COMMITTEE DECISION

We certify that we have read the present work, and that in our opinion it is fully adequate in scope and quality as thesis towards the partial fulfillment of the master's degree requirements in:

Specialization Renewable Energy Engineering

College of Engineering

Date of Discussion ……………………….

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DEDICATION3

To my parents,

to my family,

to my fiancée,

to my professors,

to my friends,

to my college,

to all whom I love,

I dedicate this work.

ACKNOWLEDGMENT

First of all, I would like to thank Allah for giving me patience and determination to pursue my higher education and for destining this work to see light. I am greatly indebted to my supervisor **PROF. SALAH AL-THYABAT** and **Dr. Hani AL-Rawashdeh** for their continuous support, encouragement, and for all their help and guideness over the past years.

My sincere thanks are also extended to the examining committee members:

Prof.Abdullah Marachli, Dr . Hani AL-Rawashdeh and Dr. Sameh AlSaqoor for their insightful notes, constructive criticism and contributions to this study.

I am also indebted to my parents for their endless love, support and encouragement. For all my brothers, especially Dr. Zeyad, and for all my sisters, thank you for your support, help and encouragement.

Finally, I would like to thank my friends, both students and academic staff, in the department of Mechanical Engineering at Al-Hussein Bin Talal University for their kindness and for the help they have offered.

Abdallah Y. AL-Daher

February 13, 2019

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LIST OF ABBREVIATIONS

Symbol	Nomenclatures	Units
CSP	Concentrated solar power	-
PVC	Photovoltaic cell	-
NREL	National renewable energy laboratory	-
PTC	Parabolic trough collector	-
LFC	Linear Fresnel collectors	-
LFR	Linear Fresnel reflector	-
HTF	Heat-transfer fluid	-
EVAP	Evaporation Emission Control	-
CFD	Contract for Difference	-
Q	Heat transfer rate	-
U	Heat transfer coefficient	$W/m^2.K$
A	Cross-section area	m^2
T_i	Inside temperatures	C
T_o	Outside temperatures	C
V_f	volumetric flow	-
ACH	Air change method	-
$Q_{L.f}$	Heat loss due to infiltration	W
h_i , h_o	Heat transfer coefficient for inside and outside the room	kj/kg
$\dot{m}_f$	Mass flow rate of the infiltrated air	kg/s
V_{room}	Room volume	m^3
N	Number of times air is changed in the room	-
P_i	Density of the air	kg/m^3
ΔP	Pressure drop	Pa
D	Pipe diameter	mm
QH	Heating load	KW

Symbol	**Nomenclatures**	Units
HDD	Heating Degree Days	-
C.V	Energy Density	J/ m^3
V	Volume	m3
CLTD	Cooling Load Temperature Difference	C
w_a	Aperture width	mm
r_r	Rim radius	mm
f	Focal length	mm
ρ	A Reflectivity	%
D_o	Outside diameter	mm
D_i	Inside diameter	mm
D_{gi}	A Plexiglas's (transparent plastic) tube of inner diameter	mm
DC	Direct Current	Amp
AC	Alternating Current	Amp
η_0	Optical efficiency	%
φ_r	A rim angle	0
r_r	A rim radius	mm
φ_r	A focal length	mm
m	An Acceptance angle	-
C	Concentration ratio	-
τ	A Transmissivity	-
α	the absorptivity	-
γ	An intercept factor	-
A_f	Geometric fraction of the lost area from the parabolic area especially at the edges	-
	The solar radiation incident angle	-
U_L	Overall heat loss coefficient	W/m^2
$\bar{F}$	Collector efficiency	-
FR	Heat removal factor by heat transfer fluid	-

Symbol	**Nomenclatures**	Units
Q_u	Useful energy transferred to heat transfer fluid	w
G_B	Average beam solar radiation	W/m^2
T_r	Receiver Temperature	c
Er	Emissivity of Receiver	-
Eg	Emissivity of glass cover	-
C_p	Heat transfer	$W/ m^2 c$
A_r	Receiver area	-
A_g	Glass cover area	-
T_i	Fluid Inlet Temperature	c
K	Tube Thermal Conductivity	W/ m c
T_a	Ambient Temperature	c
V_w	Wind Speed	m/s
Л	Fluid viscosity	Pa.s
Re	Reynolds number	-
$h_{c.c\text{-}a}$	Losses Coefficient by Convection from Cover to Ambient	-
$h_{r,r\text{-}c}$	Losses by Radiation from Receiver to Cover	-
$h_{r.ca}$	Losses by Radiation from Cover to Ambient	-
F'	The collector efficiency factor	-
h_f	Fluid convection heat transfer	$W/ m^2 c$

ABSTRACT

The consumption of fossil fuels has increased rapidly in recent years which increased the concern about energy security, carbon emissions, and climate change. Therefore, an increased attention has been given to a renewable source of energy especially solar and wind energy.

