Universidade do Estado do Rio de Janeiro

Centro de Tecnologia e Ciência

Faculdade de Engenharia

Ahmed Elsayed Ismail Ibrahim

Using Compound Parabolic concentrating Solar Collector in Asphalt Industry

Rio de Janeiro

2015

Ahmed Elsayed Ismail Ibrahim

Using Compound Parabolic concentrating Solar Collector in Asphalt Industry

Dissertação apresentada, como requisito parcial para obtenção do título de Mestre, ao Programa de Pós-Graduação em Engenharia Mecânica, da Universidade do Estado do Rio de Janeiro. Área de concentração: Mecânica dos Sólidos.

Orientador: Prof. Dr. Manoel Antônio da Fonseca Costa Filho

Rio de Janeiro

2015

CATALOGAÇÃO NA FONTE

UERJ / REDE SIRIUS / BIBLIOTECA CTC/B

I14 Ibrahim, Ahmed Elsayed Ismail.

Using compound parabolic concentration solar collector in asphalt industry / Ahmed Elsayed Ismail Ibrahim. - 2015.

66 f.

Orientador: Manoel Antônio da Fonseca Costa Filho.

Dissertação (Mestrado) – Universidade do Estado do Rio de Janeiro, Faculdade de Engenharia.

1. Engenharia Mecânica. 2. Asfalto - Dissertações. 3. Simulação térmica - Dissertações. 4. Aquecimento solar - Dissertações. I. Costa Filho, Manoel Antônio da Fonseca. II. Universidade do Estado do Rio de Janeiro. III. Título.

CDU 678.049.2

Ahmed Elsayed Ismail Ibrahim

Using Compound Parabolic concentrating Solar Collector in Asphalt Industry

Dissertação apresentada, como requisito parcial para obtenção do título de Mestre, ao Programa de Pós-Graduação em Engenharia Mecânica, da Universidade do Estado do Rio de Janeiro. Área de concentração: Mecânica dos Sólidos.

Aprovado em: 27 de maio de 2015.

Banca Examinadora:

Manoel Antonio da Fonseca Costa Filho (Orientador)

Faculdade de Engenharia - UERJ

Prof. Dr. Norberto Mangiavacchi

Faculdade de Engenharia - UERJ

Prof. Drª. Mila Rosendhal Avelino

Faculdade de Engenharia - UERJ

Prof. Dr. Nisio de Carvalho Lobo Brum

COPPE - UFRJ

Drª. Rafaela Frota Reinaldo

Petróleo Brasileiro S.A. – Petrobras

Rio de Janeiro

2015

ACKNOWLEDGMENT

Pablo de Abreu Lisboa, researcher from Cepel (Centro de Pesquisas de Energia Elétrica).

Fabrício dos Santos Dantas from INT (Brazilian National Institute of Technology) for the support with TRNSYS.

FAPERJ for the scholarship.

All the Professors that enrolled their courses during my study in UERJ.

All the people in UERJ that helped me directly or indirectly in the last two years.

Prof. Norberto Mangiavacchi for his help during the study period in UERJ and his role for getting my scholarship and enrolling the Master's Program.

Prof. Manoel Antonio da Fonseca Costa Filho for his help during the study period in UERJ and his role for getting my scholarship and enrolling the Master's Program. Moreover, his valuable guidance in order to help me to finish this dissertation.

ABSTRACT

IBRAHIM, Ahmed Elsayed Ismail. *Using compound parabolic concentration solar collector in asphalt industry*. 2015. 66f. Dissertação (Mestrado em Engenharia Mecânica) - Faculdade de Engenharia, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2015.

This dissertation presents thermal, economic and environmental evaluation of a solar heating system (SHS) which is used in an asphalt plant from computational simulation with TRNSYS. The process chosen is the bitumen heating from the storage up to the mixing temperature, using mineral oil as heat transfer fluid (HTF). The system components are the HTF-bitumen heat exchanger, the compound parabolic concentration solar collector (CPC), the auxiliary heater and the circulation pump. The TRNSYS simulation computes the mass and energy balances in the HTF closed loop every hour. Rio de Janeiro typical meteorological year (TMY) hourly weather data was used in order to perform this paper. In many instances, HTF temperature has reached a temperature that more than 238˚C, showing that the CPC is suitable for this application. Fuel savings and avoided emissions were taken into account for economic and environmental analysis. In this work describes the renewable energy sources, the asphalt plant and bitumen heater types. It also shows the Brazilian portion of the some of these sources. The results, though, made it possible to address environmentally sound public policies to encourage solar energy use in the Asphalt Industry. Moreover, it will help in reducing the high emission of the green house gases from the use of the fossil fuels in this industry.

Keywords: Asphalt Plant; CPC; Solar Heating; Thermal Simulation.

RESUMO

Esta dissertação apresenta a avaliação térmica, econômica e ambiental de um sistema de aquecimento solar (SHS) que é usado em uma usina de asfalto, através de simulação computacional com TRNSYS. O processo escolhido é o aquecimento do betume a partir da temperatura de armazenamento até a temperatura de mistura, usando óleo mineral como fluido de transferência de calor (HTF). Os componentes do sistema são o trocador de calor HTF-betume, o coletor concentrador solar parabólico composto (CPC), o aquecedor auxiliar e a bomba de circulação. A simulação no TRNSYS calcula os balanços de massa e energia no circuito fechado do HTF a cada hora. Dados horários do Ano Meteorológico Típico (TMY) do Rio de Janeiro foram utilizados para executar este trabalho. Em muitos casos, a temperatura do HTF ultrapassou 238˚C, mostrando que o CPC é apropriado para esta aplicação. Economia de combustível e emissões evitadas foram consideradas para as análises economica e ambiental. Este trabalho descreve as fontes renováveis de energia, os tipos de usinas de asfalto e de aquecedores de betume. Ele também mostra a fração brasileira de algumas destas fontes. Os resultados, portanto, mostram ser possível encorajar políticas públicas ambientalmente corretas para incentivar o uso de energia solar na indústria de asfalto. Além disso, este trabalho pode ajudar na redução da elevada emissão dos gases de efeito estufa a partir da utilização dos combustíveis fósseis nesta indústria.

Palavras-chave: Usina de Asfalto; CPC; Aquecimento Solar; Simulação Térmica.

LIST OF TABLES

LIST OF FIGURES

ABBREVIATION LIST

CPC	Compound Parabolic Concentrator
FPC	Flat Plate Collector
SHS	Solar Heating System
TMY	Typical Meteorological Year
HTF	Heat Transfer Fluid
GHG	Green House Gases
USD	United States Dollar
BRL	Brazilian Real
PV	Photovoltaic
CSP	Concentrated Solar Power
BOE	Barrel of Oil Equivalent
LMTD	Log Mean Temperature Difference Method

SYMOBOLS LIST

A_a	Aperture Area
A_{abs}	Absorber Area
A_s	Pipe External Area for Heat Transfer
CR	Concentration Ratio of Collector
θ_c	Half Acceptance Angle
Y	Intercept Factor
I	Total Horizontal Radiation
I_b	Beam Radiation On Horizontal
I_d	Horizontal Diffuse Radiation
$\dot{q}_u$	Rate of Useful Energy Per Unit Aperture Area
α,τ	Function of Angle of Incidence of Radiation on the Aperture
U_c	Heat Loss Coefficient on Receiver Area
T_a	Ambient Temperature
T_c	Collector Temperature
$\dot{Q}$	Actual Heat Transfer Rate
$\dot{Q}_{max}$	Max Heat Transfer Rate
$\dot{Q}_{Aux}$	Auxiliary Heater Heat Transfer Rate
C_{min}	Minimum Heat Capacity
C_b	Heat Capacity of Bitumen
C_f	Heat Capacity of HTF
$C_{p,f}$	Specific Heat Capacity of HTF
$C_{p,b}$	Specific Heat Capacity of Bitumen
c	Capacity Ratio
$T_{b,o}$	Bitumen Outlet Temperature
$T_{b,I}$	Bitumen inlet Temperature
$T_{f,o}$	HTF Outlet Temperature
$T_{f,I}$	HTF Inlet Temperature
$T_{o,Aux}$	Auxiliary Heater Inlet Temperature
$T_{i,Aux}$	Auxiliary Heater Outlet Temperature
ΔT_{max}	Maximum Temperature difference
ΔT_b	Bitumen Temperature difference

$\Delta T_{set\,,\,off}$	Controller Temperature Difference For Turning Off
$\Delta T_{set\,,\,on}$	Controller Temperature Difference For Turning On
ΔT_{lm}	Log Mean Temperature Difference
$\dot{m}_f$	HTF Mass Flow Rate
$\dot{m}_b$	Bitumen Mass Flow Rate
$\dot{m}_{o,Aux}$	Outlet Mass Flow Rate Of The Auxiliary Heater
$\dot{m}_{i,Aux}$	Inlet Mass Flow Rate Of The Auxiliary Heater
ε	Effectiveness
U	Average Overall Heat Transfer Coefficient
NTU	Number of Transfer Units
SF	Solar Fraction

SUMMARY

INTRODUCTION

The world is moving towards using the renewable energy sources more efficiently to reduce the usage of conventional energy sources and consequently the green house gases (GHG) emissions. The solar energy can intensively contribute to achieve this goal. Sukhatame [1], Kalogirouet al [2] and Luminosu & Fara [3] , among others who address the incipient participation of solar energy on industrial process heating, due to some technical difficulties and many economic barriers, though the same researchers emphasize its huge potential. It can be helpful as it has many ways in order to apply it which are photovoltaic, glazed and unglazed collectors and it also can be applied for heating, industrial or electricity generation purposes.

Although the solar resource is countrywide available throughout all seasons, there is few published works about solar application in the Brazilian industry, as Dantas & Fonseca-Costa [4]. Brazil had about 150 solar thermal suppliers by mid- 2013[5]. Over a six-year period, Brazil’s market more than doubled, with nearly 1 GWth added in 2013 for a total approaching 7 GWth [6]. Demand is driven largely by the economic competitiveness of solar thermal in Brazil and by municipal building regulations and social housing programs, such as “Minha Casa, Minha Vida” (“My House, My Life”), that mandate solar water heaters in new buildings for very poor families [7].

Figure 1 shows that Brazil is one of the top ten countries that use the solar thermal heating and cooling [5], however it has only 2.1 percent in this field. This small percentage is considered as a waste of the solar potential of Brazil because only china has 64 percent in this field.

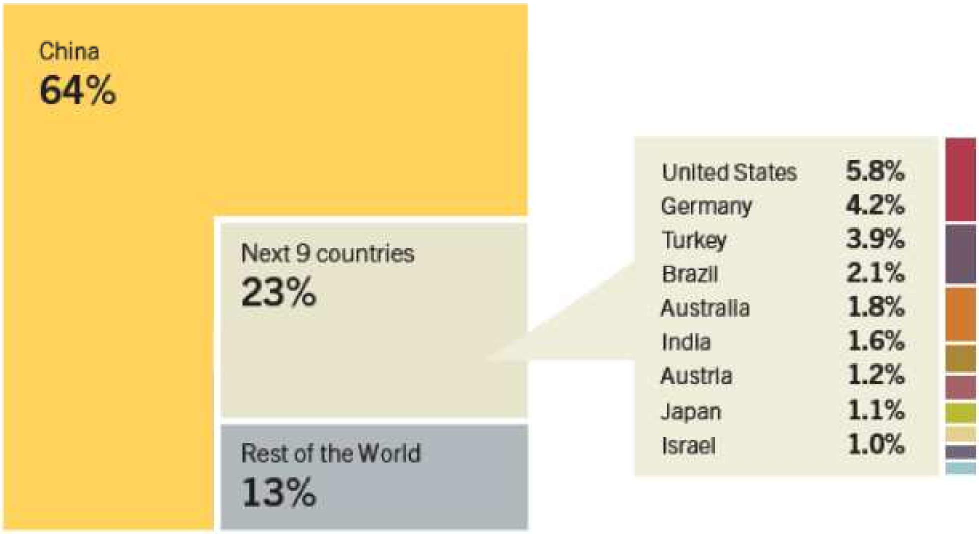

Figure 1 **Top ten countries that use the solar thermal heating and cooling [5]**

On the other hand, the industrial sector accounts for 25% of energy use GHG Brazilian emissions [8]. In 2009, as a result of the 15th Conference of Parties to the UNFCCC (COP 15), Brazil has committed to reduce by at least 36% its projected emissions of greenhouse gases for the year 2020, with an expected contribution of the industry sector through a voluntary 5% emissions cut [9].

In 2013, the total of the industrial sector´s energy usage in Brazil is about 88.3 mega tonne of oil equivalent (Mtoe) makes it the 1st in energy usage in all the sectors. The Sugar cane bagasse (fiber) is the most used renewable source in this sector by 19.5 percent and the sum of the other renewable primary sources is about 7.2 percent. This percentage still low in consideration of the uses that are still can be replaced by the renewable sources. Table 1 showing the usage of each energy source in Brazil at the end in the industrial sector of 2013 [10], figure 2 also showing the percentage of each of them during the last 30 years [10].

Table 1 **Showing the usage of each energy source in Brazilian industrial sector in 2013 [10]**

Energy Source	**Usage ($10^{3\ toe}$)**
Natural Gas	9,737
Steam Coal	3,630
Firewood	7,706
Sugar Cane Bagasse	17,238
Other Renewable Primary Sources	6,349
Diesel Oil	1,154
FUEL OIL	2,677
LPG	1,027
KEROSENE	2
GAS COKE	1,200
COAL COKE	7,807
Electricity	18,067
CHARCOAL	3,661
OTHER PETROLEUM SECUNDARIES	7,950
TAR	89

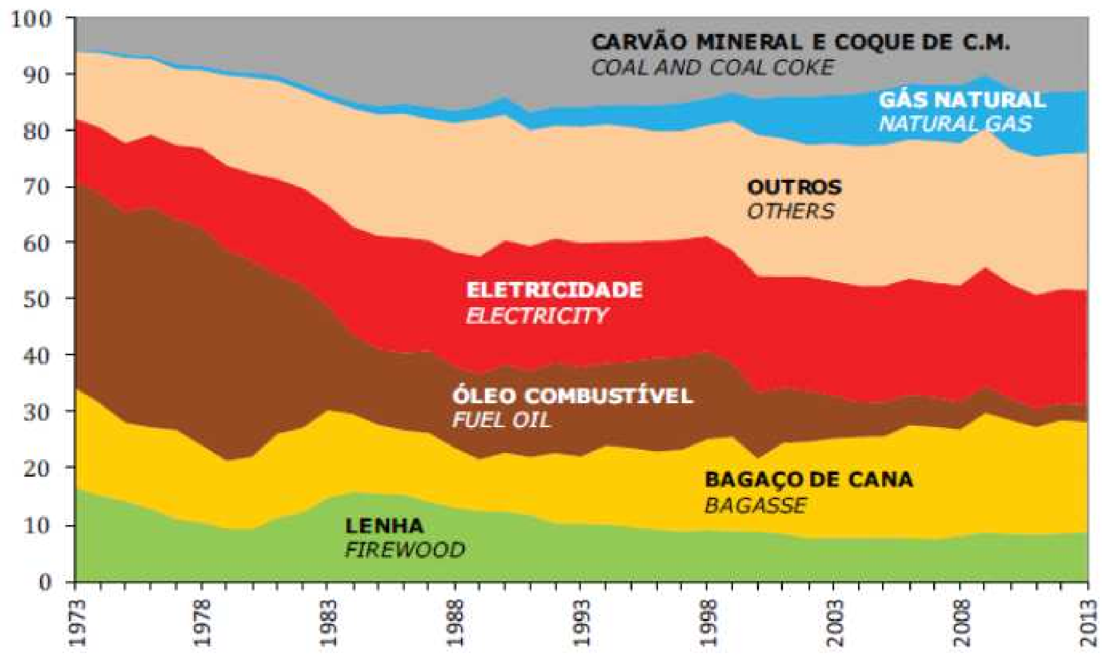

Figure 2 **Percentage of each of energy source in Brazilian industrial sector during the last 30 years [10]**

As about half GHG emissions from the Brazilian industry comes directly from process, very expensive or even impossible to reduce without undesirable production cuts, it is expected that the largest mitigation contribution in the short and medium term will come from energy efficiency measures and the use of renewable energy sources, both directed to thermal applications, because almost 80% of the electrical power production in Brazil comes, already, from renewable sources [10].

