Maximum Cooling Loads for Solar Vapour Compression AC Refrigeration System Operating Under Varying Solar Insolation

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Abstract: **Solar energy is readily available in mid-day and unavailable in the early and late time of the day, and fluctuates with the seasons of the year in many. Due to this fluctuation, there exists a mismatch between solar energy availability and cooling load energy demands in solar technology, which make them inefficient and unreliable. Sufficient harnessing and storage of solar energy for use in solar energy applications, is critical for improvement of efficiency and reliability of solar technologies. This is only possible if the solar driven refrigeration system utilizes the maximum solar energy available at a specific site, and stores some of the energy in form of ice thermal load systems.**

This study has analyzed three different sizes of solar vapour compression refrigeration systems, each fitted with an AC compressor. Four PV panels each of 200Wp were connected to the systems and exposed to different levels of solar isolations for the same period of time. The maximum cooling loads from each system, was established by the temperature drop of the water in the cooling can and the mass of ice formed in a jacket of cooling water for each of the system. An innovative control unit controlled the running of the compressors, depending on the solar insolation required by each compressor. The number of hours each compressor ran per day was recorded and by a datalogger. Results showed that solar refrigeration systems with AC compressors exhibited a maximum cooling load for different refrigeration system AC compressors, which is dependent on the solar insolation of the a specific location.

Keywords- **Solar Insolation; Vapour compression; Cooling load; Ice thermal system ITS; AC**

I. INTRODUCTION

Solar driven vapour compression refrigeration systems fitted with AC compressors operate when solar radiation is sufficient to generate the power required to run the compressors. When there is insufficient solar radiation the compressor stops and when the solar radiation level is sufficient the compressors operate and cooling is affected. Power input to the compressor required to operate solar driven refrigeration system depends on the size of the compressors and the level of solar insolation. The larger the size of the compressor the higher is the power input required to the compressor, and the vice versa. The fluctuation of solar radiation on daily and seasonal basis on different location, makes it difficult to determine the maximum cooling load output from a solar refrigeration system fitted with AC compressor specific solar insolation of a location.

This research work has studied the maximum cooling loads, developed by three solar refrigeration systems, fitted with AC compressors when the systems were operated at different mean daily solar radiation of different location and determined the maximum cooling loads developed by three different sizes of solar refrigeration system with AC compressors

II. LITERATURE REVIEW

There has been challenges in application of solar technologies as compared to other convectional sources of energy in electrical generation. Ndyabara and Lisaarita (2014) [1], revealed the challenges experienced with Solar PV systems in milk cooling associated with fluctuations of solar energy. Solar energy technology in refrigeration systems, have been studied by numerous researches, Pilatowshy *et al*., (2004[2]) , De Blas *et al.*, (2003) [3] and Victor Torres (2015) [4], and they have indicated variation of solar energy as the main challenge in the application of solar technology particularly for on farm milk cooling system. Victor *et al*., (2016) [5] observed that, the availability of electrical power generated from solar energy allows the use of convectional system. However, he noted that solar energy systems needed to be adapted to the fluctuating characteristics to ensure satisfaction of standalone systems. The use of ice as a medium of thermal energy storage is suitable not only due to its ability to deliver energy in a short time, but also storage of large latent thermal energy Axaopaulis *et al*., (2009) [6]. Ice thermal storage systems have been applicable in milk cooling as milk cooling processes has to be carried out as fast as possible to reduce microbial level in milk and hence maintain the quality of milk to the required standards Torres *et al*., (2014) [7].

A Studies on performance characterization of small milk cooler with ice storage using DC compressors and adapters carried out by Victor Torress *at al.,* (2015) [4]. From the study, computational models were developed for predicting heat transfer inside the refrigerator in relation to the amount of milk to be cooled in the refrigerator and the mass of ice formed.

There is little information on AC Solar refrigeration capacity based on available solar radiation level of a specific site, that is important in sizing of solar driven refrigeration systems. The purpose of this research is to determine the maximum cooling load of a solar refrigeration systems based on the mean daily solar radiation of a specific location. The results obtained would bridge the gap in providing information of maximum cooling loads available on a specific site based on available mean daily solar radiation which is a critical component in solar driven refrigeration sizing.