Concentrating solar power and (CSP) is a type of solar energy which uses mirrors (concentrators) to concentrate sunlight from a large area to a small area where it is absorbed and converted to heat at high temperatures. A major advantage of CSP plants over solar photovoltaic (PV) power plants is that CSP plants may be coupled with conventional fuels and can utilize thermal energy storage thermal energy storage to overcome the intermittency of solar energy.

In this work parabolic trough collector (PTC) with following parameters was designed to investigate the efficiency of a small-scale PTC to heat a synthetic heat transfer fluid which may be used for domestic heating or cooling. PTC 2m in length ,30 cm rim radius (r_r), 23 cm for the focal length (f), while the receiver tube diameter (D_o) equals 33.4mm.

It was found that the concentration ratio of the PTC was 5 times while the optical efficiency was 25 % considering all imperfections resulted from the manufacturing process. The heat losses from the PTC including convection, conduction, and radiation was calculated, and it was found the overall heat loss coefficient was 2.8 W/m^2.K while the PTC overall thermal efficiency (η_{th}) was 24.1%. The temperature of heat transfer fluid measured by a thermocouple connected to Arduino showed that temperatures were increased almost linearly with time. for five minutes operation the temperature increased by 16 degrees from an ambient temperature of 18 C.

Keywords: Solar Energy; Concentrated Solar Power; Parabolic Trough Collector;

CHAPTER ONE: INTRODUCTION

1.1. General

Several technologies are currently available to harness solar energy including photovoltaic, solar heating and cooling, concentrating solar power plants, and passive solar systems. Concentrated solar power plants (CSP), which are sometimes called thermal stations, are plants that use generated heat to produce superheated steam which operates turbines that are used to produce electricity, contrary to photovoltaic cell (PVC). According to national renewable energy laboratory (NREL), CSP requires high beam radiation (direct normal irradiance) larger than 2000KWh/year, which indicates that regions such as The Middle East, North Africa, and Southern Africa are excellent regions to build CSP plants (Castillo & Gayme, 2014).

Because of its maturity and low development risks, most current CSP plants are based on parabolic trough technology (PTC).The PTC consist of solar collectors (mirrors), heat receivers, and support structures in which the parabolic-shaped mirrors (that can be 100m long and 5 m in diameter) are constructed by forming a sheet of reflective material into a parabolic shape that concentrates incoming sunlight onto a central receiver tube at the focal line of the collector. PTC requires at least a single-axis tracking system to enable the trough to intercept the largest amount of radiation.

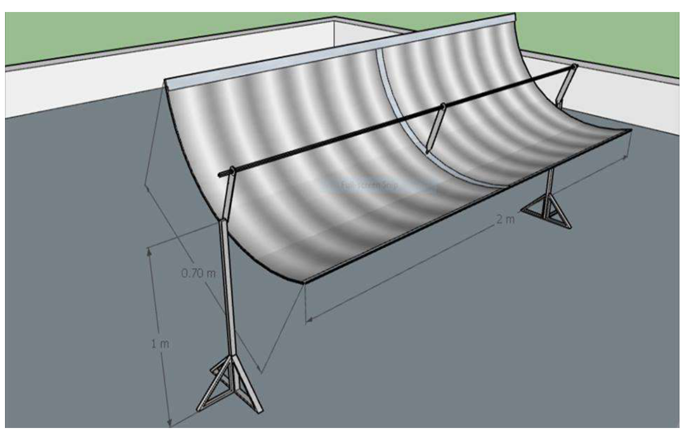

Figure 1.1 Parabolic trough collector

1. It has been the use and utilization of solar energy since ancient times, a legend has it that Archimedes utilized a "consuming glass" to focus daylight on the attacking Roman armada and repulse it from Syracuse (Sicily). In 1880, John Ericsson Built the main known explanatory trough gatherer. He utilized it to control a hot air motor (Meinel AB & Meinel MP , 1976 ; Mutlak,2011)

The French chemist Lavoisier designed a model for testing a receiver tube with concentration of sunlight using a 1.32m lens plus a secondary 0.2m lens (Mutlak, 2011; Kalogirou,2004). The American engineers Shuman and Boys built a 50-horsepower plant to pump irrigation water from the Nile River near Cairo during the First World War (Kryza,2003; Clarke,2007).

The research on developing CSP received more attention in 1960s. (Fayadh , et al. , 2018) designed and tested a receiver tube in several measurements and found that the decrease in the measurement of the receiving tube leads to a decrease in the thermal losses. He also studied and analyzed a range of graph relations in order to design the best concentration system with the highest efficiency and minimum size for the receiving tube depending on width.

