Solar Energy
And Sustainable Development
Refereed, biannual scientific journal issued by
Center for Solar Energy Research and Studies

Investigation of a solar thermal driven Refrigerated warehouse in Tripoli-Libya using TRNSYS

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Abstract: This paper, illustrates a design and simulation of a solar powered absorption refrigeration system preserves food above freezing point. The main system is modified from a commercial conventional system located at Tajoura, Libya. The target is to design and operate the system at high solar fraction and efficiency. The simulation is performed by TRNSYS to evaluate the annual thermal performance of the solar system that consists of 50-kW absorption chiller producing cold for three refrigerated rooms. The model could be classified into two main parts; refrigeration load model and solar powered refrigeration system model. The results demonstrated that the optimum system achieves 51% solar fraction consists of 48 m^2 of high performance evacuated tubes solar collectors and 5000-litre thermal storage tank, in order to power a 50-kW absorption chiller that offers cold for three refrigerated rooms of vegetables.

دراسة منظومة غرف تبريد امتصاصي تعمل بالطاقة الشمسية لمدينة طرابلس - ليبيا باستخدام الترانزس

مختار محمد بن عبيد

مركز بحوث ودراسات الطاقة الشمسية - طرابلس - ليبيا

ملخص: تم في هذه الورقة عرض تصميم ومحاكاة لمنظومة تبريد امتصاصي تعمل بالطاقة الشمسية وتستخدم لحفظ الأغذية عند حرارة أعلى من درجة التجمد. النظام مبني على منظومة واقعية موجودة في شركة تجهيز وحفظ اللحوم بتاجوراء/ طرابلس، حيث هدفت الدراسة إلى تصميم وتشغيل المنظومة عند نسبة مشاركة شمسية وكفاءة عاليتين. المحاكاة تمت بواسطة برنامج (TRNSYS) والتي تم فيها تقييم أداء منظومة شمسية تحتوي على جهاز تبريد امتصاصي مركزي متصل بثلاثة غرف تبريد، في ذات الوقت ينقسم هذا النموذج إلى قسمين رئيسيين: نموذج حمل التبريد، ونموذج منظومة التبريد الشمسية. أظهرت النتائج أن أفضل المنظومات حققت نسبة مشاركة شمسية بلغت 51 % واحتوت على 48 م^2 من المجمعات الشمسية نوع الأنابيب المفرغة ذات الأداء الحراري العالي بالإضافة إلى خزان حراري بسعة 5000 لتر لتغذية منظومة تبريد امتصاصي تعمل على تبريد ثلاث غرف لحفظ الخضروات.

Keywords: *Solar Energy, Solar Refrigeration, Solar Cooling, TRNSYS, Simulation*

1. INTRODUCTION

In History, many nations used the refrigeration as a food preservation method. For example, Greek and Roman placed large amounts of snow into storage pits dug into the ground and insulated with wood and straw. The ancient Egyptians filled earthen jars with boiled water and put them on their roofs, thus exposing the jars to the night's cool air. [1]. Libya, within its wide area and unique location, that offers a solar radiation could reach 8.1 kW/m^2/day, has a high solar energy potential [2]. Moreover, the flat topography and relatively low wind speed could be perfect for solar thermal applications. However, Libya is a petrol producer country where the fossil fuel and electric power are under subsidy, so the solar energy cannot be a competitor for the conventional systems without a governmental support. Recently, the case began to change, by 2011, The Arabian Spring and Terrorism crises have established many conflicts in MENA region especially in Libya where the power grid was damaged seriously leading to a series of shutdowns at peak cooling and heating seasons. Furthermore, due to the conflicts many people have emigrated from fighting areas to other safer sites where they need continues supply of food and other goods. So, some challenges of retarding supplied food from spoilage are appeared with the correspondent power network problems and fuel supply cuts. Refrigerated storages that work under absorption cycle could be a perfect solution, if operated by solar thermal energy in such country. However, from the ecological side, most of the Libyan electricity 37% is produced by natural gas, which is a relatively clean source of energy, and 11% of the electricity is produced by recovering heat in the combined cycle. [3] Otherwise, in peace situation, food and crops prices decrease at reaping seasons and increase at the rest of the year. So, preservation process of such goods could be profitable. Similarly, many food and crops are cheaper in some countries than in other locations, due to the low property, labour or other costs, which makes an opportunity for a profitable business of preservation by refrigeration.

