temperature reductions. Subsequently, the empirical studies was carried out in three consistent stages; the pilot studies and main physical experiments which have two individual stages to fulfill the objectives of the study and answer the research questions stated in Section 1.3 and 1.4 as shown in Figure 1.2.

After the selection of appropriate device configuration in pilot study one, the same assembly was used to conduct the pilot study two in which the temperature reduction ability of the device under different ambient temperatures was observed. After the strategy to improve the temperature reduction was found to be effective the main physical experiment in larger scale was held to test the temperature reduction of indoor spaces and the temperature reduction improvement under the appropriate strategies. The main physical experiments observe the temperature reductions that can be achieved in the internal spaces by different numbers of Peltier cooling devices and in two different volumes of spaces. Once the appropriate number of modules and the temperature reduction by these modules in the specific volumes was found the same internal space with the fixed number of modules was tested within different room temperatures and finally the temperature reduction of PCDs outer sides is noted down to arrive at the range of temperature reduction improvements.

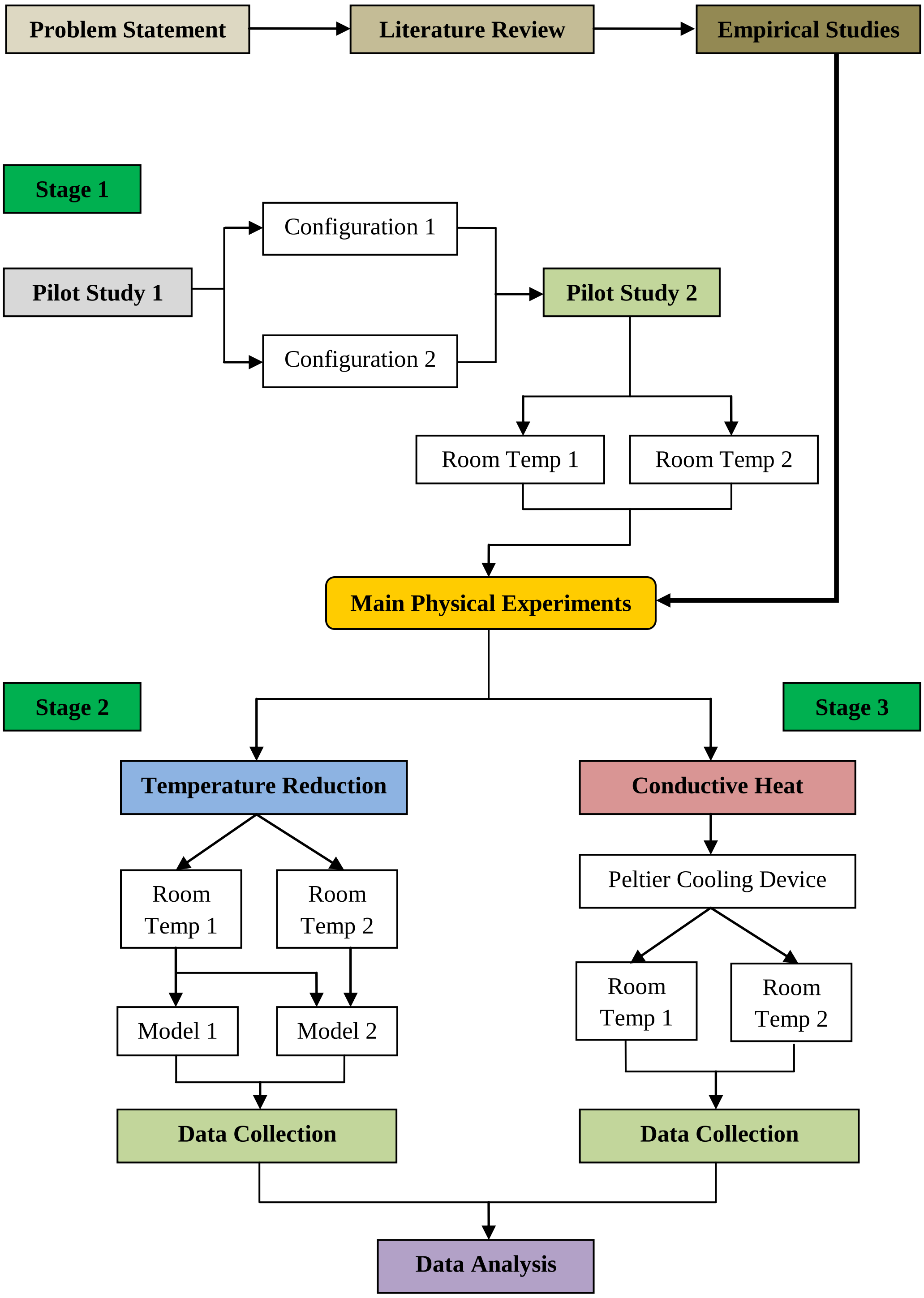


Figure 1.2: The methods and stages employed to improve the temperature reduction of Peltier cooling devices (PCD).

1.6 Scope and Limitations

The entire experimental work of the present thesis was carried out using the Peltier Device TEC1-12705; in spite of the wide range of models with higher cooling capacity levels and different design, the non-availability of them in the Malaysian market has limited the study to the existing one. However the complexity and high expenses would have been unnecessary and in the other hand the simplicity of the purchased device can help the research work to be held easily and be more understandable for future scholars who would like to develop researches on the same.

Although all the three environmental factors; the air temperature, relative humidity and the average air velocity are effective on the human comfort (Stoecker & Jones, 1982)**;** but in this thesis only the range of air temperature reduction by the Peltier cooling devices is studied and also compared to the thermal comfort band; for investigating the possibilities of the PCDs implementation to improve the temperature of buildings internal spaces.

Heat infiltration and tentative ambient condition will affect the accuracy of the data, hence the experiments has to be repeated and observed again or a minor amend has to be done before going to the next steps of data collection. Moreover data acquisitions systems adopted that is operated by electricity tends to reset during blackouts or the power usage.