1.2. The Solar Resource and (CSP) Plant Performance

In general, solar thermal technologies innovations depend on the idea of concentrating sunlight-based radiation to deliver steam or hot air to be utilized for power generation (Cabrera, et al. , 2013).

Unlike the photovoltaic panels which utilize global heat irradiance to generate an electricity, CSP has high solar power factor five times higher than PV. CSP implementation is limited due to technical and economic reasons. However, in recent years, environmental issues have focused attention on green energy resources, improving the chance for PTCs to be commercially competitive in the market (SolarPACE,2014).

1.3. Types of CSP systems

The major types of CSP systems can be summarized as follows (Figure 1.2).

1.3.1. Parabolic through collector (PTC) Technology

This technology is commercially proven. PTC are comprised of solar collectors (mirrors), heat receivers, and support structures. The parabolic-shaped mirrors are constructed by forming a sheet of reflective material into a parabolic shape that concentrates incoming sunlight onto a central receiver tube at the focal line of the collector.

1.3.2. linear Fresnel Collector (LFC) Technology

Linear Fresnel collectors (LFCs) are like parabolic trough collectors, but use a series of long flat, or slightly curved, mirrors placed at different angles to concentrate the sunlight on either side of a fixed receiver.

1.3.3. Solar Tower (Heliostat) Technology

Solar tower technology utilizes a field of flat mirrors to focus direct solar irradiation onto a receiver mounted high on a central tower where the light is captured and converted into heat. The solar fled consists of several computer-controlled mirrors, called heliostats that track the sun individually in two axes which direct the sunlight onto the central receiver where a fluid is heated up. Solar towers can achieve higher temperatures than (PTC) and (LFC) because more sunlight can be concentrated on a single receiver and the heat losses are minimized.

1.3.4. Stirling Dish Technology

The Stirling Dish System consists of a parabolic dish shaped concentrator (like a satellite dish) that reflects direct solar irradiation onto a receiver at the focal point of the dish. The receiver may be a stirling engine (dish/ engine systems) or a micro-turbine.

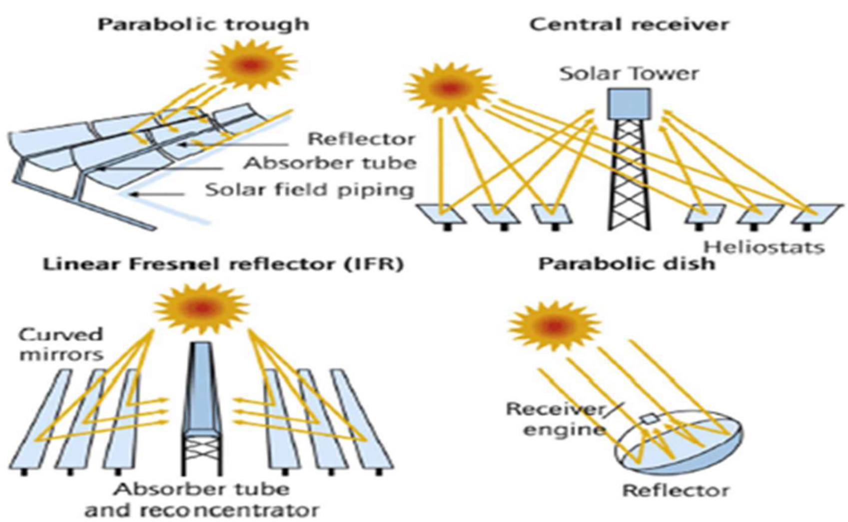

Figure 1.2 CSP systems technologies (Viebahn, et all , 2008)

1.4. Description of (PTC):

PTC consist of solar collectors (mirrors), heat receivers, and support structures. The parabolic-shaped mirrors are made of a reflective material which concentrates incoming sunlight onto the receiver tube at the focal line of the collector. The mirror should be constructed of high reflective materials having high reflectivity for all irradiation wavelength. Silver-coated glass is the most common material used in PTC, yet low-cost silver-coated polymer film called Reflectance, which can be placed on any nonporous surface, has been developed recently, as shown in Figure 1.2. (Viebahn, et al, 2008).