The Asphalt Industry is a fossil fuel consuming, emitting high amounts of the green house gases (GHG), given that each ton of asphalt needs about 10 liters of fuel in order to reach the mixing temperature [11]. The choice for this particular kind of industry and thermal process was based on data from the temperature range for the most common processes. For the application treated in this paper, the compound parabolic concentration solar collector (CPC) has shown to be the most suitable type.

There are few studies reported in the literature about process heating using the solar heating systems (SHS) in the asphalt industry, mainly done throughout the past 40 years. Henderson, Wiebelt and Parker [12] have constructed, operated and researched a solar-heated asphalt storage system in Oklahoma City, USA for two years. The storage of the asphalt water emulsion which was used in highway maintenance had required the control of temperatures between about 18 °C and 65 °C in order to avoid physical separation of the emulsion. The solar-heated asphalt storage system had performed satisfactorily and proved to be both cost-effective and maintenance-free. Hankins [13] researched other plant in Texas, USA in which the solar energy was used to compensate the energy losses from the high temperature asphalt to the environment. Luminosu and Fara [3] have constructed a laboratory installation for researching on bitumen preheating by using solar energy in Timisoara, Romania and found that the daily average temperature reached by the bitumen is within its softening temperature range.

Gudekar et al. [14] presented an experimental demonstration unit of CPC system for the application of process steam generation, highlighting that it is easy for fabrication, operation and has a lower cost compared to other available concentrating solar collector systems with further possibility of lowering the cost. Panse [15] constructed a CPC system for steam generation for industrial purpose which proved to be economic and efficient. Kalogirou [16] researched the application of solar energy in sea-water desalination. The parabolic-trough solar-collector was selected mainly due to its ability to function at high temperatures with high efficiency. The economic analysis performed, showed that results could be achieved at low investment cost.

This work presents a technical and economic study for solar heating system (SHS) application in an asphalt plant in Rio de Janeiro (Brazil) using the Brazilian fuel prices. It focuses only on the heating of bitumen, from the storage temperature up to the mixing temperature, without encompassing any other asphalt plant heating processes. On the other hand, the economic analysis is comparing four different models in the system to reach the optimum choice which depends on the user requirements.

This work also offers an environmental analysis for each model by comparing it with three different types of fuel heating systems. This will give an idea about how the asphalt industry is very polluting as the comparison contains the emitted tons of CO_2.

I. THEORETICAL FUNDAMENTALS AND LITERATURE REVIEW

1. Renewable Energy

Renewable energy is the energy sources that can be replenished naturally and continuously and should be naturally produced. Renewable energies are energy sources that are continually replenished by nature and derived directly from the sun (such as thermal, photo-chemical, and photo-electric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy) [17]. This energy sources are the main competitive for the fossil fuel and it takes its place in many fields of life, such as electric power generation, water and space heating. Renewable energy does not include energy resources derived from fossil fuels, waste products from fossil sources, or waste products from inorganic sources [18]. Figure 3 shows an overview of renewable energy sources [17].

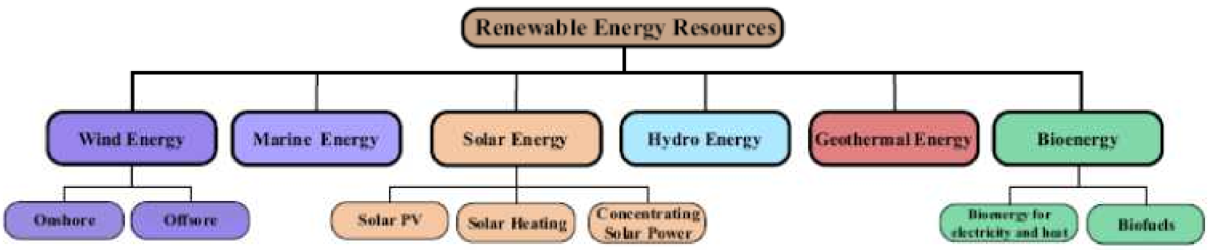

Figure 3 **An overview of renewable energy sources [17]**

Figure 4 shows that the renewable energy sources have the potential to provide 3078 times the current global energy needs [19].

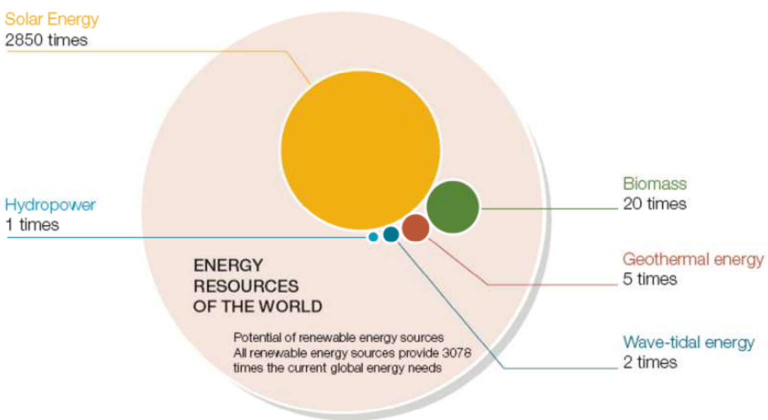

Figure 4 **Potential of renewable energy sources [19]**

1.1 Types of renewable energy sources

1. **Biomass**: is the energy comes from plants, trees and crops, and is essentially the collection and storage of the sun's energy through photosynthesis. Biomass for bioenergy comes either directly from the land, such as from dedicated energy crops, or from residues generated in the processing of crops for food or other products [20]. Biomass energy is renewable and sustainable, but shares with fossil fuels many characteristics, one of them that burning biomass can result in air pollution. While biomass can be directly burned to obtain energy, it can also serve as a feedstock to be converted to various liquid or gas fuels (bio-fuels). Bio-fuels can be transported and stored, and allow for heat and power generation on demand [21].
2. **Geothermal energy**: is the thermal energy that restored in the earth's interior and this is coming from trapped steam or water in the earth crust. It is used mainly in electricity generation and sometimes the steam is used in the cogeneration applications. It can provides an unlimited supply of energy with no pollution but Start-up and maintenance (due to corrosion) costs can be expensive
3. **Hydropower:** the movement of water generates power which is converted to an electric power using turbines. The most common sources are dams. It is relatively inexpensive way to produce electricity but can be used only where there is a water supply.
4. **The renewable marine (ocean) energy**: comes from six distinct sources: waves, tidal range, tidal currents, ocean currents, ocean thermal energy conversion and salinity gradients, each with different origins and requiring different technologies for conversion [17].
5. **Solar energy**: the solar radiation can be converted to energy which is used in heating fluids or spaces and electricity production. This paper will concentrate mainly on this kind of energy and the CSP especially the CPC collector
6. **Wind power**: is defined by the conversion of wind energy by wind turbines into a useful form, such as using wind turbines to make electricity, wind mills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships [22]. It is clean and inexpensive.

Table 2 shows the renewable energy sources and their environmental drawbacks anTable 3 shows the renewable energy sources development of usage

Table 2 Shows the Renewable Energy Sources and Their Environmental Drawbacks [17]

Energy Source	**Environmental Drawbacks**
Biomass	May not be CO_2 natural, may release GHG like methane during the production of biofuels, landscape change, deterioration of soil productivity, hazardous waste
Geothermal	subsidence, landscape change, polluting waterways, air emissions
Hydropower	Change in local eco-systems, change in weather conditions, social and cultural impacts
Marine	Landscape change, reduction in water motion or circulation, killing of fish by blades, changes in sea eco-system
Solar	Soil erosion, landscape change, hazardous waste
Wind	Noises, landscape change, soil erosion, killing of birds by blades

		START 2004[1]	END 2012	END 2013
INVESTMENT				
New investment (annual) in renewable power and fuels[2]	billion USD	39.5	249.5	**214.4** (249.4)
POWER				
Renewable power capacity (total, not including hydro)	GW	85	480	**560**
Renewable power capacity (total, including hydro)	GW	800	1,440	**1,560**
Hydropower capacity (total)[3]	GW	715	960	**1,000**
Bio-power capacity	GW	<36	83	**88**
Bio-power generation	TWh	227	350	**405**
Geothermal power capacity	GW	8.9	11.5	**12**
Solar PV capacity (total)	GW	2.6	100	**139**
Concentrating solar thermal power (total)	GW	0.4	2.5	**3.4**
Wind power capacity (total)	GW	48	283	**318**
HEAT				
Solar hot water capacity (total)[4]	GW_{th}	98	282	**326**
TRANSPORT				
Ethanol production (annual)	billion litres	28.5	82.6	**87.2**
Biodiesel production (annual)	billion litres	2.4	23.6	**26.3**

Table 3 **Shows the Renewable Energy Sources Usage [5]**

2. Solar Energy

In the last decades the scientists and researchers move to the use of the solar energy as it is the biggest source of energy and it can be used industrially or in electricity generation. On average, the energy in the sunshine that reaches the Earth is about one kilowatt per square meter worldwide. According to the Research Association for Solar Power, power is gushing from renewable energy sources at a rate of 2,850 times more energy than is needed in the world. Moreover, in one day, the sunlight which reaches the earth produces enough energy to meet the current global power needs for eight years [23].

2.1 The Solar Energy Usage Types

The Solar Energy Usage Types Consists Of Two Main Types:

a. Photovoltaic (PV): The photovoltaic is converting the direct solar energy into electricity using a semi conductor inside the photovoltaic cells. These cells can be attached together to form a large source of electric current through the direct sunlight. Solar PV combines two main advantages. Firstly, module manufacturing can be done in large plants, which allows for economies of scale. Secondly, PV has the advantage that it uses not only direct sunlight but also the diffuse component of sunlight. Solar PV produces power even if the sky is not completely clear [24]. On the other hand, generally, it is expensive on the small scale.

There some countries use this technology in a big scale, such as United States as it has the biggest PV power station all over the world which is topaz solar farm in California with the capacity of 550 MW. China also has big production plants, such as Longyangxia Dam in Gonghe County, Qinghai Province with the capacity of 320 besides Germany which has the biggest capacity of solar PV, Italy, France and many other countries. Figure 5 shows the top ten countries in PV solar energy in 2013 [5].

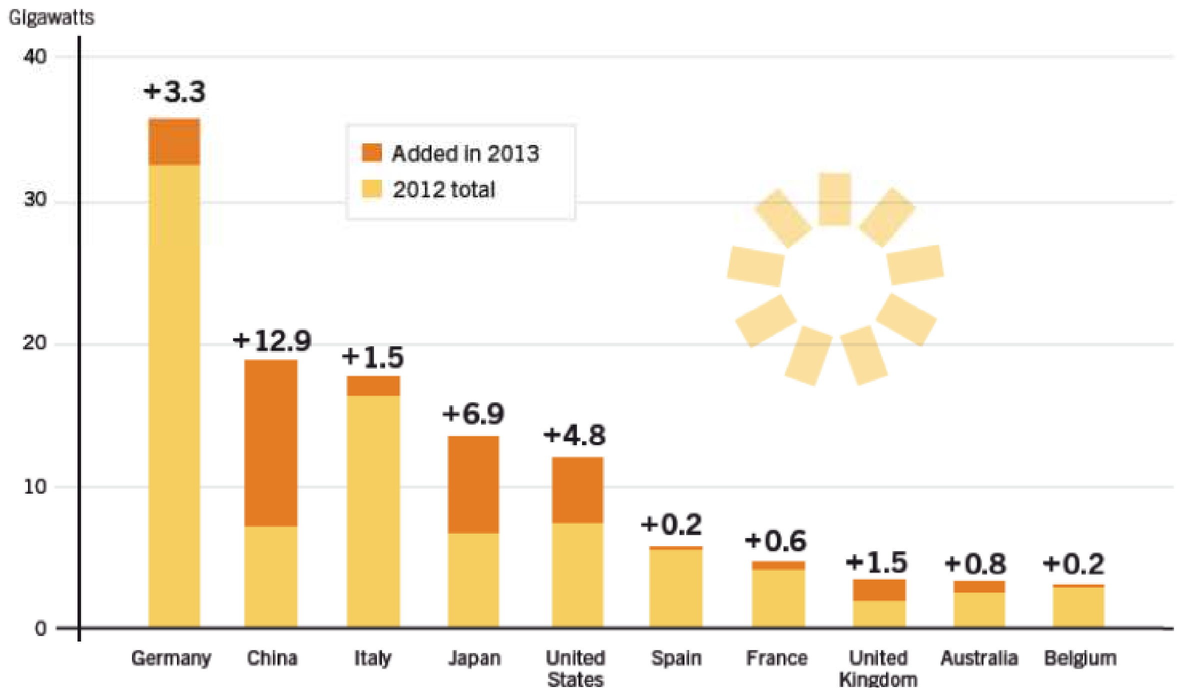

Figure 5 **top ten countries in PV solar energy in 2013 [5]**

b. **Solar Collectors:** these are devices that collects the solar radiation (light beams) and convert it to thermal energy which is used in electricity production or heating fluids for industrial purposes.

2.2 Solar Collectors Types:

Table 4 **the differences between the different types of collectors [2]**

Motion	Collector type	Absorber type	Concentration ratio	Temp. range(°C)
Stationary	Flat-plate collector (FPC)	Flat	1	30-80
	Evacuated tube collector (ETC)	Flat	1	50-200
	Compound parabolic concentrator (CPC)	Tubular	1-5	60-240
Single axis tracking			5-15	60-300
	Linear Fresnel reflector (LFR)	Tubular	10-40	60-250
	Cylindrical trough collector (CTC)	Tubular	15-50	60-300
	Parabolic trough collector (PTC)	Tubular	10-85	60-400
two axis tracking	Parabolic dish reflector (PDR)	Point	600-2000	100-1500
	Heliostat field collector (HFC)	Point	300-1500	150–2000

Table 4 [2] shows the differences between the different types of solar collectors. So there is difference in the temperature range between the flat plate collector and the concentrated collectors.

Schweiger et al. (2000) [25] distributed the temperature ranges into different categories which are:

i. Low (up to 60 ° C)
ii. Medium (60 to 150 ° C)
iii. Medium-high (150 to 250 ° C)
iv. High (above 250 ° C)

a. Flat Plate Collector (FPC)

The most commonly used collectors are the flat plate collectors (FPC) which is used mainly in domestic heating or water heating. FPC is also used in preheating for the industries that require a high temperature range. The biggest FPC system is located in Saudi Arabia and is for water heating in the Princess Noura University. The System is with the capacity of 25 MW and on area of 36,160 m^2 which is in figure 6 [26].

Figure 6 **the biggest FPC system in the world [26]**

b. Evacuated Tube Collector (ETC)

This type of collectors has operating temperature which is more than that for the flat plate collectors. Generally, it has heat pipe which is inside a vacuum-sealed tube (figure 7). However, in some cases it uses the direct flow instead of the heat pipes.