There is a scope of implementing the product of the present thesis for every type of buildings internal space cooling and developing the same by adding the photovoltaic panels to make its way to the future most efficient building air cooling system or using the PCDs as the complementary air cooler along with the existing air conditioning systems to cut down the energy wasted thermostats low temperatures.

1.7 Significance of Research

The significance of the study on the improvement of the temperature reduction by the Peltier cooling device for the internal spaces of buildings is as follows:

The main contribution of this study is related to the most important issue of the present time i.e. the global warming which is caused by the undue energy consumption. The adoption of Peltier Cooling Device as an alternative cooling method will reduce the excessive electricity usage by the air-conditioning systems and increase the demand of renewable energy such as photovoltaic panels that are highly compatible with the PCDs. Hence, the local manufacture of the device will be encouraged and ultimately cost of purchasing the device will be reduced.

The intention to design such an experimental method was to open up new approach in the use of Peltier Cooling Device as an efficient cooling instrument in reducing the temperature in internal space. This Methodology could be adopted by future researchers who would like to further improve the temperature reduction ability of the PCDs. The sequence of the present research method will simplify their experimental work to find the temperature reduction abilities of the device and the ambient affect test on the improvement of the same in small scales before the real implementations.

This study will produce a table for those who would like to incorporate the PCDs for space cooling of the internal spaces; the number of PCDs required for a specific volume and the level of temperature reduction provided in the research will ease the application of the device in space cooling that might even help the individual users to install the cooling system by themselves by referring to the same instructions.

The literatures reviewed and the information provided on the Peltier cooling device (PCD) will be available to the architects, engineers, researchers and others interested in the application of the device as an alternative cooling system that is safe to the environment. These can educate the public about sustainable living by making them realize the importance of green cooling technologies and simultaneously motivating them to adopt the systems as their space cooling gadget.

1.8 Organization of Thesis

The present thesis embraces 5 chapters that are explained as follow:

Chapter 1 provides an overview of why and how the issues related to the temperature reduction ability of the Peltier cooling devices use as an alternative cooling device in buildings at the present thesis are addressed in the form of a background study. It starts with stating the main problem of the PCDs and the hypothesis, followed by the research questions and the objectives; the descriptions of the research methods and approach involved, the scope and limitations that the research is holding and the significance of the same; lastly the concise outline of the thesis has been outlined.