PTC require high value of beam radiation, and Ma'an area has a monthly average direct horizontal irradiance of 600-800 W/m2, which makes an ideal place to use CSP in general. (Mahian,et al. , 2013)

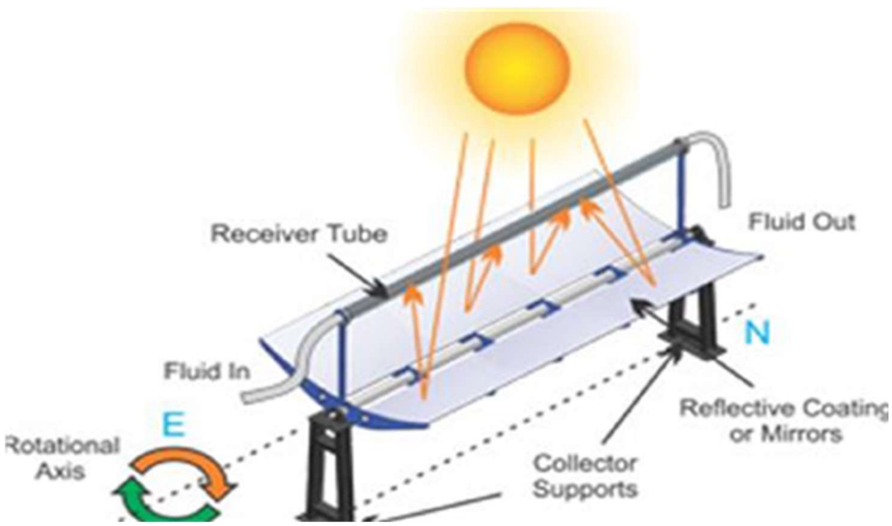

Figure 1.3 Mechanism of PTC (Viebahn, et al, 2008)

PTC, which can be 100 meters (m) long curved aperture of 5 m to 6 m, is usually equipped with a single-axis tracking mechanism to concentrate solar radiation in PTC receiver. The most common tracking system is that aligned north-south and tracking the sun from east to west. The control of such tracking system can be conducted either by a mechanical system which determines the sun position from earth rotation around the sun, or

By an electrical system which uses sensors that give a signal to the local controller which operates the electrical motors or hydraulic cylinders.

PTC receiver is comprised of an absorber tube made of coated stainless steel inside an evacuated glass envelope to reduce convective and radiative thermal losses. Tube coating allows selective absorption of short-wave solar radiation and minimizes the emitting of long wave radiation.

Heat-transfer fluid (HTF), which transfers heat from receiver tube to steam generated by circulation, consists of thermal oil stable at high temperatures. Traditionally, PTC uses a synthetic oil called “thermo oil“, which is an eutectic mixture of biphenyl and diphenyl oxide and is liquid until 12 C and is staple up to 400 C. Some PTC plants use mineral oil because it is less expensive. However, its instability at relatively low temperatures (i.e. 300 C) is one of its main disadvantages. Recently, a cheaper and more effective HTF which consists of a mixture of fertilizers called molten salt was developed. Molten salt, which is comprised of 60 %$NaNO_3$ and 40 % KNO_3, is non-toxic or inflammable and it is stable at higher temperature. In brief, molten salt is a fertilizer, cheap, non-toxic, and none flammable. Although molten salt is stable up to 540 C, its main disadvantage is the higher freezing temperature (120-220 C) which requires a robust antifreeze system (Duffie & Beckman , 2013).

PTC mirror materials are made of high reflective materials. In general, parabolic mirrors today consist of silver-coated glass mirrors because of their high proven durability. PTC mirror faces are usually produced with the molten glass flows continuously on a bath of liquid tin to ensure uniformity in produced glass. Low-iron glass is used to increase the light transmission in the solar spectrum. After the glass is cut to the right size and got grinded, it is formed to the parabolic form in an oven. Alternatively, the glass may be formed to parabolic shape by moulding. Recently, low-cost silver-coated polymer film called Reflectance, which can be placed on any nonporous surface, has been developed (Nishino,et al. ,2014; Kalogirou , 2009).

The aim of this thesis is to design a small scale unit of PTC that can be fit on the roof of any house with integrated heat storage system (Figures 1.4 and 1.5). The heat collected by the PTC will not be used to produce electricity; rather, this heat will be utilized for space heating and air conditioning and for providing hot water for domestic purposes. Space heating can be achieved by using heat exchanger to preheat the boiler water. Air conditioning can be achieved by using the heat to operate absorption chiller which can be sold with the system instead of the conventional compressor-based air conditioning units. Also heat exchanger can be added to provide hot water for domestic use. A schematic diagram of the proposed system is shown in Figures 1.4 and 1.5.