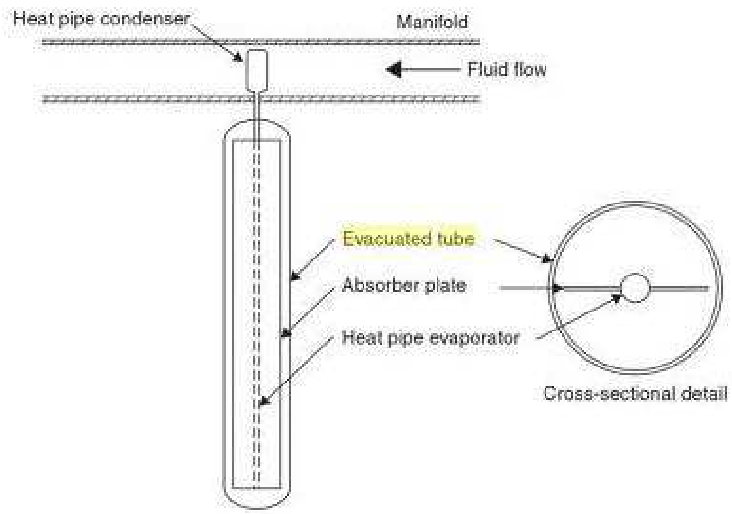

Figure 7 **Schematic Diagram of ETC [16]**

The vacuum envelope reduces convective and conductive losses this leads to higher operating temperature [16]. Figure 8 shows the evacuated tube collector.

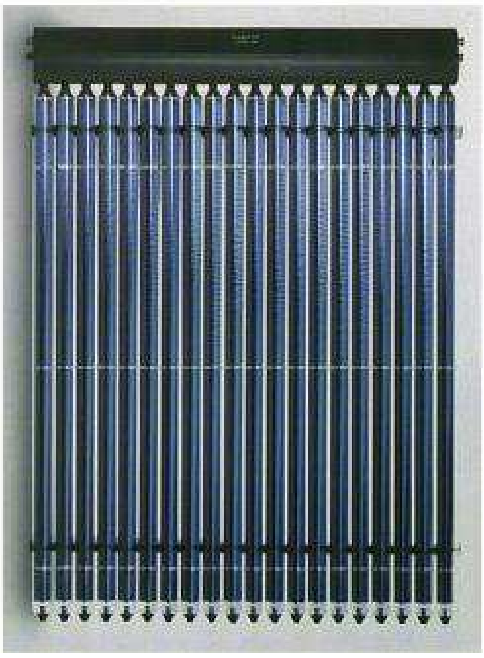

Figure 8 **evacuated tube collector [16]**

c. Concentrating Solar Power (CSP)

The concentrated solar collectors (CSP) are medium high to high temperature ranges collector. So they are chosen depend on the application and the desired output temperature, due to the high concentration of the solar radiation. Furthermore, they are also used in the electricity production. Table 5 [5] shows the CSP global capacity in 2013

Table 5 **CSP global capacity in 2013 [5]**

COUNTRY	TOTAL END-2012	ADDED 2013	TOTAL END-2013
		MW	
Spain	1,950	350	2,300
United States	507	375	882
United Arab Emirates	0	100	100
India	0	50	50
Algeria	25	0	25
Egypt	20	0	20
Morocco	20	0	20
Australia	12	0	12
China	0	10	10
Thailand	5	0	5
World Total	**2,540**	**885**	**3,425**

CSP each type has a different way in applying as they have some applications needs tracking and others does not need. Moreover, the tracking can be one or two axis tracking and also distributed into intermittent (daily or weekly tracking) or Continuous tracking [2]. Figure 9 shows an industrial application of CSP in a medicine factory in Egypt.

The biggest CSP plant in the world is Ivanpah solar facility in California (figure 10), USA. which has a net capacity of 377 MW and is in operation from December 2013 [27]. The biggest in Europe is Andasol in Granada, Spain and net capacity 150 MW.

Figure 9 CSP system for industrial usage in Egypt [28]

Figure 10 Ivanpah CSP Plant [27]

2.3 Compound Parabolic Concentration collector (CPC)

CPC is a special type of solar collector fabricated in the shape of two meeting parabolas. It belongs to the non-imaging family, but is considered among the collector having the highest possible concentrating ratio. Normally, it does not require tracking and can accept incoming radiation over a relatively wide range of angles by using multiple reflections [29].

CPC can concentrate diffused radiation, other concentrating collectors as parabolic trough and parabolic dish only concentrates the beam radiation component on the solar radiation [30].

The height and aperture area for a CPC are calculated as per the desired operating temperature. To reduce the cost the height is generally truncated to half as it slightly affects the concentration ratio [31]. Figure 11 shows the geometry of CPC.

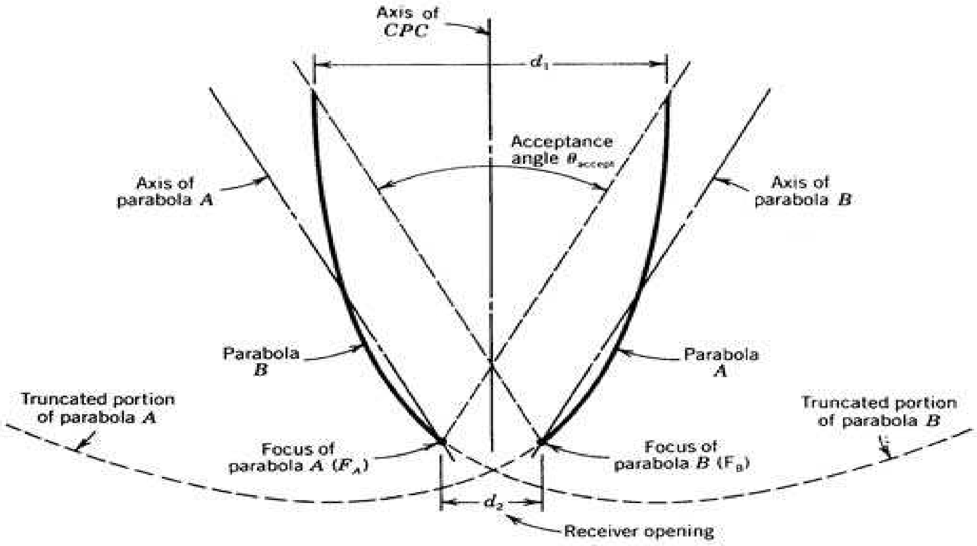

Figure 11 **The Geometry of CPC [1].**

The following terms should be presented when discussing Concentrating Collectors [1].

- Aperture Area (A_a): It is the plane opening of the concentrator through which the incident solar flux is accepted.
- Absorber Area (A_{abs}): It is the total area receiving the concentrated radiation. It is also the area from which useful energy is delivered to the system
- Acceptance Angle ($2\theta_c$): It is the limiting angle over which incident ray path may deviate from normal to the aperture plane and still reach the absorber. Concentrators with large acceptance angle need to be moved on seasonally while concentrators with smaller acceptance angle need to be moved continuously to track the sun.
- Geometric Concentrating Ratio (CR): It is the ratio of effective area of the aperture to the surface area of the absorber (equation 1).
- $CR = A_a / A_{abs}$ Eq. (1)
- Intercept Factor (Y): It is the fraction of focused energy intercepted by the absorber of a given size. For a typical concentrator receiver design its value depends on the size of absorber. When the radiation is normal to the aperture, its value is 1.
- Local Concentration Ratio: It may so happen that the absorber in some systems may not be fully or uniformly illuminated, thus in order to characterize this local concentration this term is defined. It is defined as

the ration of flux arriving at any point on the absorber to the incident flux at the entrance aperture of the concentrating system.

- Collector (Thermal) Efficiency (η_c): It is the ratio of the useful energy delivered to the absorber to the incident radiation on the aperture (equation 2).

  $\eta_c = \dot{q}_u / I_b$ Eq. (2)

  $\dot{q}_u$ is the rate of useful energy per unit aperture area and I_b is the incident radiation
- Optical Efficiency (η_o): It is the ratio of the energy absorbed by the absorber to the incident radiation on the collector (equation 3).

  It includes the effect of mirror surface, shape, transmission losses, tracking accuracy, shading by receiver, absorption and reflection properties, solar beam incident angle [1].

  $\eta_o = \dot{q}_u / (\alpha \tau I_b)$ Eq. (3)

  α, τ are the function of angle of incidence of radiation on the aperture
- The useful energy per unit aperture area delivered to the absorber is given by equation 4:

  $\dot{q}_u = \eta_o I_b - U_c(CR)(T_c - T_a)$ Eq. (4)

  U_c is the heat loss coefficient on receiver area

  T_a and T_c are the ambient temperature and collector temperature

The concentration ratio is limited as the sun is of finite size, determined by the shape factor; the concentration ratio is limited by the value 1 /sin θ_{max}. The optical efficiency for CPC is around 65%, which is 8% more as compared to a parabolic trough collector [31].

3. Asphalt Plants

3.1 Types

There are two most commonly used types of Asphalt Plants: Batch heater and the drum mix asphalt plants.

a. The Batch Heater

The batch heater asphalt Plant (figure 12) has the capacity ranges from 50 to 200 ton/hr. Moreover, it is working in batches, this means that this type produces one batch each time interval while heating the other batch in the mean time. The capacity of the plant is determined by the type of the mixture and the batch size [11].

Batch plants use a weigh pot to weigh bitumen in the batch tower before the asphalt cement is dropped into a pug mill for mixing. The pot is mounted on load cells [32].

Figure 12 **Batch Asphalt Plant [33].**

b. The Drum Mix

It has the capacity ranging from 100 to 700 ton/ hr. The aggregates are dried and heated on a large drum on continuous bases then go through the mixing process. This type is recommended for large contracts where large quantities of the same material are required over a long period of time [11]. Drum-mix plants (figure 13) use a continuous flow bitumen metering system in order to be mixed with the aggregates.

Figure 13 **Drum Mix Asphalt Plant [34].**

3.2 Mixing The Asphalt

Asphalt Mix need about 5-10 % of bitumen that should be mixed with 90-95% of aggregates which should be previously dried in 160 ˚C to remove the moisture from it [11].

The mixture is delivered at the temperature, between 275°F and 375°F (135°C to 190°C) and shall not vary more than 20°F, plus or minus, from that temperature, except that no mixture shall exceed a temperature of 375°F (190°C) . [35]

4. The Bitumen Heaters

Heating the bitumen is one of the basic functions of asphalt Plants. It is delivered to the Plant in a liquid state. The bitumen is a visco-elastic material so the behavior varies from purely viscous to wholly elastic depending on its temperature [11]. Therefore, must be low enough to allow it to be pumped from the delivery truck into the tanks. Figure 14 shows the relation between bitumen temperature and viscosity.

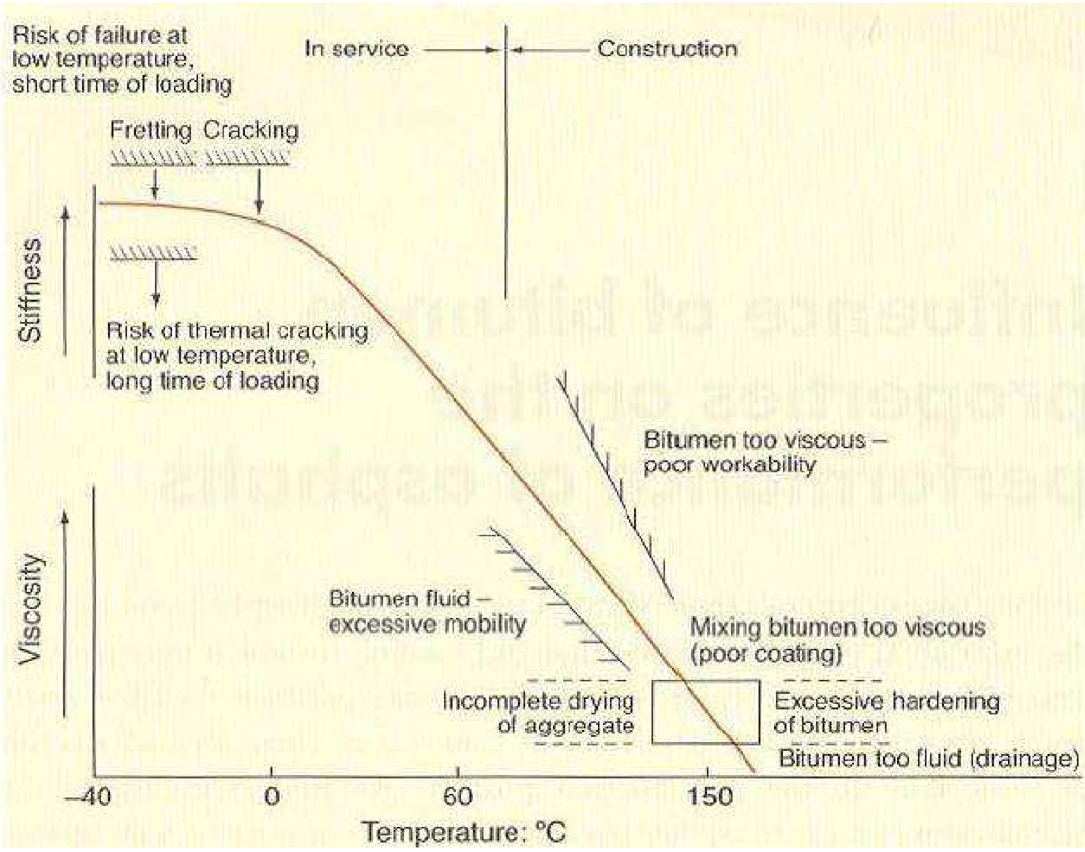

Figure 14 **The relation between bitumen temperature and viscosity [11].**

Therefore, the heaters are the responsible for raising its temperature in order to meet that specified for use (150˚C to 190˚C). However, losing bitumen temperature is not easy as an interesting phenomenon occurs as the asphalt cools. Asphalt in contact with tank inner surfaces solidifies, creating a highly effective insulation. This solidified layer retards heat loss to a major extent [32].

Two main pumps are usually for the process of heating the asphalt. The first is an unloading pump for the delivery truck to the heating tank while the other is a supply pump which supplies the mixer by the bitumen from the heating tank.

There are two main bitumen heating systems that are commonly used in the asphalt plants. Both of them use heating fuels.

4.1 Direct-Fired Tank

The direct-fired (figure 15) tank is an asphalt storage tank that has a burner mounted on one end of the tank which is directly makes a fire into the fire tube that is located inside the tank in order to heat the asphalt that surrounds it.

If anything in addition to the asphalt needs to be heated, the tank can be equipped with scavenger coils. The coils are totally independent from the burner and fire tube. They are positioned above the fire tube so they are immersed in the asphalt, enabling them to scavenge heat from the asphalt. Oil is pumped through the coils, carrying the scavenged heat to other plant components [32].