Referring to [4], the demand of Residential Buildings represents one third of the total power being consumed in the Libyan market, where 35.35% of this partition is utilized for air conditioning and refrigeration. However, the industrial and agricultural sectors are employing heat pumps for preserving food, drugs or other processes and they represent 21.22% of the total power being sold. Consequently, heat pump application could require one fifth of the total power utilized in Libya. Furthermore, According to [3], the peak demand load occurs in the summer when the utilization of air conditioning devices begins. This peak could be mitigated by the use of non-electrical devices such as absorption systems. Whereas this paper deals with commercial refrigeration, it focussed on the absorption chillers that is used in the air conditioning systems. However, using the fossil fuel to operate cooling devices could be hazard and less reliability, once a resource short occurred. Instead of that, solar thermal energy is suggested by the author as perfect solution for such problems.

Nevertheless, solar thermal driven cycles utilization was recently investigated by many researches, they are in an early stage of development up to now[5]. otherwise, commercial food preservation refrigeration did not get as interest as those for air conditioning interest, due to the low power consumption relative to the buildings of cities and the low temperature that required by refrigeration which require wide solar collecting areas to drive them.

Recently, solar powered cooling systems aim to be interesting for the researchers.[6] has reviewed the methods of coupling the absorption cycle internally by adding more stages and externally with some other refrigeration cycles in order to increase the overall COP and demonstrate future development choices. [7] Illustrates that the most thermal driven chillers have an evaporating temperature higher than zero which is not practical for some refrigeration application.

Small size absorption systems were investigated by many researchers for air conditioning purposes; [5] have modelled and designed a 17.6 kW solar powered cooling chiller. TRNSYS software was used to model the system and validated by a real installed system. The parametric study resulted the selection of high efficiency flat plate collectors of 38 m^2 and 1000 L of thermal storage, where the absorption chiller is made specially for the case. It is found that 29% of the solar radiation reached the solar storage and an average chiller COP of 0.69 is recorded. [8] also has studied a 10-kW novel absorption system combined with multistage heat storages and found that 91 m^2 of flat plate solar collectors are required to operate the system.

Despite the most of studies that deals with single stage cycle, [9] have investigated employing double stage cycle with concentration parabolic troughs that could produce higher temperatures with less required area and producing higher COP. [6] have conducted a study for a novel double stage absorption refrigeration system that could reach a refrigeration temperature of (- 60 ^oC) using a mixture of R23 and R134a as a refrigerant and N-Dimethylformamide (DMF) as an absorbent. The operating temperature was 184 ^oC within a condensing temperature of 18 ^oC which is relatively low. It was found that the corresponding COP for this chiller in such operating conditions is 0.023. However, all the studies contained solar field sizing have not mentioned the number of collector rows, where the more collectors in the row, the more temperature. Otherwise the more collector rows number, the more flowrate available. Problems of vaporisation inside tubes could occur when increasing collectors' numbers in the one row, while decreasing their number leads to resultant temperatures lower than the required.

In the national side, solid sorption cycle was studied by [10] under Benghazi, Libya City. Nevertheless, this study focussed on the sizing of the zeolite optimum thickness in the adsorption core, it reflected an earlier interest in the solar cooling in Libya. Another study [11] has investigated the technical feasibility of the solar cooling systems for several locations in Libya by studying their metrological data. Therefore, it is concluded that the solar cooling in Libya is feasible and could fulfil about 25% of the total installed capacity of the air conditioning devices in the country. The double-stage LiBr-Water absorption system that powered by solar energy is studied by [12]. Where a mathematical model and a computer simulation code is produced. However, a modification of the system is studied in order to recover the absorption heat. Where it is found that COP of 1.66 is reached with a generating temperature of 95C. Moreover, the author has recommended the addition of refrigerant and solution tanks in order to accumulate the condensed refrigerant during the high insulation time and leave it to be expanded at load time.

Figure (1) **Case Study Location**

In the same region, North Africa, Tunisian researchers and businessmen have given an attention for solar cooling projects at recent. A SIMULINK model was built and validated by an experimental work for a complete adsorption cooling system for two chambers by [13]. The study investigated the performance and operation of the cooling system that works continually which is not proper for the solid sorption systems, the COP and cooling power is found to be 0.62 and 5.6kW respectively. More information could be found in the reviews[14–16]the absorption systems are preferred to the adsorption systems, the higher temperature issues can be easily handled with solar adsorption systems. The ejector system represents the thermo-mechanical cooling, and has a higher thermal COP but require a higher heat source temperature than other systems. The study also refers to solar hybrid cooling systems with heterogeneous composite pairs, to a comparison of various solar cooling systems, and to some use suggestions of these systems.