Chapter 2 the fundamentals of building cooling in terms of temperature reduction, heat transfer and the cooling methods are discussed to arrive at the appropriate cooling systems for the hot and humid regions based on the literature. Then, the literatures on the principles of Peltier cooling; the basics of Peltier effect, the technology, the temperature reduction ability and the theories involved in cooling production of the device is reviewed that results in the realization of the most important application strategy to improve the temperature reduction of the indoor spaces. Finally the thermal comfort ranges are explained to calculate the temperature reduction demanded out of the cooling system and the comfort bands upon which the final results of the study is compared and analyzed to declare the capability of the PCDs in fulfilling the thermal comfort in the useful interior spaces.

In **Chapter 3,** the research methods and approaches adopted in the present thesis is discussed. The empirical studies stages; consisting of the pilot studies and main physical experiments with reference to the previously conducted studies on the Peltier cooling device taken from the related literatures are explained.

Chapter 4 presents the analyzed result of the empirical studies that include three main stages of the pilot studies and the main experiments. Firstly results of the pilot studies are discussed and the suitability of the PCD configuration type is decided and the temperature reductions of the pilot study two are analyzed. Then the temperature reduction ranges of each stage in the main physical experiments are compared and the correlations between them and consequently the volume of space, number of PCD modules and different ambient temperatures was found.

Subsequently the temperature of the hot side of the peltier cooling devices operated in the application strategy one was compared to the temperature of the same in the application strategy two and finally the temperature reduction improvements by the PCDs for internal spaces are calculated along with the temperature reduction guidelines as compared to the required Malaysian thermal comfort ranges.

In **Chapter 5** the overall findings and analyzed data are concluded; moreover, the possible implementations of the PCDs into the building envelope are shown, along with a summary of the temperature reductions by the PCDs in the useful interior spaces. Finally the future researches on the application of the device in buildings are recommended.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a compendium of building cooling concepts; temperature, heat transfer and the cooling methods for human's thermal comfort, followed by a review of literatures on the principle of thermoelectric (Peltier) cooling that involves the fundamentals, design, installation and the applications of the Peltier cooling device (PCD) in buildings. Subsequently the theoretical and equations that effects the quantity of cooling production by the device are discussed; in order to derive the possible application strategies to improve the temperature reduction of rooms within a building.

2.2 Temperature and Heat in buildings

Temperature is the heat intensity or the level of heat expressed in Celsius by international unit system (SI), in Fahrenheit by the United States and their absolute scales respectively known as Kelvin and Rankin. The temperature is different from the heat content or the amount of heat which is referred to the "energy in the form of molecules in motion; measured by the British thermal unit (BTU) OR Joule. (Whitman et al., 2009) The heat is never created nor destroyed, it can be only transformed and according to the second law of thermodynamics, it is always transferred from a higher temperature to a lower temperature (Arora, 2000).

The major portion of temperature rise in buildings is due to the constant transfer of ambient heat to the indoor space through their fabrics by conduction, infiltration and radiation which are known as the structural heat gains. These are also known as the outdoor heat sources, whereas the indoor heat sources are produced by the occupants, appliances and lights that in the case of small space cooling such as residential and small offices it is not considered while calculating the heat load, but in the case of commercial buildings or spaces with more number of people, this must be added up to the external heat gains (Lang, 1979).

Moreover among the structural modes of heat transfer, conduction and radiation have larger impact on the indoor space temperature , thus in this study the concentration is on the effect of conduction heat neglecting the radiation as there are no openings in the study models to gain tangible solar radiations.

2.3 Cooling of Buildings

“The goal of rational building design is to provide an environment that is pleasant, comfortable and convenient, and safe” which would be possible through close collaboration of engineers and architects (Kreider et al., 2002); although the cooling demand calculation for buildings and the selection of cooling equipment is the task of mechanical engineers but architects awareness of rules of thumb, peak and annual of load calculations and intermediate level of detailing is certainly required to provide accurate cooling for the indoor spaces (Kreider et al., 2002).