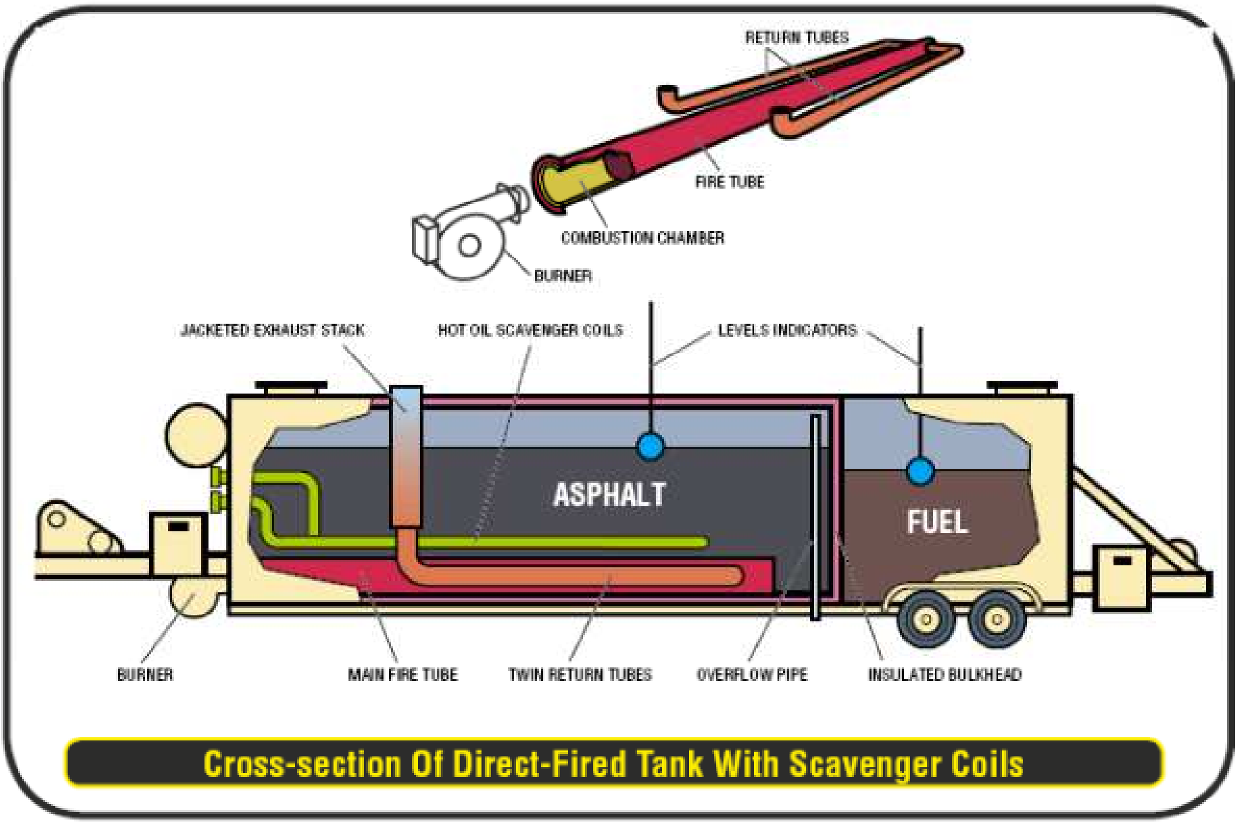

Figure 15 **The direct-fired Bitumen Heater [32]**

This type is more suitable for the small portable asphalt plants because it usually needs one tank for heating the bitumen only. However, the efficiency of a direct-fired tank is about 2 percent higher than that of a hot oil heater because of operating temperatures [36].

Direct-fired tanks has some disadvantages

1. Not suitable for large plants that require more than one tank.
2. Low rate of heat transfer because the fire tube has a limited amount of heating surface [32].

3. Is the need to always retain enough asphalt in the tank to cover the fire tube and scavenger coils. This requires retaining anywhere from 12 to 20 percent of the tank's total volume [32].

4.2 Coil Tank

The other type of heating widely used is an indirect system. It employs a hot oil heater and tanks equipped with heating coils. The system heats the HTF as it is pumped through the heater. The coils can be heated by conventional fuels or electricity.

Figure 16 **Hot oil heater Tank [32].**

Not all coil heaters (figure 16) have the same efficiency. Subtle design differences make significant differences in efficiency. Critical design factors include the flame pattern, combustion gas velocity, heat transfer surface area, thermal fluid turbulence, positioning of the helical coil, effectiveness of the insulation and how well the unit is sealed [32].

Efficiency is up to 92% [37]. Moreover, they can be used for plants with any type or size. They can also use lager burners as they do not use fire tubes [32]. On the other hand, they are more expensive.

5. Fuel Emissions

The GHG emission due to the usage of the fossil fuel is increasing. The impacts of GHG emissions and the resulting climate change have a serious impact on the global economy [38], so the need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production of green house gases. Figure 17 [39] shows the greenhouse gas emissions in the amount of CO_2 giga ton.

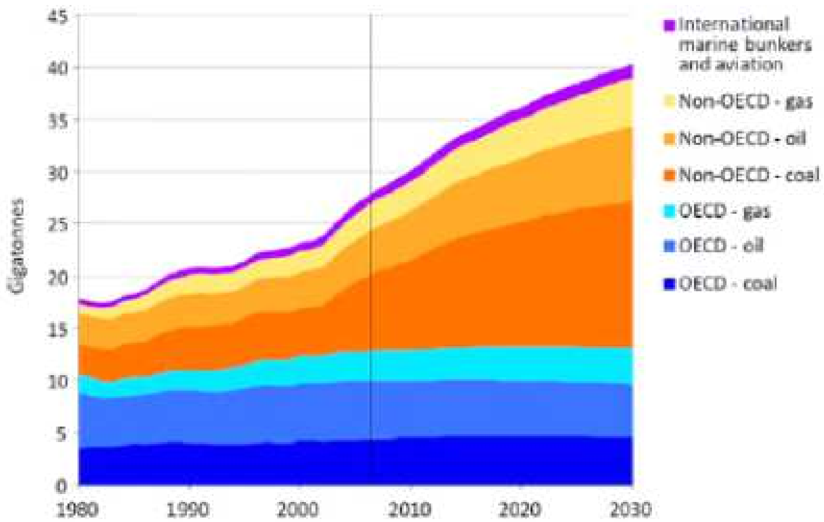

Figure 17 **GHG Emissions in CO_2 Gton [39]**

Therefore, substituting fossil fuels with renewable for industrial usage must be an important part of any strategy of reducing CO2 emissions into the atmosphere and combating global climate change [39].

Two key concerns are the availability of the fuel and the cost per Btu. However, the amount of emissions it produces when burned can be an overriding factor. Fuels that produce high levels of emissions are not well-suited for asphalt heating, as it needs special burners. On the other hand, the most commonly used fuels in Brazil are the LPG, Natural Gas and fuel oil.

II. MATERIALS AND METHODS

1. Computational Simulation Tool

Solar energy simulations were executed using TRNSYS 15, which is a computational tool developed and commercialized by the University of Wisconsin, U.S.A. It is used to simulate the transient behavior of systems and is commercially available since 1975 [40], being developed and updated constantly.

The graphical user interface called IISiBat, one of the parts of the program package, can be used for mounting the systems. Each component is modeled mathematically by a system of equations and TRNSYS solves these systems for each time interval, using analytical and numerical methods and information flow between components. Moreover, new TRNSYS components can be created using FORTRAN language
The components have a number of parameters for defining the calculation models and constants that will be used in the simulation. After choosing the units that will be part of the system, the components must be properly connected, that is, the inputs and outputs must be properly configured, ensuring the flow of information.

The interconnections are extremely important because they determine how to give the transient data stream, that is, which of the calculated values of the simulation of a module will be used as input to simulate another [41].

Case Studied

The case studied is heating bitumen to reach its mixing temperature (more than 150˚C) with mass flow rate of 9 tons/hr in Rio de Janeiro (Brazil). The industrial site consists on a medium size industry, using very typical machinery that is used in many of the asphalt plants all over the world, as shown in figure 18 [32].

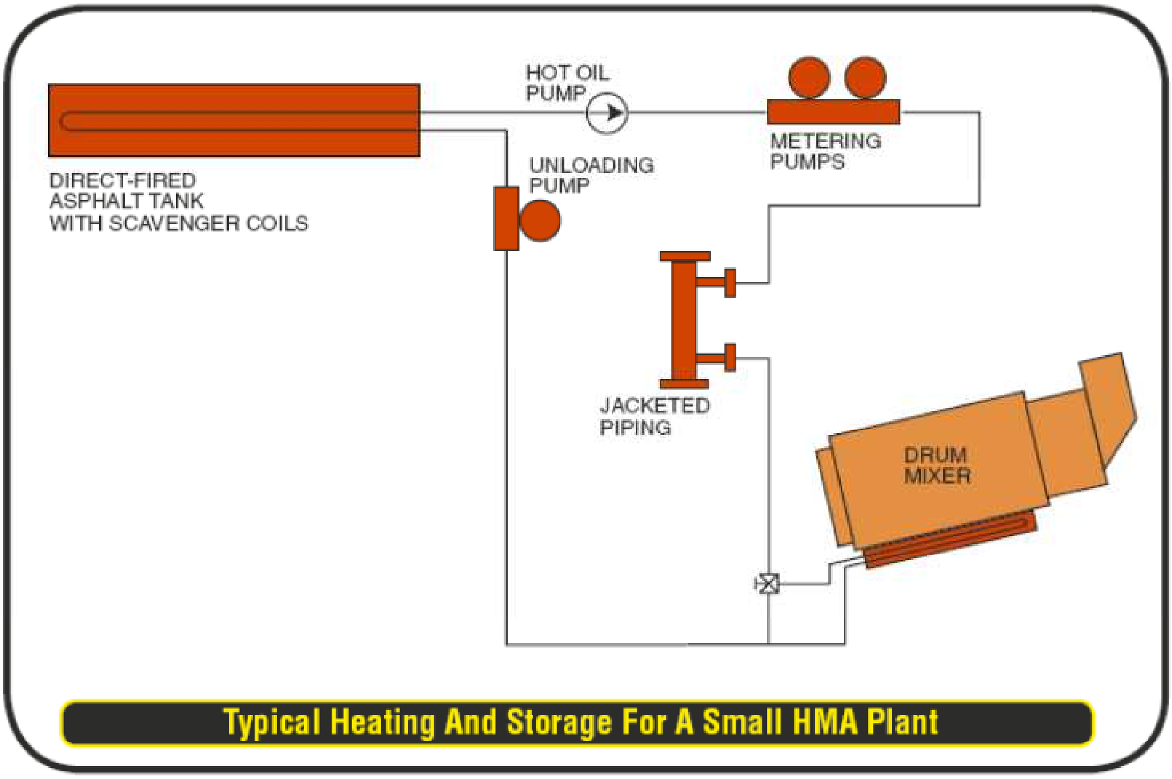

Figure 18 **Typical Heating for a small aphalt palnt [32]**

The System is to raise the temperature of the Heat transfer fluid (HTF) in order to achieve the desired temperature of the bitumen. Therefore, the plant will produce from 90 to 180 tons/hr of asphalt mix. Moreover, mineral oil will be used as the heat transfer fluid due to its high boiling temperature. Table 6 shows the properties of HTF and the Bitumen.

Table 6 **properties of HTF and the Bitumen in system**

Properties	**HTF (Mineral oil)**	**Bitumen**
Mass Flow Rate (kg/hr)	4400	9000
Density (Kg/m^3)	822	1010
Minimum Desired temperature (°C)	238	150
Specific heat capacity(KJ/Kg. °C)	2.13	1.82

2. System Optimization

To execute this work there are many optimization methods used in order to achieve the most appropriate choice for the system components and their specifications. This application has many parameters that are optimized and changed for reach the best options that lead to the main purpose of the dissertation.

These parameters include the specification of the CPC which is used in TRNSYS besides the specifications for the system itself.

3. The Solar Heating System Model

The proposed solar heating system (SHS) (figure 19), in which the HTF is circulating in closed circuit to feed the coil heating tank.

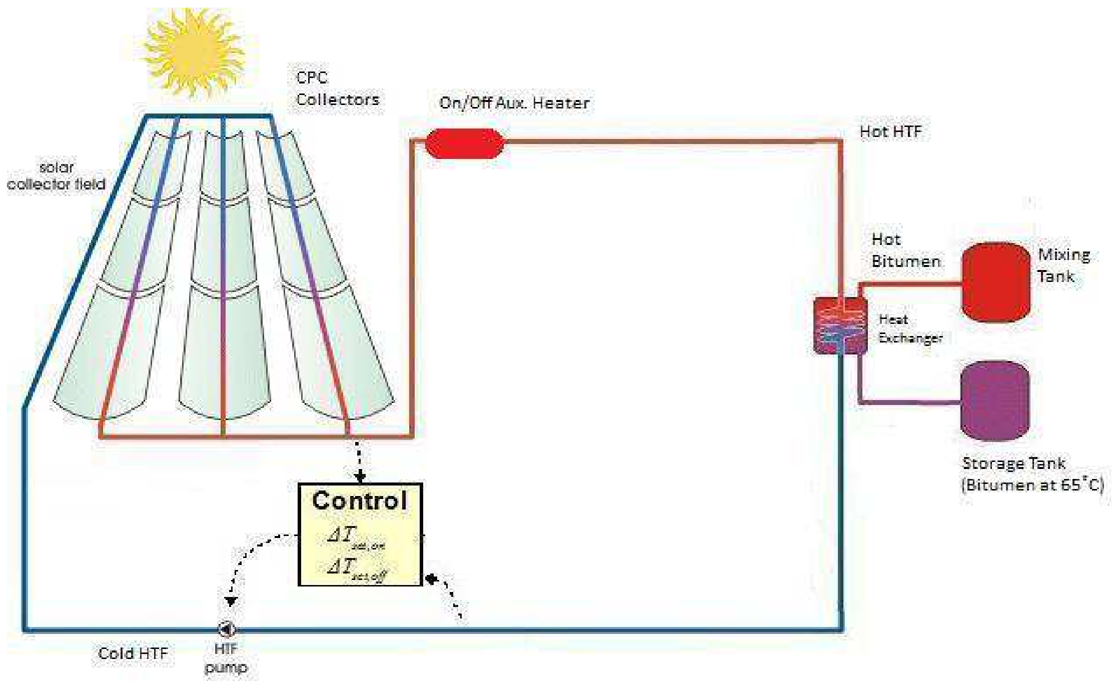

Figure 19 **Solar Heating System Model: Solar Heating System Model**

There are some assumptions are taken in consideration while executing this work which can be summarized in the following points:

- No pipeline heat losses;
- Adiabatic heat exchanger model;
- The oil flows frictionless;
- Isotropic sky solar radiation model;

- Pump electricity consumption is negligible;
- Heating produced by pump inefficiency is negligible;
- Heat losses during the night will cool down the oil to the environmental temperature;
- Oil and bitumen have constant properties;
- Taken into account the effectiveness of the heat exchanger is constant is 85%;
- Obviously, assumptions for all TRNSYS component models used are considered.
- The Fuel Prices are unchanged during the project life cycle

3.1. Model Components

It consists of a pump with a controller to circulate the HTF to the CPC´s through steel pipes, only if there is a net solar energy gain. The HTF will be heated by the CPC´s then it will flow through the pipes to go for the coil inside the coil heating tank at which the temperature of the bitumen is raised from the transportation to the mixing temperature.

1. **Coil Tank**

The Bitumen enters the tank (figure 20) at 65°C while the hot oil is piped to the tank where it heats the tank coils which will heat the bitumen. Therefore, the Heating of bitumen will take place in the tank using the following equation (equation 5) in order to reach a minimum temperature of 150 °C.

$\dot{Q}= C_b\,(T_{b,o} – T_{b,i}) = C_f\,(T_{f,o} – T_{f,i})$ Eq. (5)

In which $\dot{Q}$ is the heat transfer rate inside the exchanger, while subscripts b, f, i and o is bitumen, HTF, inlet and outlet respectively, $C_b = \dot{m}_b\,C_{pb}$ and $C_f = \dot{m}_f\,C_{pf}$ is the heat capacity rates of the bitumen and HTF while T is temperature, $\dot{m}$ and C_p are mass flow rate and specific heat capacity respectively

Maximum temperature difference that can occurs is

$\Delta T_{max} = T_{f,I} - T_{b,I}$ Eq. (6)

Maximum Possible Heat transfer is

$\dot{Q}_{max} = C_{min}\,(T_{f,i} – T_{b,i})$ Eq. (7)

While C_{min} is equal to the smaller value of C_f and C_b.. Moreover, $\dot{Q}_{max}$ is the maximum heat transfer rate.