In this paper, different absorption refrigeration cycles are reviewed. The couplings for absorption cycle construction are summarized. Based on the coupling characteristics, the absorption cycles are classified into the following categories: single effect cycle, external-circuit coupling cycles, internal-circuit coupling cycles and the cycle combined with ejector/compressor. Cycles constructed through external-circuit coupling refer to the multiple stage cycles. In these cycles, the external-circuit heat and mass couplings are employed to improve the cycle performance or temperature lift. Cycles constructed through internal-circuit coupling refer to the GAX cycles. In these cycles, the internal-circuit heat couplings are employed to enhance the cycle flexibility and internal heat recovery. The internal-circuit mass couplings are employed to enlarge the GAX temperature overlap. In the combined cycles, ejector or compressor are integrated to improve the cooling output or decrease the driven temperature. The configurations and theoretical COP of these cycles are introduced with diagrams. Related literatures are reviewed.

Above all, this work aims to examine the availability of food preservation by solar cooling systems under Libya climate in order to overcome the challenges that the national power grid face and trial to find out a more sustainable solution for the local business. Furthermore, reducing the carbon dioxide and the other harmful gases emissions.

2. METHODOLOGY

In this paper, the target is the investigation and realization of the availability of solar cooling equipment utilization for food, medicine and vegetables preservation. Therefore, a case study is implemented to design a solar thermal operated refrigeration plant for a real conventional refrigeration unit of food preservation located in Tajoura, Tripoli as depicted in Figure 1.

The followed methodology is sizing an absorption chiller instead of the conventional vapor compression chiller utilized in the site. The absorption chiller is powered by a solar thermal system consists of solar collectors and water thermal storage tank. Starting from simulating the refrigeration load along the day following that by the sizing the proper chiller and sizing thermal storage required to offer the heat for the absorption system, finally, selecting and sizing the solar collection field needed to operate the system. The period of simulation is in the summer where the higher cooling load and higher potential of solar energy as well.

3. WAREHOUSE DESCRIPTION

The study is implemented for a part of a commercial refrigeration and freezing warehouse at Tajoura, Tripoli, which belongs to the company of (Meat Production and preservation). It is being used to preserve medicine, vegetables, dairy, meat and fish. Meat and fish are frozen and preserved in very low temperature refrigerators (-20 °C), which is not the case of this study, where the other products are preserved at a relatively higher temperature of (4 to 8 °C) which this paper deals with.

4. DESCRIPTION OF THE SYSTEM

The simulated system could be divided into three parts: *the refrigerated warehouse* model; where the cooled space, loads and products are predicted instantaneously. *The absorption refrigeration cycle* is a heat driven cycle which is powered by low grade thermal energy such as: solar energy, heat recovery. Absorption process is the action when a gas phase substance is diffused into a liquid (like water). This process is exothermic process where the vessel contains the materials should be cooled.

The most popular absorption systems are the aqua ammonia systems, which is applicable to operate under water freezing point, and lithium bromide systems, where water is the refrigerant, so it is cheap and safe to be used for AC systems. The main characteristics of the both systems could be the same; generator, condenser, evaporator, absorber, throttling device and a pump.

Figure 2 illustrates the solar powered absorption system, where the heat is added to the refrigeration cycle by the solar field (collectors, circulating pump and storage tank) through the generator. In the generator, the desorption process is taking place where the refrigerant vapour is driven out to be liquefied at the condenser then throttled through the throttling valve which breaks the pressure to the evaporating pressure. In the evaporator, the liquid absorbs heat from the surroundings producing the effect of refrigeration and vaporizes. The vapour refrigerant is derived back from the evaporator by the effect of absorption, flowing through a heat exchanger in order to recover the heat and reduce absorbing temperature. The absorption process increases as the mixing temperature decreases. Consequently, the entropy decreases when the heat rejected to the environment. The weak solution, in absorbent, is pumped to the generator recovering the heat from the strong solution that flows to the absorber [1]. The strong solution then is throttled to the absorbing process pressure. The absorber and the condenser reject heat to the environment by a cooling tower system, where the generator and the evaporator imports heat to the system. The imported heat should be equal to the rejected heat.