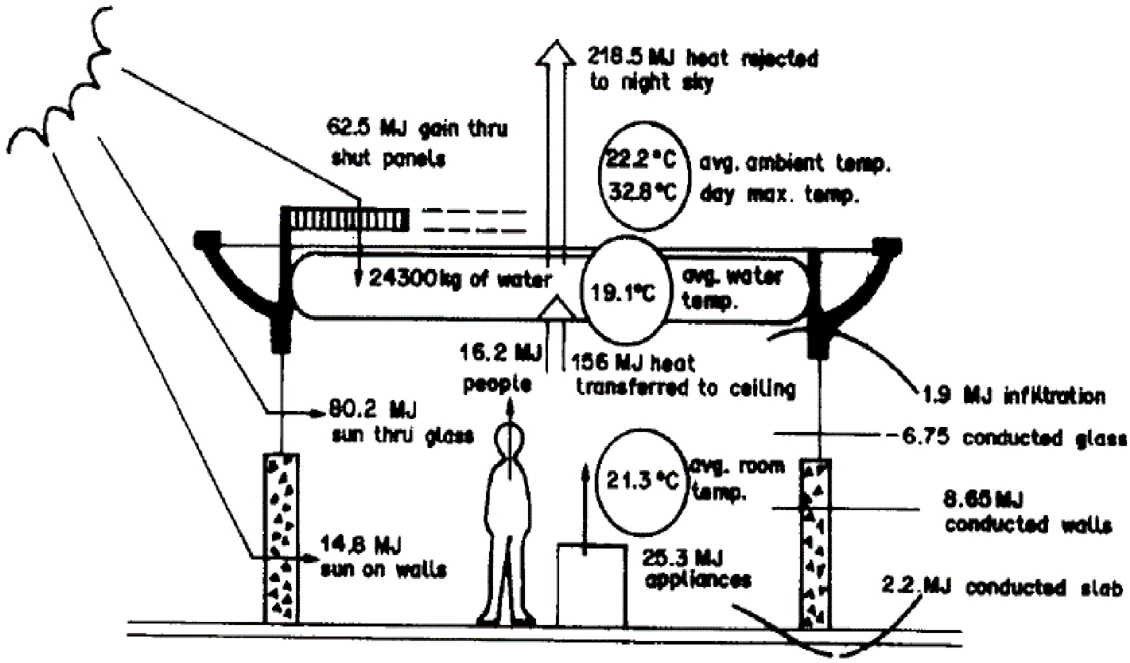


Figure 2.1: Energy flow on a typical cooling day. (Agarwal, 1989)

The awareness of incoming and outgoing heats to the buildings as well as the heats rejected to the sky or conducted through walls and slabs and the glass makes it possible to balance the overall heat loads for cooling of the buildings through design elements (Agrawal, 1989). Hence the cooling methods are the essential for balancing the heat to achieve indoor temperature reduction and cause thermal comfort in building spaces.

2.3.1 Building Cooling Methods

2.3.1.1 Natural and Passive

Natural and passive cooling of the building means to dissipate indoor heat by design techniques without the assistance of mechanical systems. The passive cooling is referred to the methods which prevent or modulate heat gain of the indoor space (Santamouris & Asimakopoulos, 1996). Some of the passive cooling techniques include evaporative cooling, wind towers, earth tunnels and appropriate shading. Whereas natural cooling involves the usage of natural heat sink (Santamouris & Asimakopoulos, 1996); such as the use of natural ventilation. The illustration of passive systems for building cooling and heating is shown in Figure 2.2.