On the other hand, the above equation can calculate the maximum heat transfer rate not the actual. So there is a relation between $\dot{Q}$ (actual heat transfer rate) which should be taken in account called effectiveness (ε). The effectiveness of the heat exchanger (equation 8) is the ratio between the actual heat transfer rate and the maximum heat transfer rate [42].

$$\varepsilon = \dot{Q}/\dot{Q}_{max} = C_b\,\Delta T_b / C_{min}\,\Delta T_{max} \qquad \text{Eq. (8)}$$

While $\dot{Q}$ is the actual heat transfer

This is because certainly the heat exchanger will not exchange 100% of the heat available between the two mediums. Therefore, after studying many heat exchangers that is already in market, it is found that 85% effectiveness is good and available in many exchangers.

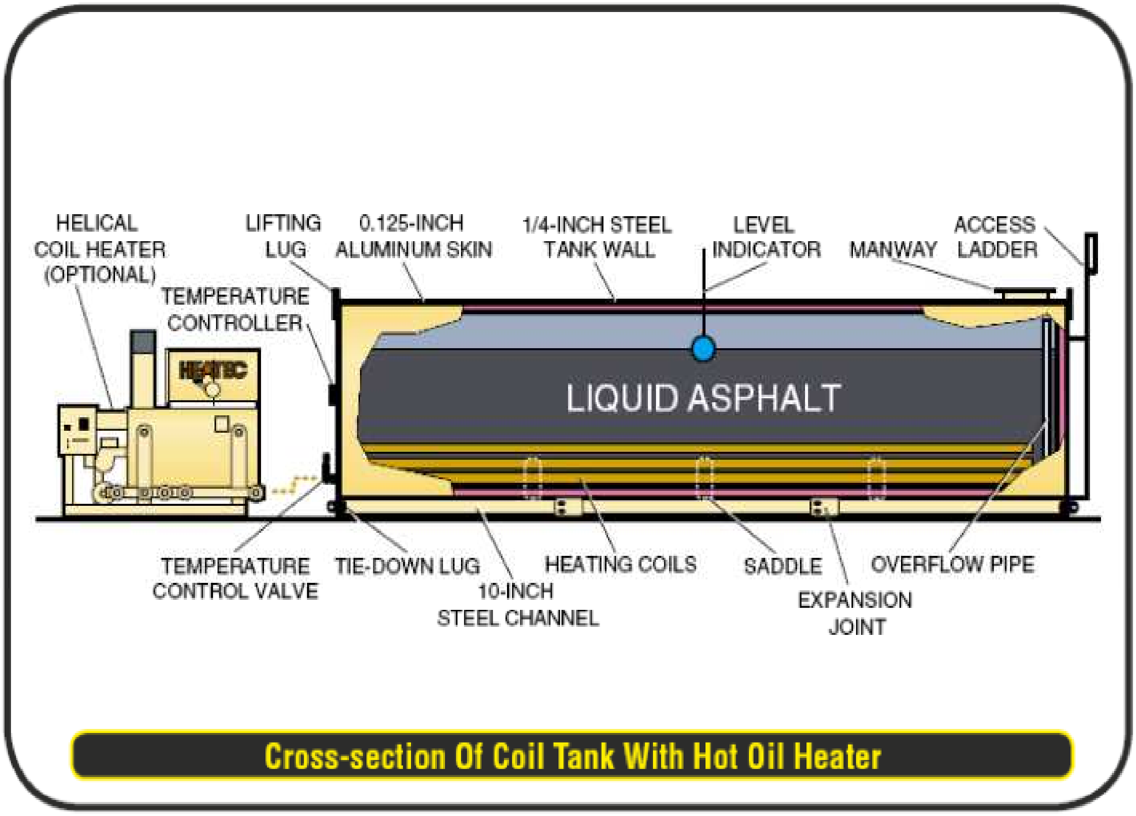

Figure 20 **Coil Tank Cross-section [32]**

Therefore the desired temperature of the HTF is raised from 210°C to 238°C in order to compensate the loss due to the effectiveness of the Coil Heater.

It is assumed that the tank is working as counter flow heat exchanger. Then, the following equations (eq. 9, 10 and 11) [43] are used in order to get the inlet oil temperature and the outlet bitumen temperature for each working hour all over the year.

$\dot{Q} = \varepsilon\, C_{min}\, (T_{f,i} - T_{b,i})$ Eq. (9)

$T_{b,o} = T_{b,i} + (\dot{Q}/ C_b)$ Eq. (10)

$T_{f,o} = T_{f,i} - (\dot{Q}/ C_f)$ Eq. (11)

Figures 21 and 22 shows the inlet oil temperature and the outlet bitumen temperature respectively in a random chosen day during the year and shows the hourly change of each of them during that day.

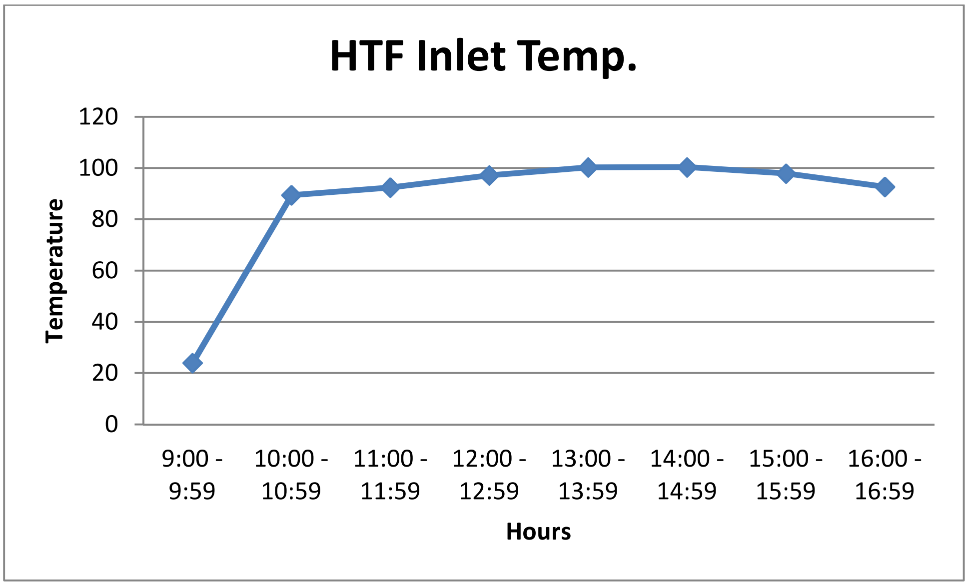

Figure 21 **Inlet Bitumen Temperature**

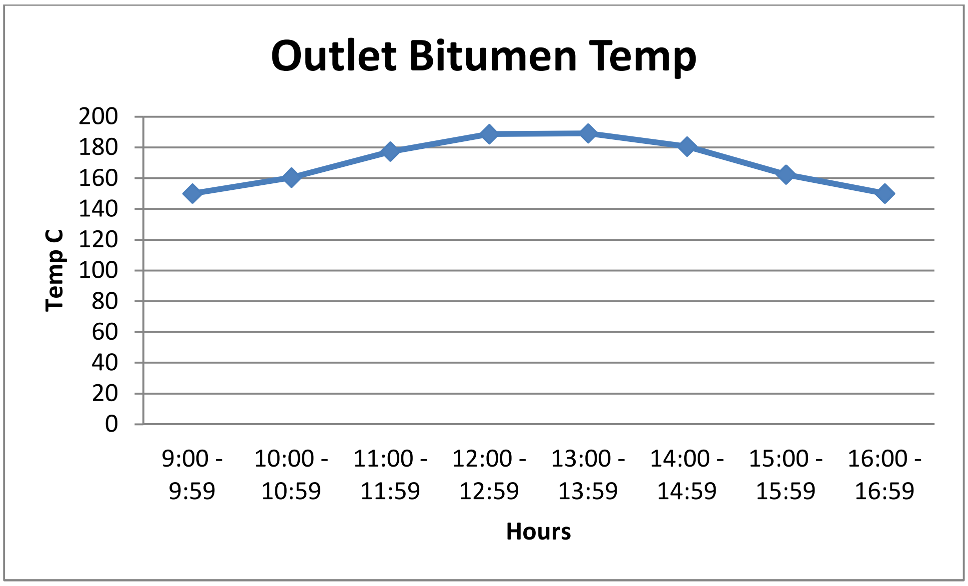

Figure 22 **Outlet Bitumen Temperature**

According to a project that is already using the coil tank with hot oil heating system in Canada [44], it was found that the Average Overall Heat Transfer Coefficient (U) is about (15 BTU/hrft^{2}F) which is (85.17 W/m2 K) for the heat exchanger from oil to bitumen.

Therefore, equation (12,13) shows the log mean temperature difference (LMTD) method [42] was used in order to estimate the minimum area of the heat exchanger for the design or for the selection processes. Table 7 shows the specification used for LMTD method.

Table 7 the specification used for LMTD method

Properties	Values
Average Overall Heat Transfer Coefficient (U)	85.17 W/m2 K
Average ΔT_{in}	24˚C
Average ΔT_{out}	88˚C

$\dot{Q} = UA_s \, \Delta T_{lm}$ Eq. (12)

$\Delta T_{lm} = \frac{(\Delta Tin - \Delta Tout)}{\ln(\Delta Tin/\Delta Tout)}$ Eq. (13)

While $\Delta T_{in} = (T_{f,o} - T_{b,i})$ and $\Delta T_{out} = (T_{f,i} - T_{b,o})$ Eq. (14)

While ΔT_{lm} is log mean temperature difference, U is the Average Overall Heat Transfer Coefficient and A_s, in this case, is the pipe external area for heat transfer.

The LMTD method is used for determining the area of a heat exchanger to achieve the outlet temperature of the cold fluid when the mass flow rates and the inlet and outlet temperatures of the hot and cold fluids are known.

Therefore, it is found that the average area of heat transfer (A_s) will be $0.092m^2$

The number of transfer units (NTU) method [43] was used in order to verify the above mentioned area (equation 15). Table 8 shows the specification used for NTU method.

Table 8 the specification used for NTU method

Properties	Values
Average Overall Heat Transfer Coefficient (U)	85.17 W/m2 K
Average area of heat transfer (A_s)	$0.092m^2$
Average minimum heat capacity	2.603 KJ/ °C

$$NTU = U\ A_s / C_{min} \qquad \text{Eq. (15)}$$

The NTU was found to be 3. Therefore, equation (16) is used in order to verify the efficiency with the above mentioned results. Table 9 shows the specification used for effectiveness calculation.

Table 9 the specification used for effictivness equation

Properties	Values
Number of transfer units (NTU)	3
Capacity Ratio (c)	0.572

$$\varepsilon = \frac{1 - \exp[-NTU(1-c)]}{1 - c\exp[-NTU(1-c)]} \qquad \text{Eq. (16)}$$

While $c = C_{min} / C_{max}$, which is the capacity ratio Eq. (17)

Therefore, using this equation by the above mentioned variables will lead to effectiveness 85% which is the same as it was mentioned before.

2. **The Pump and the pump Controller**

The HTF is circulating through the system with the pump power which is controlled by the differential controller. This controller has a control signal is chosen as a function of the difference between upper and lower temperatures T_h and T_l. The first sensor measures the temperature of HTF in the tank outlet towards the collectors ($T_{o,Aux}$) while the second measures the temperature of the HTF at the exit of the CPC ($T_{f,i}$) . The pump functions when the differential controller recognizes a preset temperature difference, $\Delta T_{set\,,\,on}$, between the sensors. On the contrary, it stops when the difference is less than another predetermined value, $\Delta T_{set,\,off}$.

It is used in modeling in TRNSYS the simplest control strategy, which is to turn off the pump and motor, if connected, or keep it off in any different situation from one of the following:

- The motor pump is on and $T_{o,Aux}$ - $T_{f,o} > \Delta T_{set\,,\,off}$
- The motor pump is off and $T_{o,Aux}$ - $T_{f,o} > \Delta T_{set\,,\,on}$

While $T_{o,Aux}$ is the auxiliary heater outlet temperature

Temperature differences must be chosen fairly criterion. If they are too far, a significant amount of solar energy will no longer be collected and utilized by the system. If too close, it runs the risk of drive cycles and short off each other and extended in duration at times when solar radiation is close to the critical level of radiation (I_c) [45].

3. **Compound Parabolic Concentration Solar Collector (CPC)**

In order to reach the above mentioned temperature, the most efficient solar collector with the least price that is able to reach it should be chosen.

CPC is the most appropriate in this case as it can reach till 300 °C without tracking system. On the other hand, the Flat Plate Collector (FPC) is the cheapest and the most available but it cannot reach this temperature level. Therefore, it can be used only as preheating solar system or in fluidizing the bitumen only. On the other hand, FPC is generally used for domestic solar water heating, while the application of CPC lies in industrial process and power generation.

In the presented dissertation, the total beam and diffuse radiation within the acceptance angle are determined. Furthermore, reflector concentration and reflective losses are considered and the effective radiation striking the absorber is calculated. This effective radiation is then used to find the energy transferred to the collector flow stream and the resulting outlet temperature.

4. **Auxiliary Heater**

There is an on/off auxiliary heater that has $T_{set,Aux}$ = 238°C which is the lowest temperature of the oil to make the bitumen reaches 150°C. This has a control system to measure the oil temperature before entering the coil heating tank. When the auxiliary heater inlet temperature is above the set point temperature, the auxiliary heater will not work so it will not add any heat to the HTF.

If $T_{iAux} \geq T_{set, Aux}$

$T_{i,Aux} = T_{o,Aux}$

$\dot{m}_{o,Aux} = \dot{m}_{I,Aux}$

$\dot{Q}_{Aux} = 0$

While T_{iAux} is the auxiliary heater inlet temperature, $\dot{m}_{o,Aux}$ and $\dot{m}_{I,Aux}$ are the auxiliary heater outlet and inlet flow rate respectively and $\dot{Q}_{Aux}$ is the auxiliary heater heat transfer rate

On the other hand, when the auxiliary heater inlet temperature is below the set point temperature, the auxiliary heater will work to add the heat needed to the HTF in order to reach 238 ˚C which is illustrated in equation 18.

If $T_{iAux} < T_{set, Aux}$ then

$T_{o,Aux} = T_{set}$

$\dot{m}_{o,Aux} = \dot{m}_{I,Aux}$

$$\dot{Q}_{fluid} = \dot{m}_o.C_{pf}.(T_{set} - T_{iAux.}) \qquad \text{Eq. (18)}$$

Then, the hot bitumen goes to the mixing process with the aggregates while the cold HTF will go again to the collectors through the pump and so on.

This way in heating bitumen is widely used in many asphalt plants that are using conventional fuel.

It is recommended to put a bypass in the system before the collector. This is because in the colder regions in the rainy or snowy days the CPC will not function appropriately. Therefore, the bypass will drive the HTF directly to the auxiliary heater as there will be no energy gain from the CPC.

5. COMPUTATIONAL SIMULATION

Simulation of the system was executed using two software applications; Excel and TRNSYS. Each one of them has a certain role in order to execute the simulation.

First, TRNSYS was used in order to make the simulation of the CPC. The simulation of the CPC cannot done by excel as TRNSYS gives accurate results of the heating of the HTF due to the radiation and other factors that were taken from the EPW file. Therefore, the main task was to know the outlet temperature of the HTF from the collector ($T_{f,o}$).

Second, Excel simulates the heat exchanger. It was used to determine the Bitumen outlet temperature from the Coil Tank ($T_{b,o}$). Moreover, it was used to calculate the inlet temperature of the HTF inside the collector ($T_{f,i}$) which is equal to the its outlet temperature of the Coil Tank.

Excel application also was used in calculating the saved fuel due to the usage of the solar heating system. In addition to the CO_2 avoided emissions and other calculations in the economic and the environmental studies. Figure 23 shows the flow diagram of the simulation of the model.