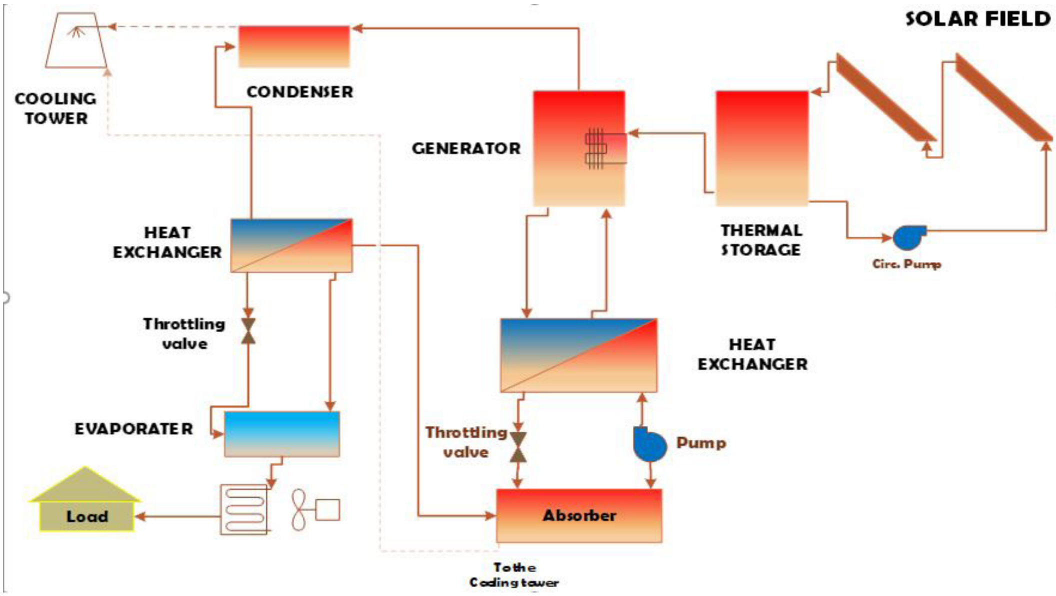

Figure (2). schematic diagram of a simple solar powered absorption cycle

5. MODELING AND SIMULATION

The appropriate design of such system could be a complex process due to the presence of many factors and data such as climatic data for the location, the equipment performance and costs. So, simulation software should be powerful tools for modelling, simulation, optimization and then evaluation the system. For this work, TRNSYS 17 is used to model and simulate the system. TRNSYS is created by solar energy laboratory at University of Wisconsin-Madison, mainly for renewable energy research. It offers a transient simulation and a combination of the weather and technical data of the renewable energy devices and a graphical user interface (GUI) that facilitate the work on the software without a long code writing. TRNSYS contains a library of different formatted meteorological data within the ability to accept the user's recorded file. All components of the solar cooling system are available in the main library provided by TRNSYS.

The selection of the most benefitable solar field could be occurred by the comparison between the solar fraction of the system and the efficiency of the solar field as constraints. According to equation (1), Solar fraction represents the share of the thermal energy gained from the solar field to the total demand, where it increases as the collection area increases. Nevertheless, the efficiency of the solar field decreases as the area of collectors increase. However, the increase of thermal storage size could promote the useful energy extracted from the solar field.

$$S.F = \frac{\dot{Q}_s}{\dot{Q}_s + \dot{Q}_{AUX}} \quad \text{..........} \quad (1)$$

$$\eta = \frac{\dot{Q}_s}{G \times A_C} \quad \text{..........} \quad (2)$$

Where:

S.F: the solar fraction

$\dot{Q}_s$: the thermal useful Power from the solar field, W

$\dot{Q}_{AUX}$: thermal power from the auxiliary system, W

G: the solar radiation, W/m^2

A_C: Collectors Area, m^2

η: Collector's thermal performance, %

According to the above, the selected functions for optimization are the values of the solar fraction and efficiency.

As mentioned above, a TRNSYS model is employed to model and simulate the system. First, the refrigerated space was modelled in order to evaluate the transient refrigeration load so, it is able to study the response of the system under different conditions. The case study characteristics are demonstrated in Table 1.

Table (1) system characteristics

System part	Device	Characteristics
Refrigerated Envelope	No. of partitions (cooled rooms)	6 rooms (1 chiller for each three)
	Temperature set point	5
	Assumed preserved goods	Potatoes
	Solar collectors	48 m^2 of AMK_DRC10 Evacuated tubes
Solar field	Thermal storage	5000 Lt within a helical HX inside.
	Heat transfer fluid(HTF)	Pressurised pure water
Absorption chiller	2 X Aqua-ammonia chillers	2 X 50 kW
	Cooling tower	Wet cooling tower

5.1. Refrigeration Loads

Refrigeration loads could be classified into four components:

- The transmission load, which represents the heat transferred into the refrigerated space through its boundaries. Heat gain from any space boundary could be calculated by the basic equation [16]:

$$Q = UA\Delta t \quad \text{..........} \quad (3)$$

Where:

Q: heat gain, W

Δt: Temperature difference between the inside and outside air temperature, K

The overall coefficient of heat transfer U of the wall or ceiling can be derived by the equation 4:

$$U = \frac{1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3}} \quad \text{...} \quad (4)$$

Where:

U: The overall coefficient of heat transfer, $W/m^2.K$.

x: Layer thickness, m.

k: Thermal Conductivity (W/m.K).