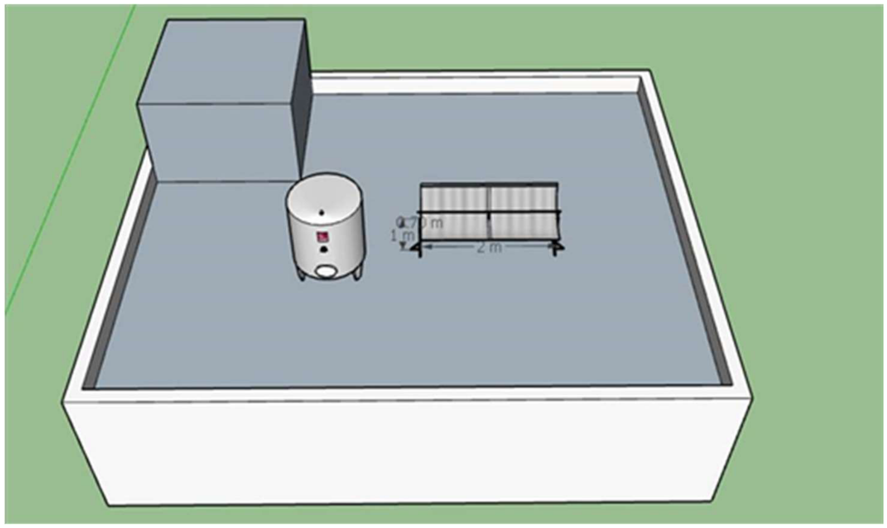

Figure 1.4 Schematic diagram of the proposed PTC mounted on a roof of a house

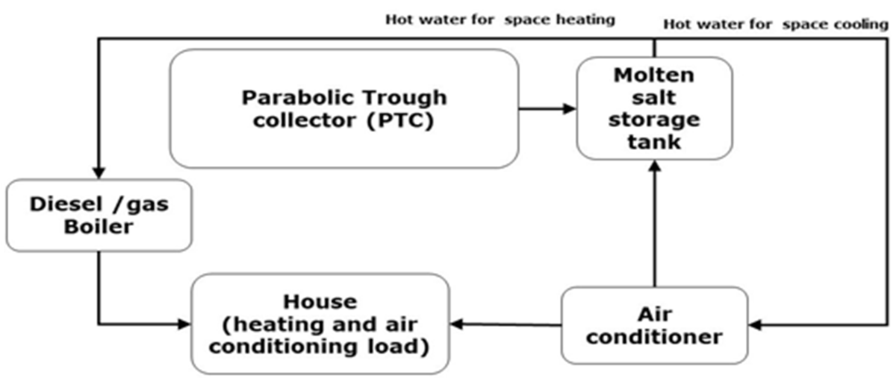

Figure 1.5 Schematic diagram of the proposed PTC system

This thesis consists of six chapters. Following this introductory chapter, chapter 2 summarizes the major achievements related to PTC technology as cited in the literature. Chapter 3 presents a detailed description of heating and cooling load calculations, while chapter 4 gives a detailed description of the PTC design and measurement system. Chapter 5 depicts the results and discussion of the current thesis. Chapter 6 presents the major conclusions and recommendations.

CHAPTER TWO: LITERATURE REVIEW

PTC design and performance have been thoroughly investigated by several researchers. Grimmer (Grimmer,1979) conducted a comparison between the ability of accepting diffuse radiation by both compound parabolic and simple parabolic solar collectors in respect to their reflective arc length. The results showed that PTC concentration ratio is 10 times higher than simple parabolic solar collectors, but simple parabolic solar collectors reflector cost is 4.4 times cheaper from compound parabolic collectors. Therefore, simple parabolic trough may be more cost effective than the compound parabolic concentrator.

Studied the principle design factors that influence the performance of a PTSC such as spectral directional reflectivity of the mirror system, the mirror-receiver tube intercept factor, the incident angle modifier, the end thermal loss, effect of tracking errors and receiver tube misalignment. He carried out the performance analysis of PTSC with synthetic oil and water as working fluids, and he formulate the efficiency of solar parabolic trough collectors in terms of absorber wall temperature, absorber emissivity, wind speed, and radiation level in order to predict the performance of the PTC with any working fluid. (Mutlak , 2011)

Designed a simple welded frame structure PTC that with stand high static loads. by studying the deflection characteristics under various load conditions, it was found that the structure withstood the load corresponding to extreme wind load conditions and that it is suitable for developed countries because it is cheap. (Thomas,1994)

Analyzed PTC design parameters that effect PTC performance such as reflectivity of the mirror system, the mirror-receiver tube intercept factor, (Clark,1982) the effect of tracking errors and receiver tube misalignment, and thermal losses , and connected them to economic factors of PTC solar fields such investment tax credit, energy equipment tax credit, income tax cost of auxiliary system, cost of collector at installation, costs of maintenance and taxes, costs of fuel, and capital cost in order to develop a model to analyze energy costs produced by PTC power plants . (Odeh , et al., 1998) compared the efficiency of parabolic trough collectors operating with synthetic oil and as heat-transfer fluids.