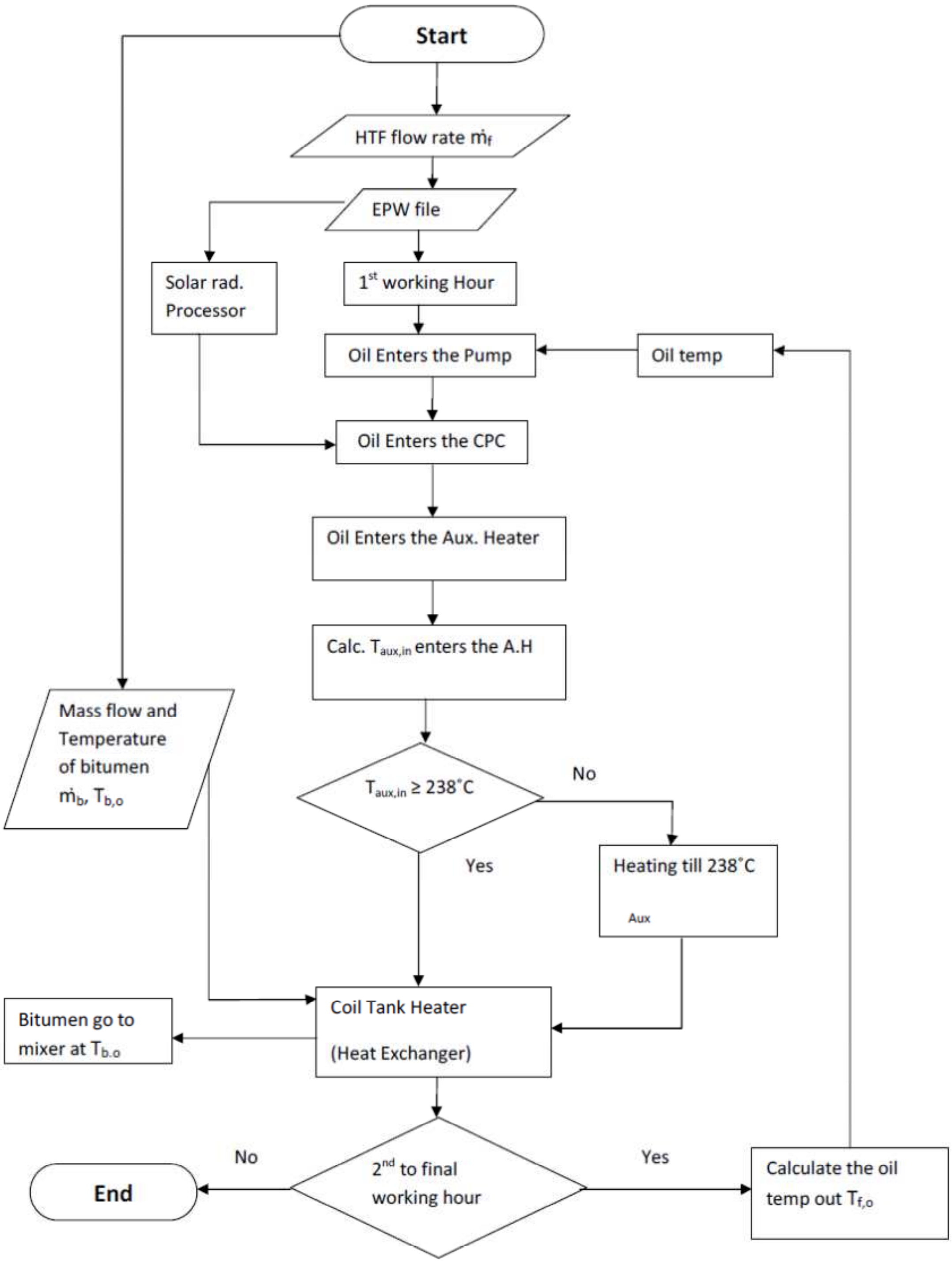

Figure 23 Flow diagram of the Model

5.1 THE TRNSYS MODEL

The case studied is heating bitumen to reach its mixing temperature in an asphalt plant in Rio de Janeiro (Brazil). Typical meteorological year (TMY) data for the city of Rio de Janeiro were used which were built from EPW files obtained at LabEEE (2013) web site [46], loaded to TRNSYS using TYPE 9a component. Data consisted on total and diffuse horizontal irradiation both hourly (I, I_d), ambient temperature (T_a) and also the temperature of the bitumen (65 ˚C) before entering the coil heating tank

The component called TYPE 16i (table 10) (radiation processor / total horizontal diffuse known) contains the equations for the basic treatment of solar radiation , with various parameters such as output , including the angle of incidence , extraterrestrial radiation , the total radiation on tilted surface.

In addition to calculating the transposition of the horizontal radiation to the inclined surface of the collector, has advanced features such as the calculations for tracer surfaces (tracking) and over an inclined surface. The latter ones are not used in the proposed model, but model of Liu and Jordan “isotropic sky model” was adopted and implemented.

Available solar radiation was calculated using the isotropic diffuse sky method developed by Liu and Jordan (1963), detailed in [43]. The radiation on the tilted surface is considered to include the three components: the beam radiation, the isotropic diffuse radiation, and solar radiation reflected from the ground.

From the horizontal values of global (I) and diffuse (I_d) radiation, available in the EPW file, the value of beam radiation on a horizontal surface (I_b) was calculated by making the simple subtraction (equation 19):

$$I_b=I-I_d \qquad \text{Eq. (19)}$$

Table 10 **TRNSYS TYPE 16i model.**

	#	Name	Corresponding choice
Parameters	1	*Horizontal radiation mode*	5 (I and Id)
	2	*Tracking mode*	1 (fixed collector)
	3	*Tilted surface mode*	1 (isotropic sky model)
	4	*Starting day*	1
	5	*Latitude*	Φ = -22,9º (Rio de Janeiro)
	6	*Solar constant*	Solar Constant: G_{sc} = 4.871, kJ/h.m²
	7	*Shift in solar time*	0º (no shift)
	8	*Not used*	-----
	9	*Solar time?*	-1(No change)

Inputs	1	*Total radiation on horizontal*	I (TMY file)
	2	*Diffuse radiation on horizontal*	I_d (TMY file)
	3	*Time of last data read*	1 (TMY file)
	4	*Time of next data read*	1 (TMY file)
	5	*Ground reflectance*	ρ_g = 0,2
	6	*Slope of surface*	$\beta = \lvert\Phi\rvert$ = 22,9º
	7	*Azimuth of surface*	γ = 0º (on equator)
Output	1	*Extraterrestrial on horizontal*	H_0
	2	*Solar zenith angle*	θ_z
	3	*Solar azimuth angle*	γ_s
	4	*Total horizontal radiation*	I
	5	*Beam radiation on horizontal*	I_b
	6	*Horizontal diffuse radiation*	I_d
	7	*Total radiation on surface 1*	I_T
	8	*Beam radiation on surface 1*	I_{Tb}
	9	*Sky diffuse on surface 1*	I_{Td}
	10	*Incidence angle for surface 1*	θ
	11	*Slope of surface 1*	β

After the solar radiation processor, the compound parabolic concentration solar collector should come. This is because the processor’s outputs are allocated as inputs for the CPC which is the heating device in the system which heats the heat transfer fluid (HTF).

The type 74 (Table 11) is the CPC which also needs another inputs and parameters that are common in many collectors because it depends on the materials used for it

Table 11 **TRNSYS TYPE 74 CPC**

	#	Name	Corresponding choice
Parameters	1	*Number in series*	1
	2	*Collector area*	Total area of the collector
	3	*Fluid specific heat*	C_p = 2.13 kJ/kg.K
	4	*Collector fin efficiency factor*	0.9
	5	*Overall Loss Coefficient*	1.51
	6	*Wall reflectivity*	0.9
	7	*Half-acceptance angle*	36°
	8	*Truncation ratio*	0.67
	9	*Axis orientation*	1 (receiver axis is horizontal and in a plane with a slope “transverse”)
	10	*Absorptance of absorber plate*	0.95
	11	*Number of covers*	1
	12	*Index of refraction of cover*	1.526 (glass)
	13	*Extinction coeff. thickness product*	0.0375
Inputs	1	*Inlet temperature*	T_i (inlet temperature of the fluid)
	2	*Inlet flowrate*	$\dot{m}_i$ *(inlet mass flow rate of the fluid)*
	3	*Ambient temperature*	T_a
	4	*Incident radiation*	I_T
	5	*Total horizontal radiation*	I
	6	*Horizontal diffuse radiation*	I_d
	7	*Ground reflectance*	$\rho_g = 0,2$
	8	*Incidence angle*	θ
	9	*Zenith angle*	θz

	10	*Solar azimuth angle*	Γs
	11	*Collector slope*	$\beta = \lvert\Phi\rvert = 22{,}9^{o}$
	12	*Collector azimuth angle*	*0 (collector azimuth is facing the equator)*
Outputs	1	*Outlet temperature*	T_o
	2	*Outlet flow rate*	$\dot{m}_o$ *(inlet mass flow rate of the fluid)*
	3	*Useful energy gain*	*Q*

The pump and its controller are also working in order to feed the CPC so they have the inlet temperature and flow rate of the CPC is the outputs of the Pump and the controller is only to check if the fluid temperature need to be pumped into the CPC to gain more heat or not.

Table 12 and 13 showing type 3d pump and type 2b pump controller respectively and their parameters, inputs and outputs.

Table 12 **TYPE 3d Pump**

	#	Name	Corresponding choice
Parameters	1	*Maximum flow rate*	ṁ
	2	*Fluid specific heat*	C_p = 2.13 kJ/kg.K
	3	*Maximum power*	N/A
	4	*Conversion coefficient*	0
Input	1	*Inlet fluid temperature*	T_i
	2	*Inlet mass flow rate*	ṁ
	3	*Control signal*	*sig*
Output	1	*Outlet fluid temperature*	Inlet temp. For CPC
	2	*Outlet flow rate*	Inlet mass flowrate For CPC
	3	*Power consumption*	-----

Table 13 **TYPE 2b pump controller**

	#	Name	Corresponding choice
Parameters	1	*No. of oscillations*	3 (The number of control oscillations allowed in one time step)
	2	*High limit cut-out*	320 ºC
Input	1	*Upper input temperature Th*	T_o
	2	*Lower input temperature Tl*	T_i
	3	*Monitoring temperature Tin*	T_i
	4	*Input control function*	-----
	5	*Upper dead band dT*	Temperature difference for turn on the pump: $\Delta T_{set,on}$
	6	*Lower dead band dT*	Temperature difference for turn off the pump: $\Delta T_{set,off}$
Output	1	*Output control function*	*sig*

The TYPE 25c module completes the set of employee components, performing the function of registering in text file type simulation results for each hour of the year.

The connections between the modules for modeling proposal have been made to reflect the correspondence between the variables employed in this study and the parameters, input and output modules as described in the above mentioned tables. The resulting model is shown in (Figure 24), which was built from the TPF file ("IISiBat"), formatted to improve visual understanding and with addition of some external visual elements to TRNSYS.

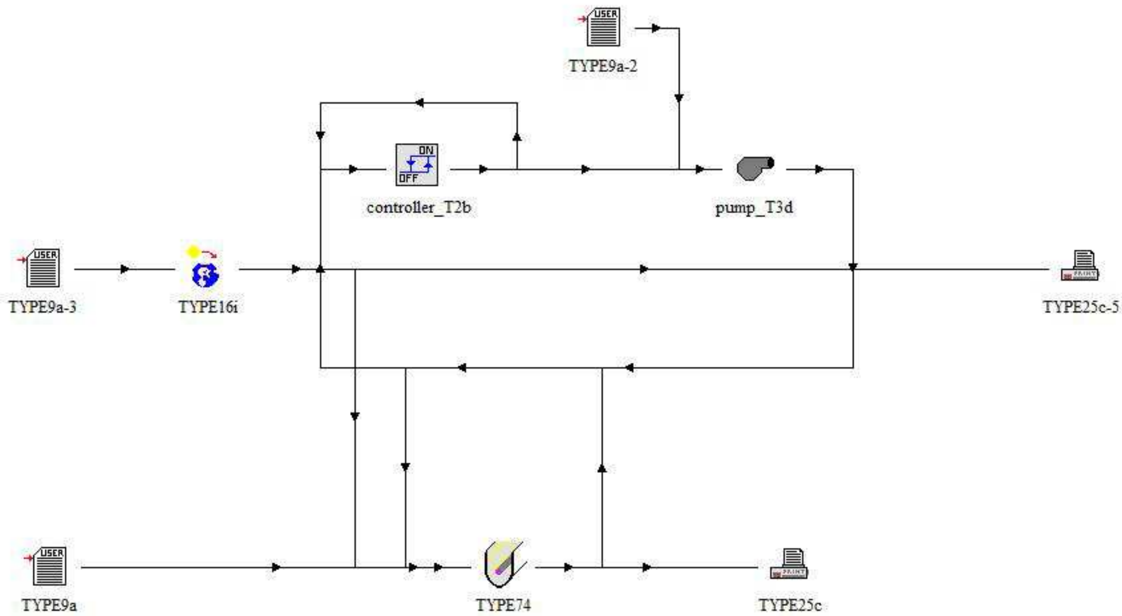

Figure 24 **TRNSYS model**

6. Economic Analysis

The whole economic modeling uses the United States Dollars (USD). Price surveys were carried out on April/2015. The exchange rate from Brazilian reais (BRL) to USD is 3.04 BRL/USD [47].

The SHS is used in order to raise the temperature of the bitumen from the storage temperature (65°C) to the mixing temperature of (135 °C to 190.6 °C) [35], on the other hand, it should not exceed (230°C) in order to prevent auto-ignition [48]. The system used in this research can make a maximum temperature of bitumen below this temperature and with minimum temperature of 150°C. This is because the heat losses are excluded in the coil heating tank. It can permit the efficiency of the coil heating tank till 90 percent.

In order to reach this temperature range by conventional fuel, will be so costly and will emit GHG. On the other hand, it is not cost effective to operate the system solely on solar energy due to the relatively high cost of the equipment and the high percentage of inactive time. Therefore, there is an on/off auxiliary heater that has T_{set} = 238°C which is the lowest temperature of the oil to make the bitumen reaches 150°C.

On the other hand, the difference is calculated in the amount conventional fuel between the FHS and each model of the SHS systems. Therefore, it is translated to amount of money depends on the price of the fuel.

$\dot{Q} = \dot{m}\, C_p\, \Delta T$ eq. (20)

Where ΔT in equation (20) in the points that did not reach the mixing temperature is:

1. Fuel System: the difference between the exit and the inlet temperature of bitumen which is equal to (150°C – 65°C)
2. SHS: the difference between the set 238 °C and the inlet temperature of the HTF in the auxiliary heater.

It was found that there is a lack of information about the price per m^2 for the CPC due to its rareness. However, there were one is already installed in India by Enersun Power Tech Pvt. Ltd [15]. The Price of the CPC per m^2 is 100 USD. On the other hand, it was an experimental model so the price of a PTC that is already installed is the most suitable for this economic evaluation. The price of the PTC is 194.7 USD/m^2 [49]. Table 14 show the specifications used for the economic analysis.

By using the Brazilian price in Brazilian Real (BRL) per barrel of oil equivalent (BOE) of each fuel (Table 15), a yearly difference was calculated in USD using the discount rate of 15% and the operating life-cycle of 15 years.