Table (2). physical and thermal properties of the warehouse envelope

Room Boundary U-value Calculations (Polystyrene)			
Part	Thickness of layerv#1	Thermal Conductivity of layer #1	U-value
Walls & Roof	0.15	0.037	0.247

The increase in the thermal resistance values of the thermal shield leads to drop of the convective heat transfer coefficient, which is neglected in eq.(4) as ASHREA recommends [16]. Type 88 in TRNSYS could model the refrigerated space, which programmed as a simple lumped capacitance single zone structure subject to internal loads. Heat gain by solar radiation is neglected due to the envelop structure that covers the refrigerated space. The physical and thermal properties of the warehouse envelope is given in Table 2.

- The product load, which represents the heat removed from and produced by products brought into the refrigerated space by reducing the temperature of the products and removing the respiration load of the vegetables and fruits. Furthermore, product refrigeration load appears at the beginning of the refrigeration process after placing the product in the warehouse. As the product reaches the storing temperature, this part of the load is going to be eliminated. In TRNSYS, product load could be modeled by type 59 which represents the dynamic thermal behavior of a body using the lumped capacitance model.

- In this paper, it is assumed that potatoes are stored in the warehouse,

- The infiltration air load, which represents heat gains associated with air entering the refrigerated space. The air exchange load is estimated by Gosney and Olama equation which is recommended by [16].

$$Q_{inf} = 0.221A(h_i - h_r)\rho_r\left(1 - \frac{\rho_i}{\rho_r}\right)^{0.5}(gH)^{0.5}\left[\frac{2}{1+\left(\frac{\rho_i}{\rho_r}\right)^{1/3}}\right]^{1.5} \quad .. (5)$$

Where:

$\dot{Q}_{inf}$: average infiltration load, kW

A: Doorway area, m^2

h_i: enthalpy of infiltration air, kJ/kg

h_r: enthalpy of refrigerated air, kJ/kg

ρ_r: density of refrigerated air, kg/m^3

ρ_i: density of infiltration air, kg/m^3

g: gravitational acceleration =9.81 m/s^2

H: Doorway height, m

For modeling infiltration in TRNSYS, many components were utilized; Type 14 used for door opening frequent, Type 33 is used for outlet and inlet air properties and the equation used to apply equation (5) and collaborate the other Types.

- The internal load, which deals with the heat produced by internal sources, e.g. lights, electric motors and people working in the space.

In order to model the Internal Load in TRNSYS, three components of calculator (Type 14) were used. Moreover, an equation was used to evaluate the heat equivalent of the labour.

5.2. Absorption system

TRNSYS employs Type 107 component to model and simulate the absorption chiller. As mentioned above, the market trends to the air conditioning application of solar absorption systems, which require temperatures above ice melting point, from 7 to 15 and above. Furthermore, the available detailed information about the low temperature absorption chiller is not enough to construct a data file for it and the available one is normalized data which should be suitable for many chillers.

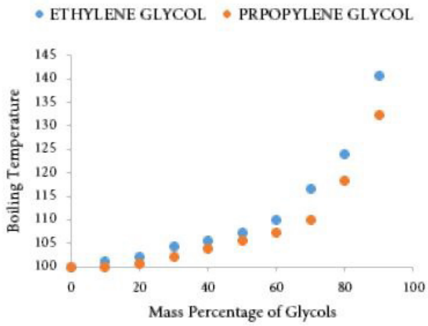

Figure (3) Illustrates the boiling temperature of water/glycols mixture at different glycol mass fraction [17]

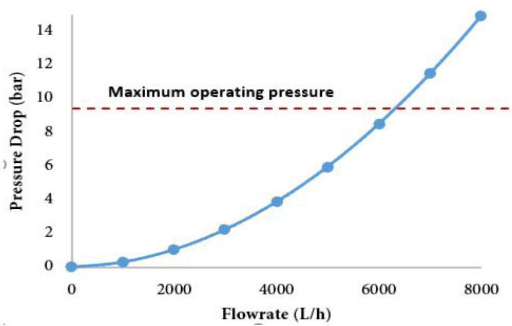

Figure (4). Pressure drop through one solar collector for each flow rate value [18]

5.3. Solar field

The solar field consists of three components; solar collectors, thermal energy storage and, the hydraulic system (circulating pump and piping). Water is used as a heat transfer fluid (HTF) and for thermal storage. Adding glycols to the water with percentage less than 70% would not increase the boiling temperature more than 116, referring to Figure 3. In addition, the collector outlet could exceed such low boiling limits permanently which could be risky due to the close flash point values. Furthermore, water glycol mixtures could be corrosive and flammable. Although increasing the solar system pressure could increase the boiling temperature, that could limit the allowable number of the collectors in series as the allowable pressure difference is reduced. Overall, the second choice, increasing the system fluid pressure, is selected due to the low expected cost and technical feasibility.

Referring to Figure 4, flat plate solar collectors operates with high performance during the lower operation temperature, but its performance decreases dramatically when fluid temperature increase. While the evacuated tube solar collectors are demonstrated to possess higher performance at higher operation temperatures. Thus, evacuated solar collectors are more suitable for solar powered cooling that requires high temperature feeding.