III. OBJECTVES

(I) To analyze the cooling loads developed from solar driven refrigeration system with varying AC compressor capacities when exposed to varying mean daily solar radiation.

(I) To determine the maximum cooling loads of a specific capacity of solar driven solar driven refrigeration system would develop under varying mean daily solar radiation.

IV. MATERIALS AND METHODS

The maximum cooling loads for three solar driven refrigeration systems fitted with varying compressors capacities were obtained by exposed the systems PVs to varying solar radiation for the same period of time. Three AC compressors systems of 200W model TL5G Danfoss, 250W modelTLS5T Danfoss and 350W model SC12G Danfoss integrated with their corresponding evaporators were connected to a PV system of 800W. An inverter was connected to the system which supplied AC power from the PV modules to each of the compressors. A PLC power control unit connected to a smaller 30Wp panel controlled the 'on' and 'off' status of the three compressors depending on the available solar radiation levels, and the power required to operate each compressor. A Kipp and zomen (Germany) model SP lite2, Pyranometer with an accuracy of $\pm 5\%$ measured the variation of solar radiation after every 3 minutes. The time taken by each of the refrigeration system to operation, when each compressor was 'on' and the mean daily solar radiation were recorded daily by COMBI-LOG 1021 data logger for a period of six hours. Figure 1 shows the plant layout for the solar driven refrigeration system.

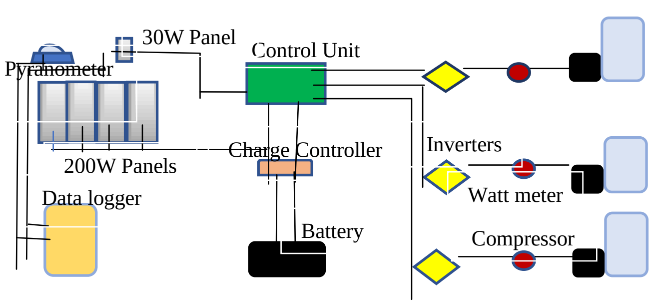

Fig.1. Plant layout of the solar Driven Refrigeration System

The cooling load for each refrigeration system, was obtained from of the temperature drop in 20kg of water can, and the mass of ice formed from 15 kg of water adjacent to the water can. The water-cooling can was place centrally in the ice container, which was in tern surrounded by an outer jacket of a brine solution of 35% concentration as a secondary refrigerant in which the evaporators of each refrigeration system was submerged. To reduce heat influx into and out of the cooling vessel, 60 mm thick Polystyrene extruded light form insulation of density 21.5kg/m^3 was used. Figure 2 shows the cross section of the milk cooling vessel in each of the solar driven refrigeration system.

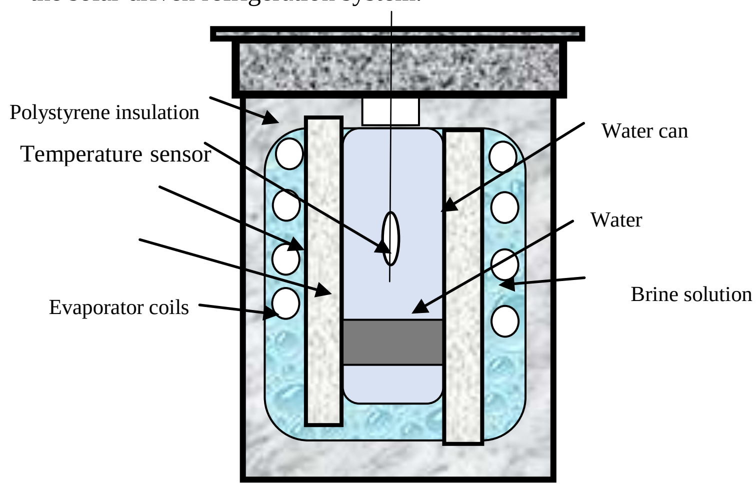

Fig.2. Cross section of the milk cooling vessel

To ensure the control unit generated the correct voltage that corresponded with the varying solar radiation, there was need to calibrate the control unit