Table 14 Specification used for the economic analysis

Properties	**Value**
Project Life Cycle	15 years
Price of the CPC (including installation)	194.7 USD/m^2

Table 15 **Brazilian fuel prices [50].**

Fuel Type	**Price/ BOE. (BRL)**
LPG	442
Fuel oil	264

Natural gas	246

In order to calculate the fuel savings and test the feasibility of the study, solar fraction (SF) should be taken into consideration. This is because the fuel savings solar factor (equation 21) depends on the yearly fuel savings (equation 22) and the amount the fuel prices also. In which the solar fraction is the amount of the fuel saved each year by using the solar heating system.

$$\text{Solar Fraction} = 1- \frac{\text{fuel consumption by SHS}}{\text{fuel consumption by FHS}} \qquad \text{eq. (21)}$$

$$\text{Yearly Fuel Savings} = \text{fuel Prices x FHS fuel consumption x SF} \qquad \text{eq. (22)}$$

7. Environmental study

Environmental study in this work is concerned about the emissions avoided due to the difference of the amount of fuel used each year. It was calculated in a yearly basis in ton of CO2 using the official Brazilian official emission factors (Table 16); those are in accordance with the International Panel of Climate Changes (IPCC) [8]. Moreover, the low heat value (LHV) and density of each type of fuel from the biomass data book [51].

Table 16 **official Brazilian official emission factors [8].**

Fuel Type	**Emission Factors** ($t\ CO_2/t$)
LPG	2.91997
Fuel Oil	3.09436
Natural gas	2.61934

Avoided emissions depends on the fuel savings also which is interpreted to tons. Equation 23 shows how the avoided emissions are calculated to give results in the units of (tCO_2/year) for each type of fuel and also for each model of the three models.

$$\text{Yearly Avoided Emissions} = \text{Emission Factor x FHS fuel consumption x SF} \qquad \text{eq. (23)}$$

III. RESULTS

In order to reach this temperature Range with each system were calculated the British Thermal Units (BTU) required monthly and yearly so the system need a yearly total of $4.4x10^9$ BTU.

was used to avoid entering the oxidizing or the auto-ignition range for bitumen [48]. Therefore, the biggest area that serves the above mentioned purpose was 700 m^2. Moreover, the three models (table 17) that were tested have a variation step in area equal to 100 m^2.

Table 17 The three Models and their areas

Model Number	**Area**
Model 1	500 m^2
Model 2	600 m^2
Model 3	700 m^2

1. Economic Analysis

The three models are explained economically in the basis of solar fraction, fuel savings, net present value (NPV), Payback period and Internal rate of return (IRR).

In order to give more understanding for these terms, the following explanation for each term is required:

NPV: the sum of the discounted cash flows minus the original investment. These cash flows suffered a discount by the discount rate (i) in order to interpret the change in the value of money during a given period [52]. It is explained in equation 24.

$$NPV = \sum_{n=1}^{n=N} \frac{CF_n}{(1+i)^n} \qquad \text{eq. (24)}$$

Payback Period: The length of time required to recover the cost of an investment [52]. So it is used the discounted cash flows in order to minimize the risk of the future changes calculations.

IRR: it the discount rate which equates the summation of the net present value of the cash flow throughout the project lifecycle to the initial investment cost (equation 25) [52].

$$\text{Initial investment cost} = \sum_{n=1}^{n=N} \frac{CF_n}{(1 + IRR)^n} \qquad \text{eq. (25)}$$

Assuming the highest value found for carbon credits, the calculation results in lesser than 10% of its yearly incomings. Since that carbon credits depends on a special negotiation and there is no assurance that it will be gained, so the carbon credits are not added in the economical evaluation.

a. Model no. 1 Comparison

In the first model that is used in this work has a collector area of 500 m^2

Figure 25 The Monthly Btu required from conventional Fuel for the bitumen heating between Fuel and Solar Heating Systems. Figure 26 shows the Hourly outlet HTF temperature for January.

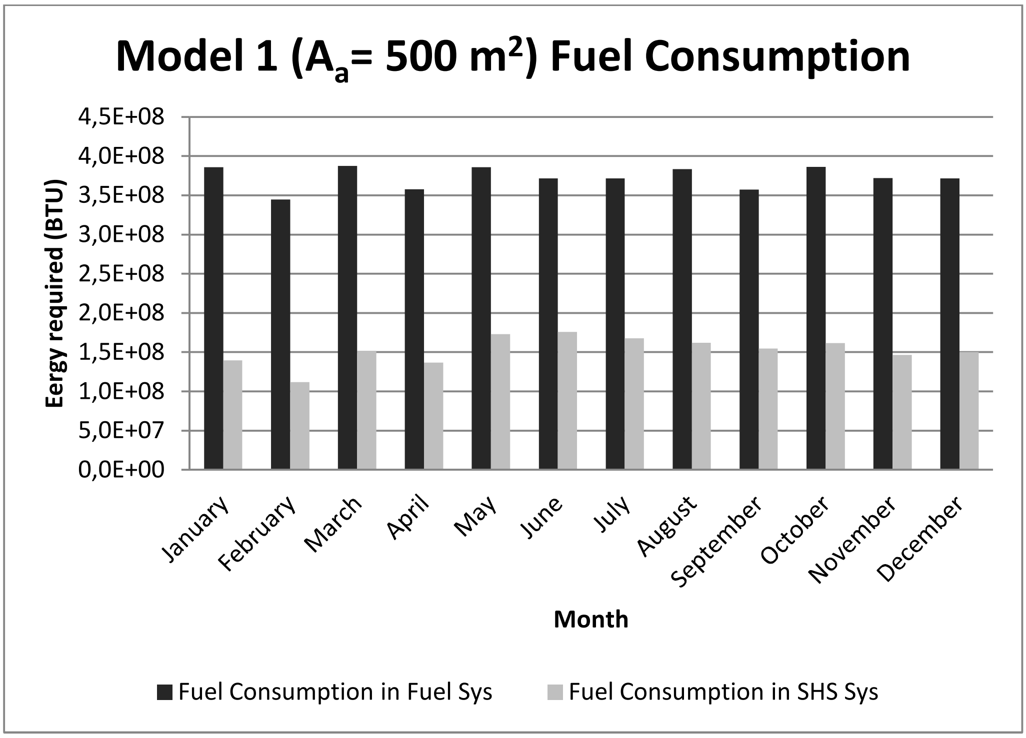

Figure 25 **Comparison monthly BTU required**

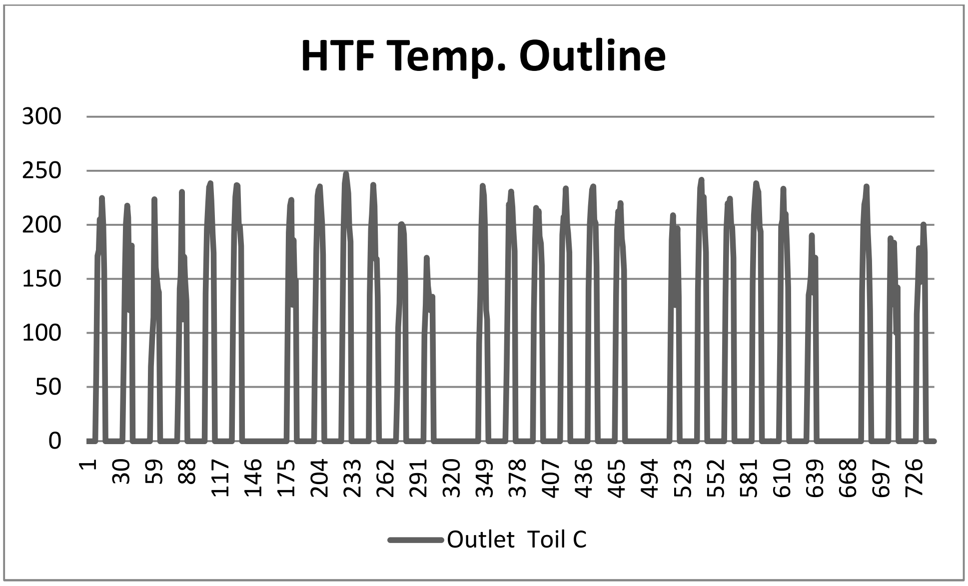

Figure 26 **Hourly outlet HTF temperature for January for Model 1 (A_a= 500 m^2)**

Equation After calculating the net BTU required by both systems the yearly Solar Fraction found is about 59.1 %.

Table 18 shows the properties of each type of fuel that is used in the comparison and the economic criteria all over the life-cycle of the CPC.

Table 18 **the amount of solar fraction and its economic status**

Fuel Type	Yearly Fuel Savings (USD)	NPV (USD)	Payback Period (years)	IRR
LPG	66282	290,226	2	68%
Fuel oil	39589	134,144	4	40%
Natural gas	36890	118,360	4	38%

Model no. 2 Comparison

In the first model that is used in this work has a collector area of 600 m^2

Figure 27 The Monthly Btu required from conventional Fuel for the bitumen heating between Fuel and Solar Heating Systems. Figure 28 shows the Hourly outlet HTF temperature for January

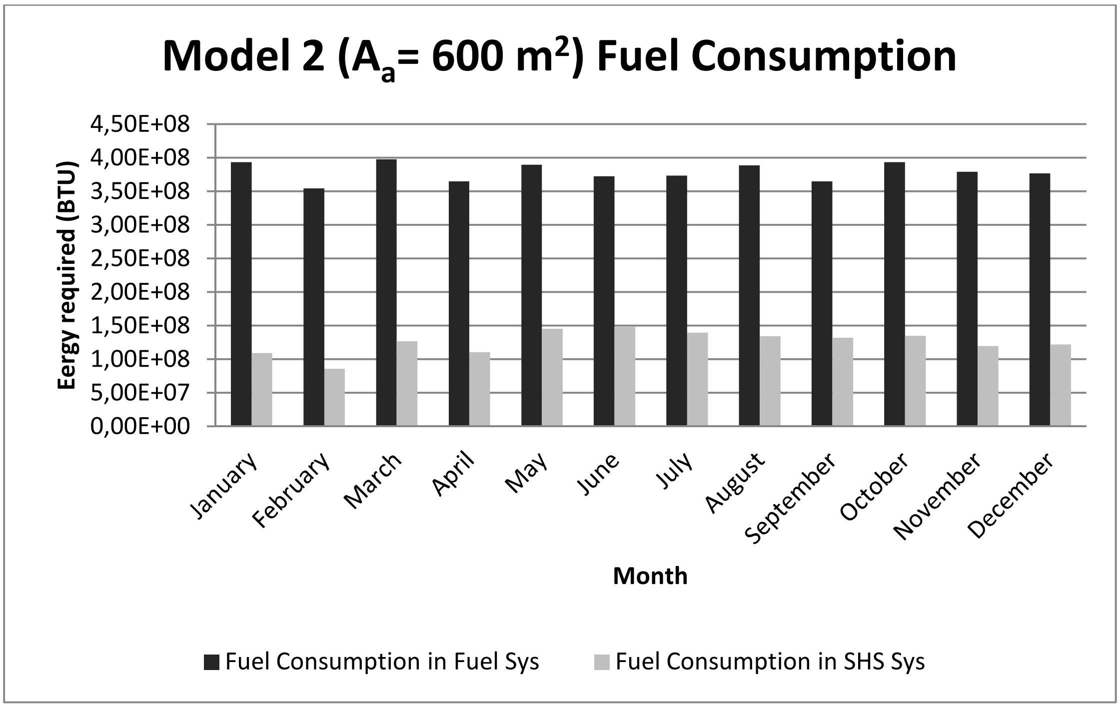

Figure 27 **Comparison monthly BTU required**

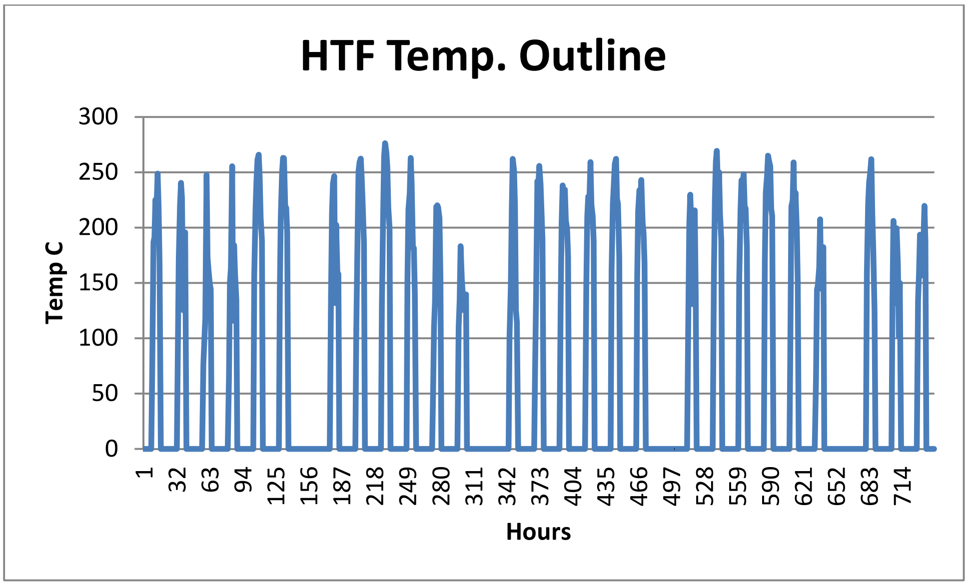

Figure 28 **Hourly outlet HTF temperature for January for Model 2(A_a= 600 m^2)**

After calculating the net BTU required by both systems the yearly Solar Fraction found is about 66.8%.

Table 19 shows the properties of each type of fuel that is used in the comparison and the economic criteria all over the life-cycle of the CPC

Table 19 **the amount of solar fraction and its economic status**

Fuel Type	Yearly Fuel Savings (USD)	NPV (USD)	Payback Period (years)	IRR
LPG	76233	328,943	2	65%
Fuel oil	45333	149,428	4	49%
Natural gas	42428	131,275	4	36%

b. Model no. 3 Comparison

In the first model that is used in this work has a collector area of 700 m^2

Figure 29 The Monthly Btu required from conventional Fuel for the bitumen heating between Fuel and Solar Heating Systems. Figure 30 shows the Hourly outlet HTF temperature for January