A model of the thermal losses from the PTC was developed in terms of absorber wall temperature, absorber emissivity and internal working fluid convection to predict the performance of the collector with any working fluid.

Investigated the techno -economic performance of polygene ration PTC system. The system consisted of a steam circuit that feeds a small-scale turbine, solar driven absorption chiller, direct heating system and water distillation unit. The study showed that the size and orientation of the available space have driven the design and selection of storage and conversion technologies. And that the utilization factor of the system was 0.66. it was also found that the economical sides of such a technology need improvement due to the high cost of the small-scale components of this technology. (Kiwan, et al., 2018)

Designed a small parabolic collector for use in solar thermal Research in South Africa a program. In Thomas and Michael's study the length of the complex is 5 meters, the width of the Aperture is 1.5 m, and the angle of the edges is 82.2 degrees. The surface is made up of Stainless-steel Sheets covered with SA-85 film. The receivers were fabricated for comparison including one closed in an evacuated glass cover. it was found that the peak efficiency of 55.2% and 53.8% Obtained with non-shielded and glass cover reception, respectively. (Duffie , 2006)

The English F. Shuman and the American C.V. (Fernández-García, et al. , 2010 ; Krüger , et al. , 2008) Young men developed a 45 KW drawing plant for water system in Maadi, Egypt which utilized the vitality provided by trough gatherers ,In 1913 The pumps were driven by steam engines, which have got the steam from the allegorical troughs. The framework could draw 27,000 liters of water for each Moment. Despite the achievement of the plant, it was closed in 1915 because of the beginning of World War I and because of lower fuel costs which made the utilization of burning more practical.

In Jordan, there are Studies for using parabolic trough collector systems for domestic heating and air conditioning. Indeed, there are still no genuine CSP application in Jordan, yet there are some tests at a small scale. In the Dead Sea Spa Hotel (Maytah,2012) a parabolic trough collector has been utilized to produce boiling water to drive a two-arrange alkali retention chiller in summer. The framework is comprised of three lines of illustrative sun-oriented collectors, and the reflectors have been made of 0.8mm Aluminum sheets secured with Aluminum Covering. The HTF is dispersed among the collectors through 38mm steel pipe which is protected with 80mm Rockwool.

Has designed a project using parabolic trough collector including multi uses for comparative purposes. In this project which was located at the roof top of the engineering department of Mutah University, CSP technology was utilized for a Tri-Generation of electricity, Water Distillation, and Cooling/Heating. The project employed 40 CSP parabolic trough Reflector panels that cover 240 m^2 of solar matrix area to generate 120 kW thermal power (KW) peaks with 15 KW Electrical (KW), 100 KW of heating and 20 KW of cooling; it can also produce 150 L/hr. of distilled water. (Maytah, 2012)

In another study, (Li , et al. , 2016) designed a prototype of parabolic trough collector located in Sanlucar la Mayor Solar Platform, in Seville, Spain, to generate about 8 MW of thermal power. This prototype consists of an evaporator solar field (EVAP) with three parallel loops of 800 meters each. (Kolb,2011) managed to evaluate the possible next-generation high-temperature Molten-Salt Power Towers. This solar receiver innovated under the help of the U.S. Department of Energy's Sun Shot Program in order to concentrate solar irradiation using an air-particle mixture to move a gas turbine or a combined cycle at much increaser temperature than the state-of-the-art molten salt receivers.

Built a Numerical-stochastic model (i.e. CFD model) and radioactive heat transfer model, (Mutlak ,2011) then designed an optimization methodology to study results like wall window geometry, receiver and receiver geometry properties optimization. (Arzhakov, 2016) worked out a simplified design procedure of parabolic trough solar field for industrial heating applications. A parabolic trough solar heating system has been designed and simulated using meteorological data of Ipoh, Malaysia. The researchers predicted growth up of parabolic trough solar collector system for electricity generation by steam power cycles, but there is huge potential for this technology to be used in industrial heating applications.

Contributed to the design and performance assessment of a parabolic trough collector for commercial competitiveness of PTC. In this study, a three-meter long parabolic trough collector was designed, constructed and tested to assess its performance. (Al Asfar ,et al. , 2014).

CHAPTER THREE: HEATING AND COOLING LOAD CALCULATIONS

3.1. Introduction

Air conditioning system design is a sub discipline of mechanical engineering based on the principles of thermodynamics, fluid mechanics, and heat transfer, and it aims to provide thermal comfort and acceptable indoor air quality. On the other hand, heaters are appliances whose purpose is to generate heat for the building either via central heating or any other means which uses diesel powered boilers or electric heaters to raise the temperature of the place to comfort residence. In this work, solar energy collected by PTC and absorbed by the heat-transfer fluid circulating inside its absorber will be used to heat the water used in central heating boiler, provide the heat to warm water for domestic purposes, and also provide heat for absorption cooling cycle which used for air conditioning in summer.