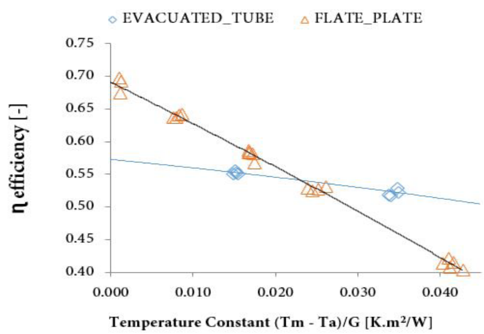

Figure (5) Performance curve of flat plate and evacuated tube solar collectors [CSERS **laboratory Test data**]

The selected solar collector is DRC10 from AMK-Collectra company for evacuated solar collector modelling, which is available in CSERS and performance test was applied by CSERS Laboratory as shown in Figure 4.

Large scale solar field hydraulic design might be a complex problem due to the high pressure drop correspondent to the relatively large flow rate, as Figure 5 illustrates. Therefore, the number of collectors in series is limited to the maximum operating pressure for the one collector which is normally not more than 10 bars. Whereas, concentrating trough collectors (CTC) could tackle high pressures, temperatures and flowrates. they need a tracking system and driven by beam radiation only therefore, their capital and running costs could be too high for small and medium projects.

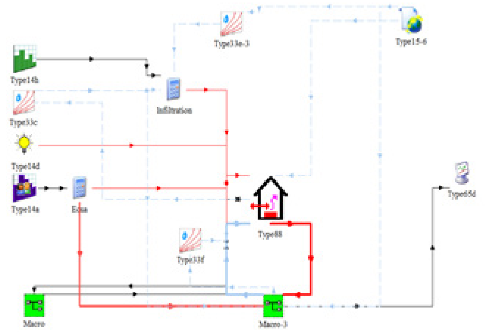

Figure (6). TRNSYS model of the refrigeration system

5.4. Weather data and psychrometric calculations

The meteorological data is extracted from Meteonorm for Tripoli Airport in Libya. Such data are available from TRNSYS library by Type 15-6. Weather file contains hourly data, and interpolated data for the intervals less than one hour, for dry and wet bulb temperature, humidity, wind speed, solar radiation (Beam, Diffuse and reflected) and solar angels. Wherever the psychometrical data about the internal conditions are requested, type 33 is used for psychrometric chart calculations, where a special subroutine is called to evaluate any of moist air properties by two known input properties.

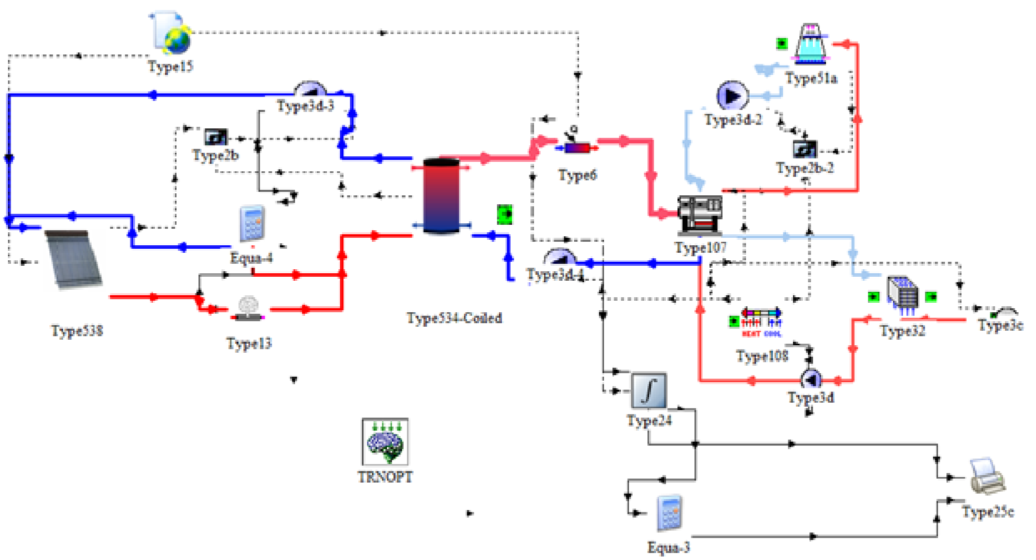

Figure (7). TRNSYS model of the solar field

6. RESULTS AND DISCUSSION

6.1. Refrigeration Loads

Refrigeration loads are modeled and evaluated by TRNSYS as shown in Figure 9, where the maximum load is approximately 35 kW, while the size of the appropriate chiller could be 50 kW for safety and reliability. Those results are for three refrigerating rooms which are the half of cooled rooms number. Actually, there could be a problem in solar powered