Calibration of the control unit

The calibration of the control unit was done by use of the manufacturer calibrated Kipp and zomen (Germany) model SP lite 2. Pyranometer with an accuracy of $\pm 5\%$. The 30Wp polycrystalline solar panel fixed next to the 200Wp panels, generated a voltage as the signal to the control unit that corresponded to the solar radiation obtained by the pyranometer. The generated voltage was regulated in order to produce the equivalent of the solar radiation corresponding to the solar radiation of the pyranometer. To determine accuracy of the generated voltage, the solar radiation obtained from the pyranometer was plotted against the solar radiation from the control unit. Figures 3 and 4 show the Coefficient of Correlation and voltage tracking of the solar radiation of the control unit during calibration and at a mean daily solar radiation of 414.37W/m^2.

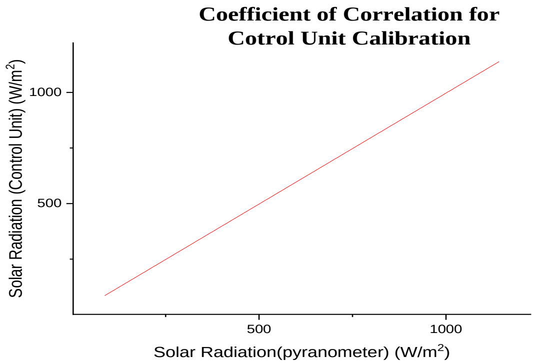

Fig.3. Coefficient of correlation solar control unit solar radiation

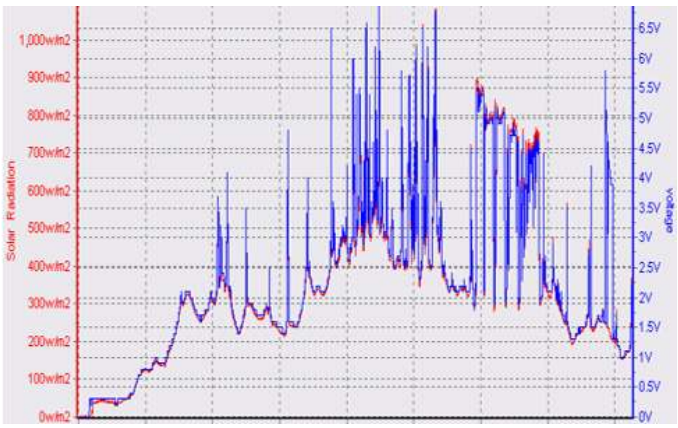

Fig. 3. Solar radiation voltage tracking by the control unit

Since each refrigeration system, exhibited minimum and maximum cooling loads at different mean daily solar radiation operating bands. The cooling load for each refrigeration system was considered separately as in figures. 4, 5 and 6 of ice formed. The minimum, average and maximum solar radiation for each band was established as shown in table 1

Table 1. Refrigeration system mean daily solar operating bands

Compressor size (W)	Operating mean solar radiation band (W/m^2)	Mean daily solar Radiation (W/m^2)		
		Minimum	Average	Maximum
200W	100.281- 420.715	213.653	350.682	414.382
250W	420.715-580.391	446.988	497.548	570.847
350W	580.391-670.803	580.391	623.362	664.358

To evaluate the performance for each refrigeration system, the total cooling load was obtained as the sum of direct cooling load obtained from the water and the mass of ice formed in each refrigeration system. Table 2 shows mean daily cooling loads for each refrigeration system while Table 3 shows the mass of formed in the cooling processes with varying mean daily solar radiation. cooling loads for each refrigeration system. The number of hours each compressor operated in each day, was obtained by summation the number of seconds recorded by the data logger for each compressor daily. The cooling load kWh for each compressor was obtained from the compressor rating from the manufacturer's catalogue and hours of operation.