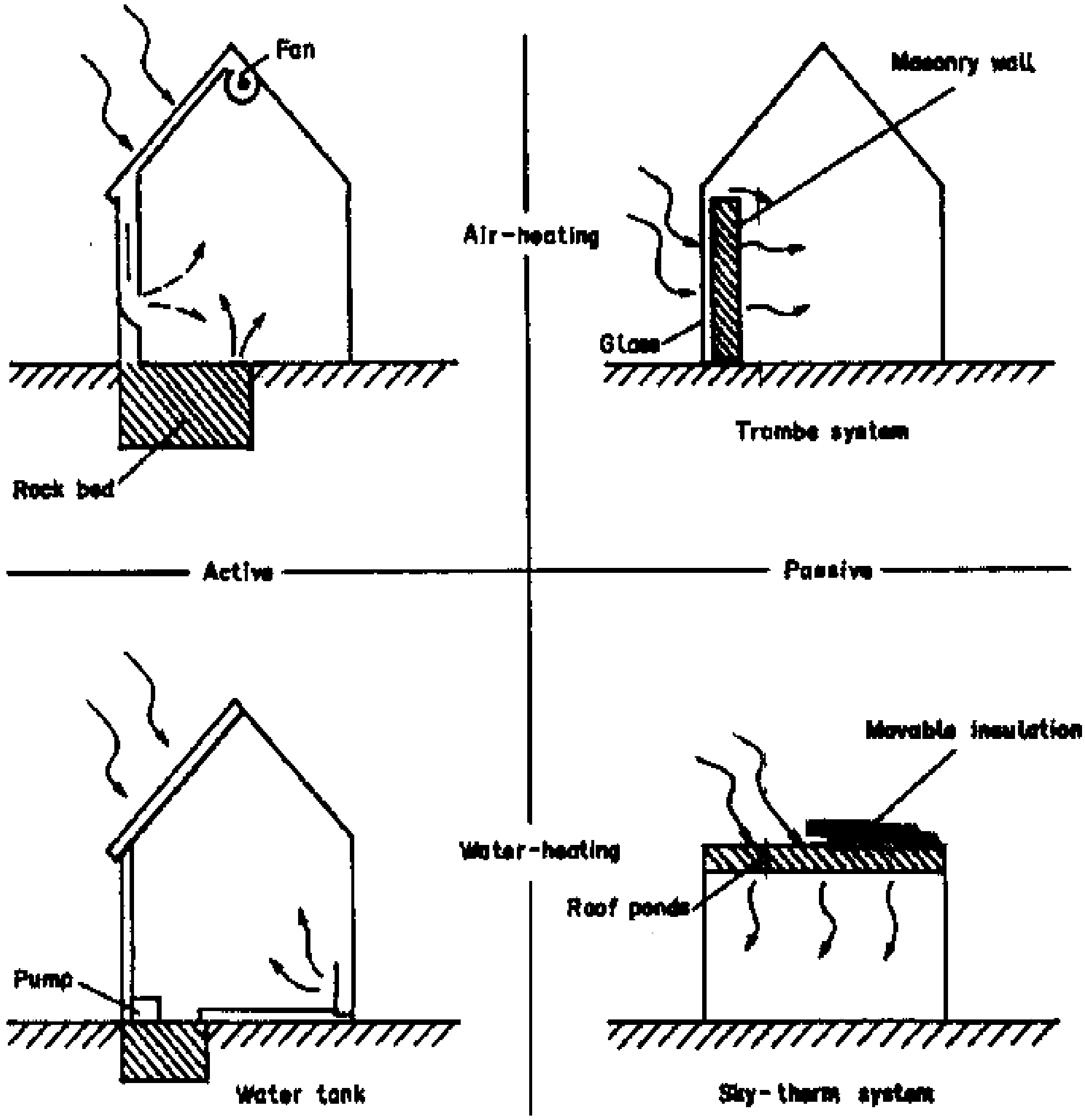


Figure 2.2: Using water and air as working fluid in passive and active systems (Agrawal, 1989).

The difficulties that the passive systems requires specific building design approach and large interior space for thermal energy storage (Agrawal, 1989) makes it complex to be applied for building space cooling, especially as an add on cooling means to the existing built spaces. Hence considering that most of the buildings are already built and necessitate cooling systems, alternatives to the natural and passive methods have to be considered.

2.3.1.2 Mechanical and Artificial

The mechanical systems for building cooling were produced as the field of thermodynamics got advanced (Santamouris & Asimakopoulos, 1996) namely; mechanical fan, turbine ventilators, Vapor compression systems, gas compression systems, air conditioning systems and thermoelectric system. The mechanical fan is mostly used for mechanical ventilation (Kolokotroni & Aronis, 1999) which is mostly effective at night as it does not generate any cooling. Turbine ventilators are more powerful than the natural stack ventilation and able to improve the thermal comfort but not completely fulfill the same in hot and humid buildings (Ismail, 2010).