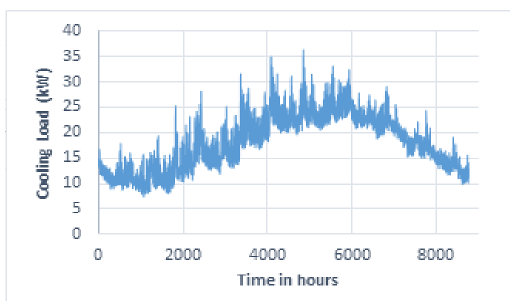

Figure (8). The Annual Refrigeration Load

6.2. Parametric study

6.2.1. Effect of (TES) size and collection area

It is obvious, according to Figure 11 which demonstrates the parametric study results, that the higher thermal energy storage size, the higher solar fraction for the same collection area. Otherwise, the largest amount of refrigeration load occurs during the day, so the storage size should be smaller than the continues solar heating systems. Furthermore, the increase in the collection area leads to an increase in the solar share. However, the amount of the solar share promotion decreases as the collection area increases. Where 10 m^2 increase in the collection area, from 40 to 50 m^2, for the case of 1000 litres TES could produces 2% promotion in solar share factor, Figure 10 the same increase of the collection area, from 80 to 90 m^2, cannot increase the solar factor by 1%. On the other hand, it is illustrated by Figure 10 that the increase of the storage size has no significant effect on the cost, in comparison with the increase of the solar collection area.

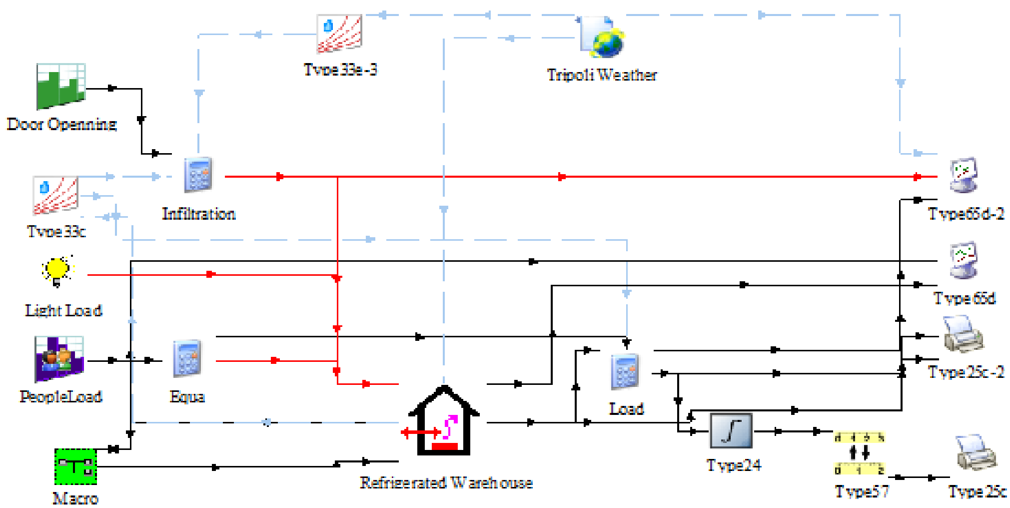

Figure (9). Refrigeration Load Model

6.2.2. Effect of solar collectors' tilt angel

Figure 10 illustrates the effect of solar collector tilt angle on the system solar fraction in summer and winter. Obviously, the system in July is more sensitive for the change in tilt angle than in January. Furthermore, it is demonstrated that the solar fraction decreases gradually in summer time as the tilt angle increases. By contrast, the opposite occurs in winter. Overall, the optimum angle for all the year is approximately 42° as shown in Figure 11, while utilizing 150-tilt angle should not cost the winter solar fraction more than 5% and that could promote the summer solar fraction by the same amount.

Theoretically, the solar path is high in summer, so the tilt angle should be low in order to decrease optical losses and vice versa in winter. So, the results shown above is acceptable.

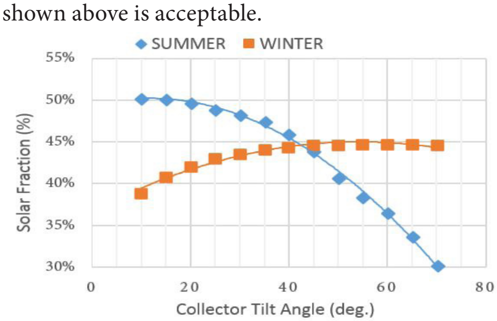

Figure (10) The Effect of Collector Tilt Angle in Summer and Winter

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6.2.3. Effect of Increasing(HTF) Boiling Temperature

The implementation of sensitivity analysis for the HTF boiling temperature by rising the operating pressure has demonstrated a high accordant increase of the system solar fraction as shown in Figure 12.