Table 2. Refrigeration systems cooling loads

Mean daily Solar Radiation W/m^2	Refrigeration Cooling loads kWh		
	200W	250W	350W
213.651	0.0914	0.0904	0.0665
350.682	0.183	0.112	0.0791
414.368	0.229	0.181	0.163
446.985	0.243	0.221	0.179
497.848	0.242	0.240	0.226
570.848	0.241	0.263	0.248
623.362	0.245	0.260	0.256
664.358	0.241	0.262	0.258

Table 3. Mass of ice formed by refrigeration system

Mean Daily Solar Radiation W/m^2	Compressor sizes W and mass of ice formed kg		
	200W	250W	350W
213.651	4.38	4.18	3.16
350.682	5.78	5.43	3.26
414.368	6.27	6.78	4.34
446.985	6.63	6.89	5.92
497.848	6.71	7.03	6.88
570.848	6.73	7.24	6.91
623.362	6.72	7.35	6.95
664.358	6.74	7.34	6.94

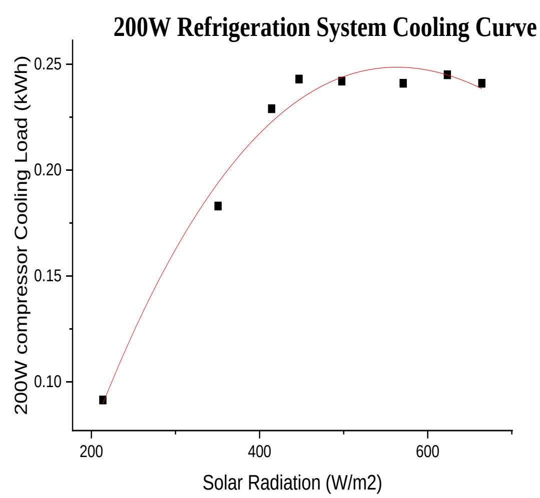

Fig.4. Cooling load curve for 200W refrigeration system

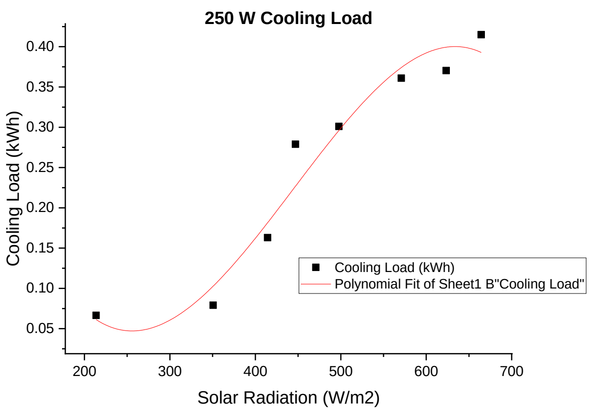

Fig.5. Cooling load curve for 200W refrigeration system

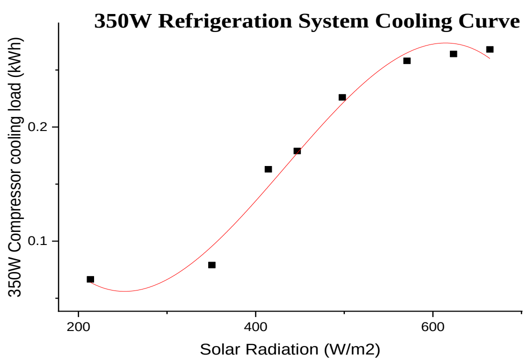

Fig.6 Cooling load curve for the 350W refrigeration system

To determine the accuracy of the solar driven refrigeration systems the cooling of each refrigeration system was investigated at different solar radiation and compared with the previous cooling loads obtained. Table 4 shows the cooling loads obtained for the three refrigeration system when operating at different solar radiation. From table 3 and cooling curves