In the other hand, the latest cooling technology being the air- conditioning systems can maintain the temperature to the optimum level required in buildings; however the thermoelectric or Peltier cooling system is more environmental friendly as compare to vapor compression air conditioner which has ozone layer depletion potential and expensive absorption air-conditioner with sophistications and bulkiness structure; based on the comparative investigation of cooling systems in Figure 2.3 shows an air-conditioner in cooling mode.

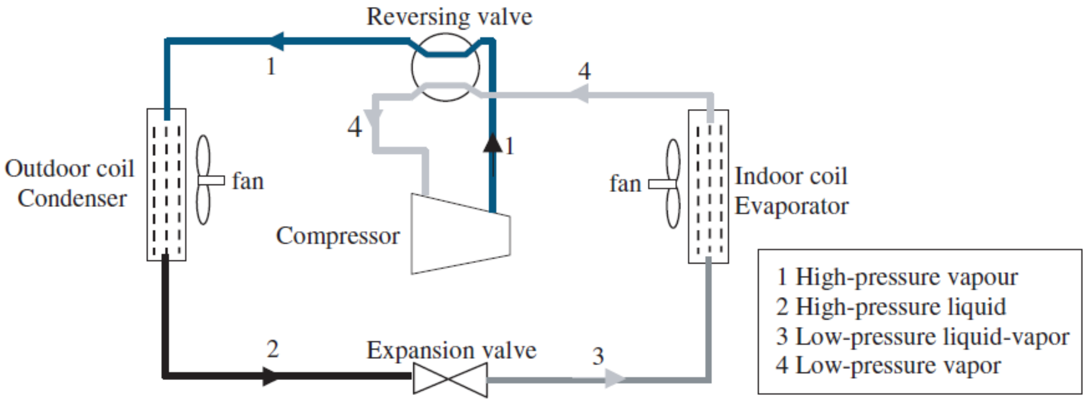


Figure 2.3: Schematic of air-conditioner in cooling mode (Riffat & Qiu, 2004).

Whereas in Figure 2.4: makes it evident how the thermoelectric air-conditioner or the peltier cooling device cycle is as compare to other mechanical cooling systems such as the conventional air-conditioner that was seen in Figure 2.3. The light weight of Peltier cooling system, with no mechanical moving parts which saves on the maintenance, makes them a suitable alternative to the present air-conditioning systems.

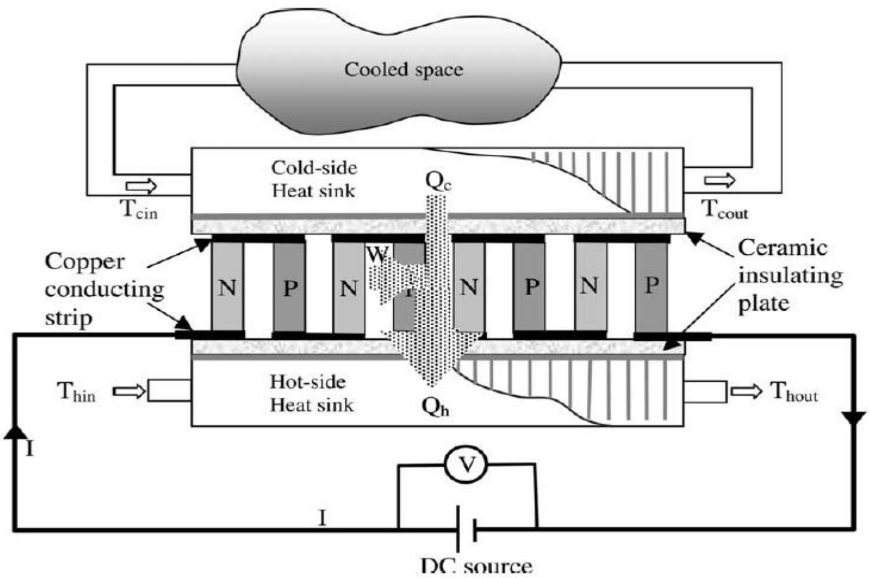


Figure 2.4: Schematic diagram of thermoelectric air-conditioner (Riffat & Qiu, 2004).

Five different physical phenomenon namely; Peltier effect, seebeck effect, Joule effect, Thomson effect and Fourier effect that take place at two junctions of two dissimilar but connected metals or semiconductors; make temperature differences in the opposite junctions (Zemansky & Richard, 1981). The diagram in Figure 2.4 has described the cycle of the thermoelectric or peltier cooling graphically.