3.2. The specifications and conditions of the residential building used in this project

In this project, a small house in Al Hussein Bin Talal University Housing residential Complex in Ma'an city-Jordan with an area of 150 m^2 has been chosen to implement this project (1). According to ASHRAE handbook (Howell, 2017), table 3.1 shows the specifications of the location while Figure 3.1 is a schematic view of the house.

Table 3.1 Average climate properties of the location according to ASHRAE handbook, 2017.

Parameter	Value
Latitude	31.956^o North
Longitude:	35.945^o East
Wind speed	3.6 m/s
Height above sea level	1100 m
Outside temperature design(summer)	34 C^o
Outside temperature design(winter)	3 C^o
Outside relative humidity (Summer)	35 □
Outside relative humidity (winter)	60 □
Type of building	Residential
Number of occupants	Five

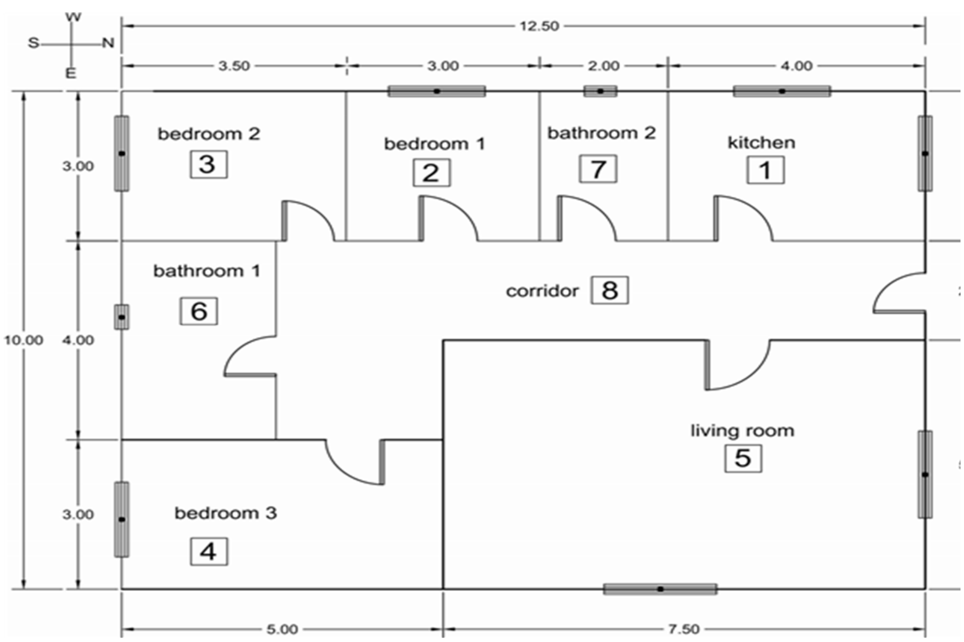

Figure 3.1 Schematic top view of the house

Heat transfer coefficients of outside walls, inside walls, and ceiling of the building were calculated according to ASHRAE handbook (Howell, 2017) and Jordanian building specifications using equation 3.1. Tables 3.1 – 3.4 summarize the results of these calculations. (Alassad & Hammad, 2011).

$$\boldsymbol{Q = UA(T_i - T_o)} \quad \textbf{(3.1)}$$

Where A: is the cross-section area of pipes

T_i, T_o are the outside and inside temperatures , respectively .

Table 3.2 Specifications and heat transfer coefficients for outside walls

Layer (outside-inside)	Type	Thickness (cm)	Thermal Resistance (m^2.K/W)
Layer 1	Plaster	2	0.017
Layer 2	Concrete	20	0.114
Layer 3	Insulation	2	0.500
Layer 4	Plaster	3	0.025
Heat transfer coefficient (U)=0.656W/m^2.K			

Table 3. 3 specifications and heat transfer coefficients for inside walls

Layer (outside-inside)	Type	Thickness (cm)	Thermal Resistance (m^2.K/W)
Layer 1	Plaster	2	0.017
Layer 2	Cement brick	20	0.222
Layer 3	Insulation	2	0.500
Layer 4	Plaster	3	0.025
Heat transfer coefficient (U)=0.764 W/m^2.K			

Table 3.4 Specifications and heat transfer coefficients for house ceiling

Layer (top-down)	Type	Thickness (cm)	Thermal Resistance (m^2.K/W)
Layer 1	Asphalt Mix	2	0.028
Layer 2	Concrete	5	0.029
Layer 3	Insulation	3	0.750
Layer 4	Reinforced Concrete	10	0.057
Layer 5	Plaster	2	0.017
Heat transfer coefficient (U)=0.881 W/m^2.K			

The heat transfer coefficients values for floors windows tabulated in (Alsaad & Hammad,2011) were adopted in this work. Table 3.5 summarizes heat transfer coefficient values.