On the other hand, the maximum allowable flow rate of the system is decreasing due to the increasing hydraulic losses within the increase in the flow rate, which requires higher pumping head that could exceed the maximum allowable operation pressure inside the solar collector. Nevertheless, a pressurised solar field is investigated in this study, while other options are available for studying such as; looking for another fluid, testing nanofluids or converting to concentrating systems which allows higher pressures and flowrates within the use of thermal oils.

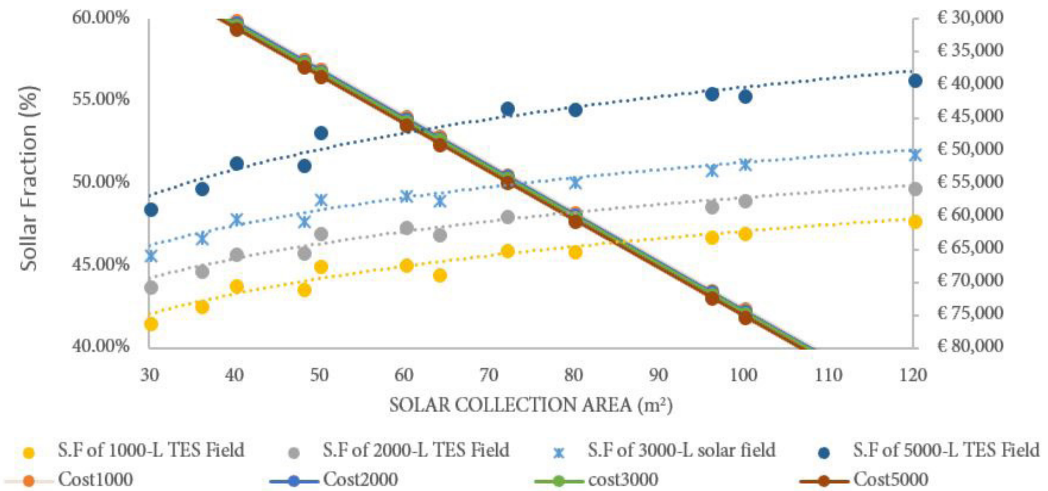

Figure (11). the results of various solar field scenarios

7. CONCLUSIONS

In conclusion, solar thermal powered refrigeration unit is modelled and simulated by TRNSYS. The results demonstrated that the higher HTF temperature, the more efficient system. Thus, to increase the boiling temperature of the HTF, the working pressure is increased, where changing fluid type was not so useful. The boiling temperature used in the model was 1330C which is corresponding to 3 bar operating pressure. A solar field of 6X8 collectors in serious and parallel respectively was selected due to their solar fraction and efficiency within a tilt angle of 150 which found as the optimum in all seasons. However, the thermal storage is 5000-L. the model has shown a result of 51% S.F.

Otherwise, utilizing solar powered refrigeration requires the employment of large scale solar field. However, the target temperature and HTF flow rate are relatively higher, which requires more collectors in series to produce higher temperatures, more parallel branches in order to lower the flowrate for each collector and reduce the required head.

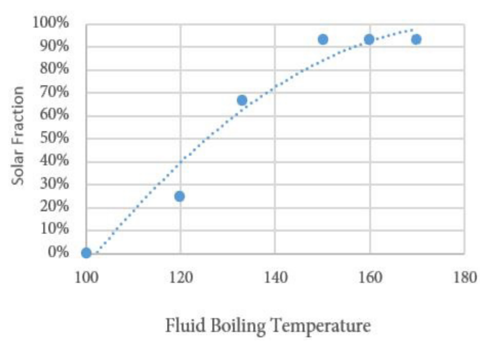

Figure (12). the effect of HTF boiling temperature on the solar fraction of the system

8. FURTHER WORK

It is known that there are many types of solar collectors such as: EVC, CPC and concentrating trough collectors (CTC), which could be employed to drive the solar refrigeration systems. Thus, it is recommended by the author to conduct a multi-criteria decision-making study supported by thermal optimization and feasibility study with one of the economic measures in order to select the most fit solar collector type for refrigeration applications (air conditioning, preservative cooling above 0 °C and preservative cooling below 0 °C).According to this work, it is recommended for subfreezing temperature applications to employ concentrating collectors, whereas the fluid flow and temperature difference higher. Furthermore, the utilization of various HTFs under different pressures could provide some developments for the system.

However, it is crucial to construct another model for the absorption chiller component that relies on a mathematical model and easy to model any chiller. Moreover, the warehouse storage model should be validated or compared with some other models and software.

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