2.3.2 Green Cooling Systems

Even though the adoption of passive methods instead of air- conditioning systems reduces the CO2 emissions; (Kolokotroni & Aronis, 1999) but the use of air conditioning in hot and humid climatic condition is vital to make a comfortable indoor space, as the latent heats are very high (Alpuche et al., 2005) and according to (Zain et al., 2007) in such climatic condition discomfort is experienced due to the high heat load of the interior; hence there must be an appropriate natural ventilation strategy to remove the excessive heat or else the mechanical cooling systems is indeed required. However these cooling systems have to be green to fit into the built spaces that are designed to be efficient.

In the United States of America for a building to be LEED certified, it must achieve enough points in each categories that is judged upon, namely; sustainable sites, water efficiency, materials and resources, indoor environmental quality, innovation and design process and finally the energy and atmosphere which is in fact the most important of all, consisting of one third of the total LEED points.

In order to accomplish the points for the energy and atmosphere category the HVAC systems of buildings are checked for the amount of environmental impact in terms of energy consumption and also the refrigerants ozone depletion potentials (Whitman et al., 2009). Therefore by reducing the energy consumption of the cooling system and replacing its refrigerant by a more eco-friendly material, there will be a better chance for a building to be certified as green that ultimately helps the environment.

Nevertheless of the LEED aiming to help the efficiency of building design, most of the criteria were according to the US policies. Therefore the Malaysian government developed a code of practice named as MS1525 and GBI green building index to serve the same purpose considering the local needs of the built environment to become efficient. The six criteria based on which the buildings are awarded green certification is shown in Table 2.1 of; describing the importance of the green cooling systems to maintain the indoor environmental quality (EQ) of buildings.

Table 2.1 The GBI and LEED rating system (GBI, 2012).

1	Energy and atmosphere (HVAC)	1	Energy Efficiency (EE)
2	Indoor Environmental Quality	2	Indoor Environmental Quality (EQ)
3	Sustainable sites	3	Sustainable Site Planning & Management (SM)
4	Material and resources	4	Material and Resources (MR)
5	Water efficiency	5	Water Efficiency (WE)
6	Innovation and design process	6	Innovation (IN)

The two criteria in which the cooling systems can gain points for the buildings to be green certified are highlighted in the Table 2.1 in both LEED and GBI systems, despite of the fact that the objectives of the present study focuses on the second criteria through temperature reduction and improvement of indoor environment but yet the energy efficiency of the cooling systems are touched upon in the next section of the literature review by adding the solar or photovoltaic technologies as an additional to any cooling system.

2.4 Principle of Peltier cooling

2.4.1 Peltier Effect

Thermoelectric or Peltier effect is a physical phenomenon that converts the electric voltage to temperature differences and vice versa. According to (Riffat & Qiu, 2004) “in a circuit containing two junctions between dissimilar conductors or semiconductors, heat will be transferred from one junction to the other by applying a DC source.”

Similarly with the help of Peltier effect, the Peltier device or a thermoelectric module makes temperature gradient at its opposite junctions; named as the hot side and the cold side (Riffat & Ma, 2003) and based on (Gillott et al., 2010) the Peltier effect is one of the factors responsible for the cooling production in the Peltier device (PC); which decides the heat pumped at the cold side of the thermoelectric module or on the other words the amount of cooling effect generated by the PC. Figure 2.5 by (Huang et al., 2005) describes how the direct current is travelled clockwise from the p-type semi-conductors to the n-type semiconductors in the peltier device.