Table 4. Refrigeration Cooling loads at different solar radiation

Solar Radiation. W/m^2	Refrigeration system Cooling Loads		
	200W system	250W system	350W system
346.146	0.181	0.113	0.087
436.446	0.248	0.147	0.159
473.276	0.246	0.241	0.196
501.188	0.257	0.278	0.241
543.459	0.251	0.296	0.244
609.296	0.237	0.387	0.252
629.678	0.253	0.399	0.265
652.791	0.248	0.398	0.268
683.189	0.246	0.381	0.266

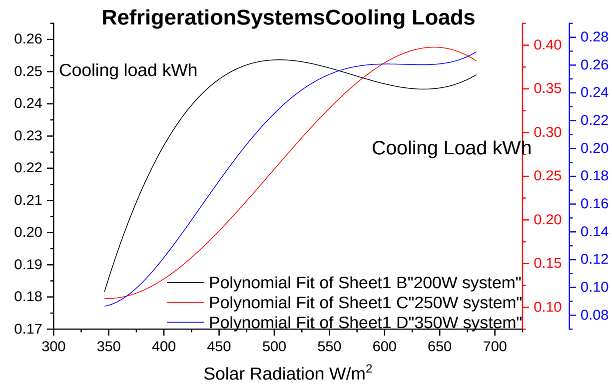

Fig.7. Refrigeration system cooling loads

V. RESULTS AND DISCUSSIONS

The cooling loads for the 200W, 250W and 350W solar driven AC refrigeration systems are as indicated in tables 3 and 4, and the corresponding cooling curves are as indicated in figures 4,5 and 6. From the tables and cooling curves it is observed that, the 200 W Refrigeration system operated continuously from a mean daily solar radiation of 213.651 W/m^2 to 664.358W/m^2 and generated corresponding cooling load of 0.0914 kWh and 0.398 kWh respectively. The 250 W refrigeration system, operating between the same mean daily solar radiation generated a minimum of 0.904 kWh and a maximum of 0.467 kWh. The last refrigeration system of 350 W, generated a minimum of 0.065 kWh and a maximum of 0.482 kWh. The 200 W refrigeration system showed highest cooling load between a mean daily solar radiation of 213.652 W/m^2 and 446.985W/m^2. The 250 W refrigeration system, had the highest cooling load between a mean daily solar radiation of 446.985 W/m^2 and 497.848 W/m^2. The last refrigeration system of 350 W capacity, showed highest cooling load between 570 W/m^2 and 664.358 W/m^2. The mass of ice formed which was also part of the cooling load showed similar trend with the mean daily solar radiation as indicated in Table 3.

When the refrigeration systems were exposed to different solar radiation levels the cooling loads for each of the refrigeration systems were as indicated in table 4, while the corresponding cooling curves are as in figure7.

From Table 4 and figure7 it is observed that maximum cooling load for the 200W refrigeration system was experienced at solar radiation of 473.276 and 501.188 W/m^2. Maximum cooling load for the 250 W refrigeration system occurred when the solar radiation was between 609.296 and 629.678 W/m^2. the 350 W refrigeration system, showed a maximum cooling load when the solar radiation levels were between 628.678 and 652.791 W/m^2. The two cooling trends in the three refrigeration systems show similar maximum cooling loads at corresponding solar radiation levels as evidence in the cooling curves.

VI. CONCLUSION

The cooling loads developed from three solar driven AC vapour compression refrigeration systems have been studied, based on mean daily solar radiation available at a specific site. From this study it is observed that the maximum cooling load developed by the refrigeration system is dependent on the compressor capacity, and the level of the mean daily solar radiation of a site.

A refrigeration system with compressor capacity of 200 W has a maximum cooling load of 0.246 kWh at a mean daily solar radiation between 502 and 544W/m^2. A larger Refrigeration system with a compressor capacity of 250W, develops a cooling load of 0.398 kWh when the mean daily solar radiation is between 609 and 629 W/m^2. A refrigeration system having a compressor capacity of 350 W, has a maximum cooling load 0.268 kWh, when the solar radiation is between 629 and 652 W/m^2. From this information solar driven refrigeration systems can be accurately designed for specific location, based on the mean daily solar radiation level.

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