Table 3.5 Heat transfer coefficients for floors and windows (Powers,2007)

Building part	Heat transfer coefficient ($W/m^2.k$)
Floors	0.153
Glass window with aluminum frame	5.6
Outside steel door	5
45 mm wooden partition	1.5

3.2.1. Heating load calculations

The heating load of a space consists of the following components:

- Heat loss rate through all exposed walls, ceiling, floor, windows, doors and walls between a heated space and an unheated space (portions walls);
- Infiltration heating load required to warm outside cold air infiltrated to the heated space through cracks of windows and doors, and outside cold air infiltrated due to opening and closing of doors;
- Domestic hot water load.;
- And all other loads such as emergency heating loads and safety factor load.

3.2.2. Heating load due to infiltration

Two methods are used to calculate the volumetric flow rate of infiltrated air V_f into an air-conditioned space, which are:

- The air change method (ACH).
- The crack age method.

Heat loss rate due filtration calculated by air change method is conducted by equations 3.2-3.4. The number of times in which room's air changed is given in table 3.6.

$$Q_{L,f} = \dot{m}_f(h_i - h_o) \tag{3.2}$$

$$V_f = N \times V_{room} \tag{3.3}$$

$$\dot{m}_f = \rho_i V_f \tag{3.4}$$

Where $Q_{L,f}$:heat loss due to infiltration (w)

h_i, h_o : heat transfer coefficient (kj/kg) for inside and outside the room.

$\dot{m}_f$: mass flow rate of the infiltrated air(kg/s).

V_{room}: room volume (m^3).

N : number of times air is changed in the room.

ρ_i : density of the air (1.2 kg/m^3).

Table 3.6 Number of air change of the room due to infiltration (Powers,2007)

Type of Room	Number of Air Change / Hour (N)
Rooms with windows or exterior doors on two sides	1.5
Living rooms	1.0
kitchens	2.0
Bedrooms	0.5
Bath rooms	2.0

Referring to Figure 3.1, detailed heating load for each of the eight rooms in the house is given in tables 3.7-3.14. A summary of the heating load for all rooms is shown in table 3.15. For Room 1, the heat loss due to infiltration is:

$$N = 2$$

$$V_f = 2 \times 12 \times \frac{3}{3600} = 0.02 m^3/s$$

$$\dot{m}_f = 1.2 \times 0.02 = 0.024 kg/s$$

$$Q_{L,f} = 0.024(35 - 10) = 600\ W$$

Table 3.7 Heating loads for room 1 (kitchen)

Room No. : 1 (kitchen) Area of Room: 12 m^2 High of Room: 3 m		Interior design conditions: Ti = 20 ^oC ; Φi = 40%; hi = 35 kj/kg Outside design conditions To = 3 ^oC; Φo = 60%; ho = 10 kj/kg		
	Area m^2	U W/m^2.^oC	$(T_i - T_o)$ ^oC	Q = UA(T_i-T_o) Watt
Walls :				
N-Wall	9	1.09	6	59
E-Wall	7	1.09	6	46
S-Wall	9	1.09	0	0
W-Wall	7.5	1.24	21	196
Ceiling:	9	1	21	189
Floor:	9	0.153	14	20
Windows:				
-Window	-	-	-	-
E-Window	-	-	-	-
S-Window	-	-	-	-
W-Window	0.5	5.6	21	59
Doors:	2	1.5	6	18
Infiltration:	-	-	21	144
			Q_{room} =	**1535**

Table 3.8 Heating loads for room 2 (bed room 1)

Room No. : 2 (Bed room 1) Area of Room: 9 m^2 High of Room: 3 m		Interior design conditions: Ti = 24 ^oC ; Φi = 40%; hi = 42 kj/kg Outside design conditions To = 3 ^oC; Φo = 60%; ho = 10 kj/kg		
	Area m^2	U W/m^2.^oC	$(T_i - T_o)$ ^oC	Q = UA(T_i-T_o) Watt
Walls :				
N-Wall	9	1.09	6	59
E-Wall	7	1.09	6	46
S-Wall	9	1.09	0	0
W-Wall	7.5	1.24	21	196
Ceiling:	9	1	21	189
Floor:	9	0.153	14	20
Windows:				
N-Window	-	-	-	-
E-Window	-	-	-	-
S-Window	-	-	-	-
W-Window	0.5	5.6	21	59
Doors:	2	1.5	6	18
Infiltration:	-	-	21	144
			Q_{room} =	**731**