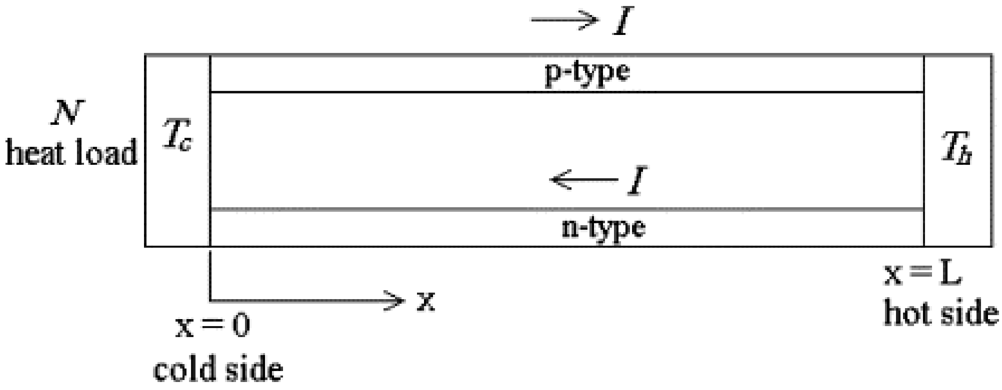
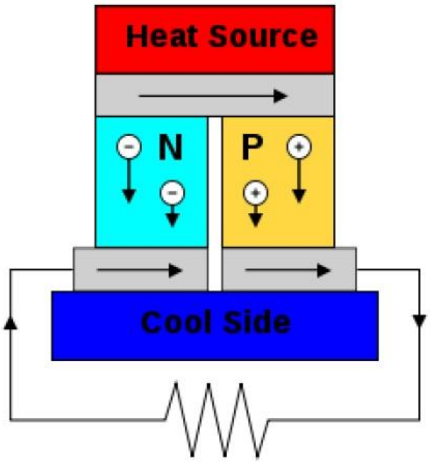
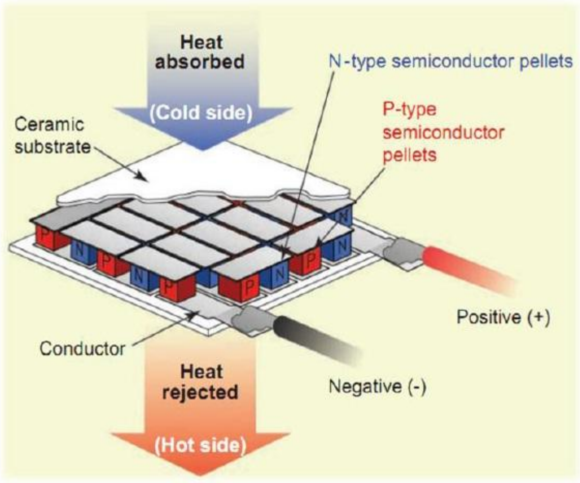


Figure 2.5: Schematic diagram of a Peltier Device (PC) (Huang et al., 2005).

2.4.2 Peltier Device (PD)

"Peltier cooling device (Thermoelectric cooler/heater) is an element which employs the basic peltier effect to yield heating at one side and cooling at the other side" (Quisenberry & DeVilbiss, 1996)**.** The temperature differences that occurs at two opposite junctions of the Peltier module, when direct current passes through semiconductor materials (Riffat & Ma, 2004). The cooler starts functioning when the Peltier effect pumps the heat from the cold side and transfers it to the hot side, where it's finally dissipated to the ambient. The basic unit of the Peltier cooling device is actually a "thermocouple composed primarily of an n-type and a p-type semiconductor element placed electrically in series and thermally in parallel" (Huang et al., 2005) which are sandwiched between two thermally conductive materials and at the same time a good insulator for the electricity (Riffat & Qiu, 2004). The graphical representation of Peltier device can be seen in Figure 2.6 a) which shows the hot and cold side of the Peltier Device.





(a) (b)

Figure 2.6: a) Basic Peltier Device configured in generator model; b) complete module as a Peltier cooler or heater (Jurgensmeyer, 2011).

2.4.3 Peltier Cooling Device (PCD)

Thermoelectric or Peltier coolers are solid state devices that adopt Peltier effect to build temperature gradient and generate cooling. (Gillott et al., 2010) "A thermoelectric cooler consists of a thermoelectric module, a heat sink connected to the hot side, and a cooling-load heat exchanger connected to the cold side. The heat load Q_L is absorbed at the cooling-load heat exchanger, conducted to the hot-end plate, and then pumped to the hot side of the thermoelectric module." The illustration of the basic model of such a cooler is displayed in Figure 2.4 by (Huang et al., 2000) while Figure 2.7 by (Riffat & Ma, 2003) is showing the operation of Peltier cooling device in the cooling mode.