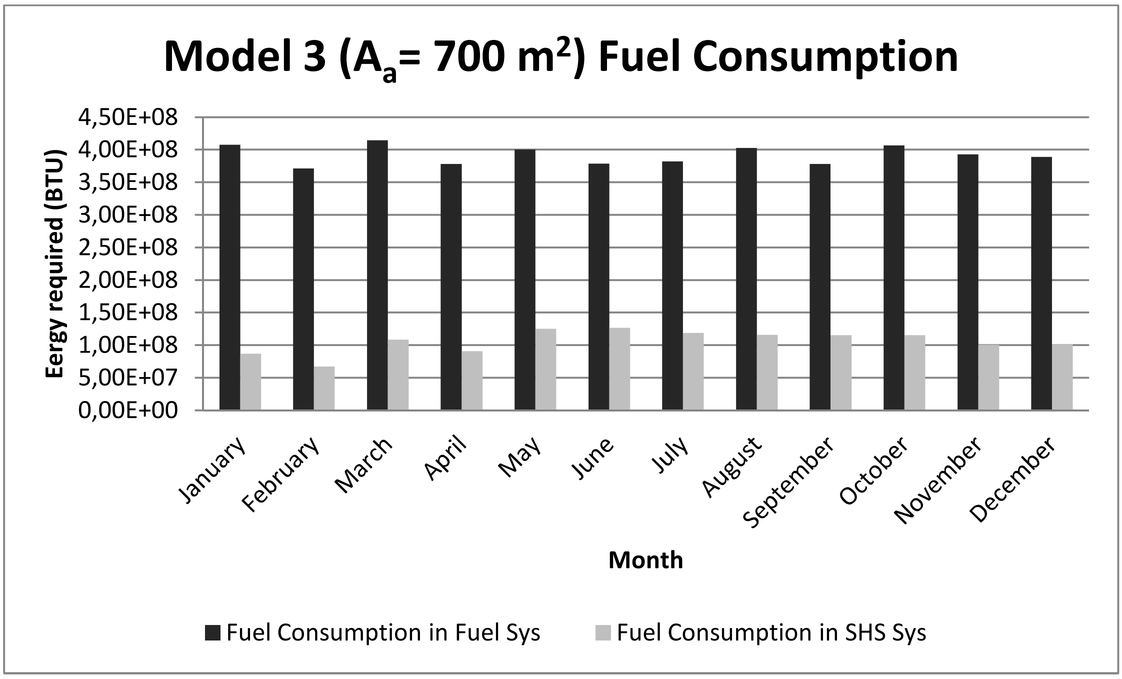

Figure 29 **Comparison monthly BTU required**

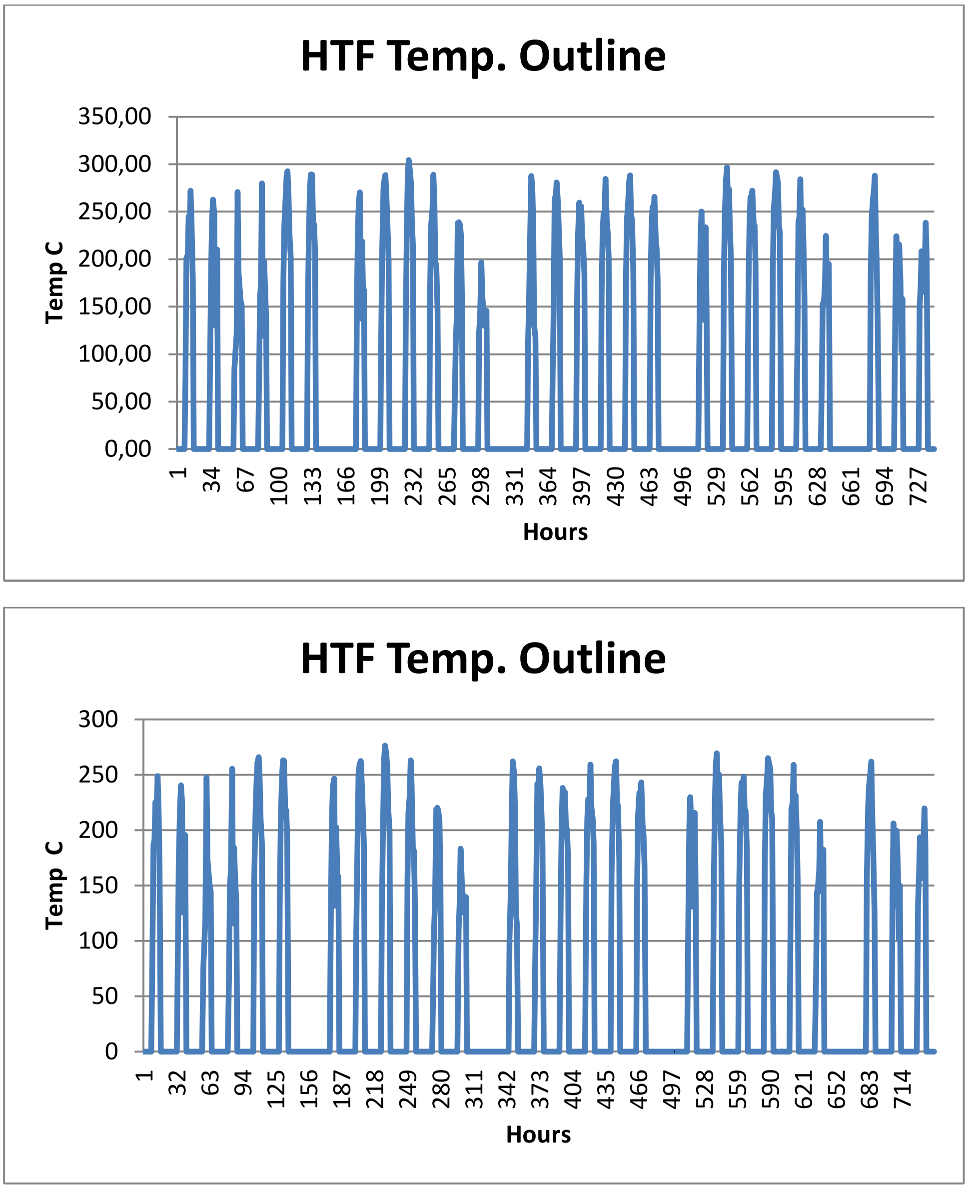

Figure 30 **Hourly outlet HTF temperature for January**

After calculating the net BTU required by both systems the yearly Solar Fraction found is about 72.9%.

Table 20 shows the properties of each type of fuel that is used in the comparison and the economic criteria all over the life-cycle of the CPC

Table 20 **the amount of solar fraction and its economic status**

Fuel Type	Yearly Fuel Savings (USD)	NPV (USD)	Payback Period (years)	IRR
LPG	85952	366,302	2	63%
Fuel oil	51338	163,901	4	37%
Natural gas	47837	143,433	4	35%

2. Environmental Study

The three models are explained environmentally by calculating the amount of avoided emissions in the units of CO_2 tons per year (t CO_2/year). These units used because it should be interpreted to carbon credits which can give more profit in the economic analysis if it is used.

a. Model 1

Table 21 Emissions avoided for 500 m^2 model

Table 21 **Emissions avoided for model 1**

Fuel Type	Saved fuel tons (t/year)	Avoided emissions (t CO_2/year)
LPG	98.6	287.8
Fuel Oil	64.2	198.7
Natural gas	59.2	155

b. Model 2

Table 22 Emissions avoided for 600 m^2 model

Table 22 **Emissions avoided for model 2**

Fuel Type	**Saved fuel tons (t/year)**	**Avoided emissions (t CO_2/year)**
LPG	113.4	331
Fuel Oil	73.8	228.5
Natural gas	68.1	178.3

c. Model 3

Table 23 Emissions avoided for 700 m^2 model

Table 23 **Emissions avoided for model 3**

Fuel Type	**Saved fuel tons (t/year)**	**Avoided emissions (t CO_2/year)**
LPG	127.8	373.2
Fuel Oil	83.3	257.6
Natural gas	67.7	201

IV. CONCLUSION

The World faced many energy crises in the last century and in the beginning of this century too. This leads to more research about renewable sources of energy. In 2002, the amount of solar energy that reaches the Earth’s surface every hour is greater than humankind’s total demand for energy in one year [53]. The major barrier for increasing solar energy usage is its high investment cost and the low cost of conventional fuels. However, in the case studied it has been proven to be economically favorable because of the high energy consumption for asphalt industry.

The CPC proved to be economically and thermally efficient for such application, despite of its high investment cost and the large area of land that should be occupied by the collector.

The results, though, made it possible to address environmentally sound public policies to encourage solar energy use in the Asphalt Industry. Moreover, it will help in reducing the high emission of the GHG in this industry.

In order to minimize the risk of the investment cost or the in cash flow the carbon credits are not taken into account, besides the change in fuel prices throughout the project life cycle is not considered. Moreover, the project life cycle is 15 years instead of 20 years which is generally considered for such studies.

The results are found encouraging more studies about extending solar energy use on other processes from asphalt industry. These processes can include the storage of the bitumen in its fluid state and dry the aggregates to remove humidity which is the most energy consumption process in this industry.

It is recommended to offer more solar energy courses and to have experimental facilities to assure this purpose. This will give more understanding for how capable is the renewable energy sources to substitute the conventional fuels.

The study case serves as an indicative that energy policies are needed for increasing the solar energy penetration of high temperature industry. The urge to increase sustainability and reduce the environmental footprint on all human activities, promote the continuous pursuit of solutions for the constraints involving industrial solar heating systems.

REFERENCES

[1] S.P.Sukhatme and J.K. Nayak. “Solar energy principle of thermal collection and storage”, 3rd Edition, India: Tata Mcgraw hill, 2008, Page No.233, 234.

[2] S. A. Kalogirous, “Solar Energy Engineering Process and Systems”, 2nd Edition, Oxford: Elsevier, 2014, pp 126.

[3] I. Luminosu, L.Fara. “Experimental research on bitumen preheating (fluidization) by using solar energy in passive mode.” International Journal of Thermal Sciences 48 (2009) 209–217

[4] F. Dantas and M. Fonseca-Costa. “Thermal and Economical Analysis of the Solar Preheating of Steam Boiler Feed Water”. 2014 Journal of Energy and Power Engineering 8 (2014) 775-784.

[5] REN21 (2014). "Renewables 2014: Global Status Report", Paris, France, 2014

[6] F. Cardoso, “Brazil: Residential Demand Drives Market,” Solar Thermal World, 24 July 2013
http://solarthermalworld.org/content/brazil-residential-demand-drivesmarket

[7] A. D. Rosell, “Brazil: Rising Electricity Prices Put Spotlight on Solar Thermal,” Solar Thermal World, March 2014 http://solarthermalworld.org/content/brazil-rising-electricityprices-put-spotlight-solar-thermal.

[8] Brazilian Government / Ministry of Science and Technology, 2011, Second Official Brazilian Communication to COP - IPCC (executive summary). CGMGC, 2010. Brasília. http://www.mct.gov.br/upd_blob/0215/215070.pdf (Accessed on April, 4th. 2015.)

[9] Brazilian Government / Ministry for the Development of Industry and Commerce (MDIC), 2012. Sectorial plan of mitigation of climate change for a low carbon emission economy in the transformation industry). Brasília/DF.

[10] EPE [Empresa de Pesquisa Energética], 2014. National energy balance – base year 2013 – final report. CDU 620.9:553.04(81). Brasília/DF, 2014

[11] J. Read, and D. Whiteoak. “The Shell Bitumen Handbook”, 5th ed. London: Thomas Telford, 2003. pp. 268-74

[12] J.B.Henderson,J.A. Wiebelt andJ.D. Parker. “Use of Solar Energy For Heating Asphalt In Storage Tanks.” Applied Science Publishers Ltd, England. (1980) 221 228

[13] K.D.Hankins. “Solar Heating An Asphalt Storage Tank” 229-1, June 1978

[14] A. S. Gudekar, A. S. Jadhav, S. V. Panse, J. B. Joshi, A. B. Pandit “Cost effective design of compound parabolic collector for steam generation.” Solar Energy 90 (2013) 43–50

[15] S. Panse. “Compound parabolic solar collectors for solar process heat” Wels, Austria: International Conference Solar Process Heat,2011 http://www.wsed.at

[16] S.A Kalogirou. “Solar thermal collectors and applications”. Prog. Energy Combust. Sci. 2004, 30, 231–295

[17] O. Ellabban, H. Abu-Rub, F. Blaabjerg, “Renewable energy resources: Current status, future prospects and their enabling technology”. Renewable and Sustainable Energy Reviews 39, (2014), 748–764

[18] The Texas Renewable Energy Industries Alliance, Texas, USA. ⟨http://www.treia.org⟩ [accessed on 30/4/2013].
[19] European Renewable Energy Council (EREC). “Rethinking 2050: A 100% Renewable Energy Vision for the European Union”. Brussels, Belgium; 2010.
[20] K. Srirangan, L. Akawi, M. Moo-Young, CP. Chou, “Towards sustainable production of clean energy carriers from biomass resources”. Appl Energy, 2012; 100: 172–86
[21] D.O. Hall, JI. Scrase “Will biomass be the environmentally friendly fuel of the future?” Biomass Bioenergy 1998; 15(4/5):357-67
[22] K. Kaygusuz, “Wind power for a clean and sustainable energy future”. Energy Sources Part B 2009; 4(1):122–32.
[23] Greenpeace International/EREC: “energy revolution – a sustainable global energy outlook”. 2008. Page 122.
[24] K. Brankera, M. J. M. Pathaka, J. M. Pearcea, “A review of solar photovoltaic levelized cost of electricity”. Renewable Sustainable Energy, Rev 2011; 15: 4470–82.
[25] H. Schweiger , J. F Mendes, N.Benz, K.. Hennecke, G. Prieto, M. Cusí, H. Gonçalves. “The potential of solar heat in industrial processes: a state of the art review for Spain and Portugal. In: EUROSUN 2000. Copenhagen, Dinamarca, 2000.
[26] Millinium Energy Industry, Reference Projects, 2014
[27] Ivanpah, Solar electric generation system. http://www.ivanpahsolar.com/
[28] UNIDO, “Renewable Energy in Industrial Applications-An assessment of the 2050 potential”, Vienna, Austria, 2011.
[29] G. M. Kaplan. “Understanding Solar Concentrators”, Volunteers in Technical Assistance, Inc. Virqinia, USA.1985.
[30] G D Rai “Non-conventional Energy Sources”. Khanna publisher, New Delhi, India, 2000.
[31] K. Sukhatme, and Suhas P. Sukhatme. “Solar Energy: Principles of Thermal Collection and Storage”. 2nd edition, India: Tata Mcgraw hill,1996,pp.237
[32] Heatec, “ Technical Paper T-140- Heating and Storing Asphalt at HMA Plants”. Tennessee, USA., 2015.
[33] http://www.bridgat.com/
[34] www.asphaltequipment.com
[35] R. C. West, D.E. Watson, P.A. Turner, J. R. Casola “Mixing and Compaction Temperatures of Asphalt Binders in Hot-Mix Asphalt”.Washington:National Academy of Sciences, 2010
[36] HOT-MIX MAGAZINE, “Heating and Storing Asphalt at HMA Plants” Volume 4, Number 3, p 28-29
[37] Performance Heating,LLC, atalanta, usa , http://www.performance-heating.com/products/thermal-fluid-heaters-helical-coil
[38] S. V. V. Raman, S. Iniyan, R. Goic, “A review of climate change, mitigation and adaptation.” Renewable and Sustainable Energy Reviews, 2012;16:878–97.
[39] IEA, International Energy Agency. World energy outlook 2009. OECD/IEA, Paris, 2009.

[40] S. KLEIN, et al. “A method of simulation of solar processes and its application”. Solar Energy, v. 17, n. 1, p. 29 – 37, 1975.

[41] P.A. Lisboa, “Programa de simulação de sistemas de aquecimento solar”. Dissertation for mechanical engineering master program, State University of rio de Janeiro, Brazil 2012.

[42] A. Bejan, G. Tsatsaronis, and M. Moran, “Thermal Design and Optimization”, New York, John Wiley & Sons, 1996, pp 275

[43] J.A. Duffie, W.A. Beckman,” Solar Engineering of Thermal Processes”, Wiley Interscience Publication, New York, 1991, pp. 94-95.

[44] http://www.eng-tips.com/, [accessed on 15/3/2015]

[45] TRNSYS Manual, Volume 1, 2002.

[46] Brazilian EPW Files [Online], LabEEE, 2013, http://www.labeee.ufsc.br/.

[47] Banco Central Do Brasil http://www.bcb.gov.br/

[48] “The Shell Bitumen Industrial Handbook”. London: Thomas Telford, 1995. Ch. 3

[49] A. S. Gudekar, A. S. Jadhav, S. V. Panse, J. B. Joshi, and A. B. Pandit, "Cost effective design of compound parabolic collector for steam generation," Solar Energy. 90, 43-50 , 2013.

[50] Ministério de Minas e Energia, “Relatório do Mercado de Derivados de Petróleo”, Número 111, março de 2015.

[51] B. Boundy,S. W. Diegel, L. Wright, S. C. Davis. “Biomass Energy Databook.” 4th edition, 2011,Apenddix A

[52] http://www.investopedia.com/

[53] O. Morton, “Solar energy: A new day dawning?: Silicon Valley sunrise”. Nature journal,443, 6 ,2002.