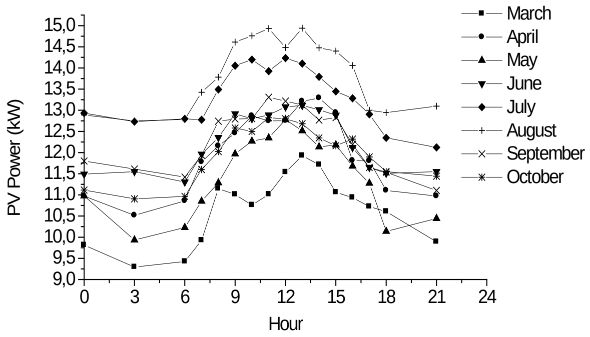

Figure 12: Hourly variation of PV power for the 1st days of the months from March to October 2012, for an evaporating temperature Te=0°C

According to the results, it is higher in August with a value of 14.94 *kWp* and insolation of 4.86 *Wh/m²/day*. The minimum value is obtained in March at 3 am with 9.29 *kWp* and the maximum at 2pm (14.94 *kWp*) on august, while on April there is a minimum value of 9.93 *kWp* at 3 pm and a maximum of 12.77 *kWp*.

Figure 13 gives the hourly variation of the output of the PV modules for evaporating temperatures of *-10 °C, -5 °C, 0 °C, 5 °C* and *10 °C* in April. It could be seen that it is low for an evaporating temperature of 10 °C and higher for an evaporating temperature of *-10 °C*. We could therefore conclude that when the evaporating temperature decreases as the power of PV modules increases.

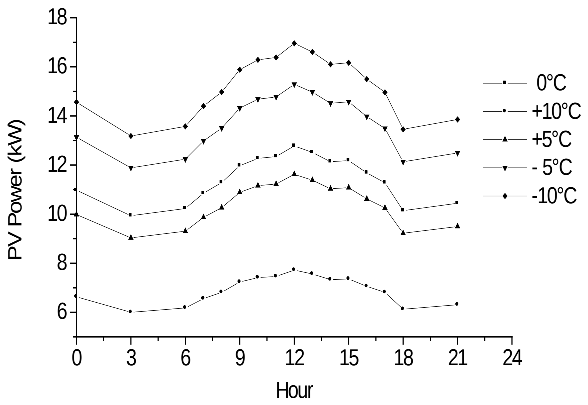

Figure 13: Hourly variation of PV power for evaporating temperatures of 0°C, +10°C, +5°C, -5°C and -10°C on 1st April 2012

After calculating the different powers and energies provided by the PV panels as shown on figures 14 and 15, we can make a comparison between them and the powers and energies absorbed by the compressor.

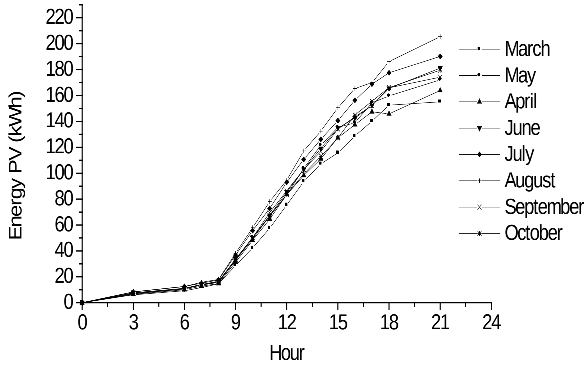

Figure 14: Hourly variation of PV energy for the 1st days of the months from March to October 2012, for an evaporating temperature Te= 0°C

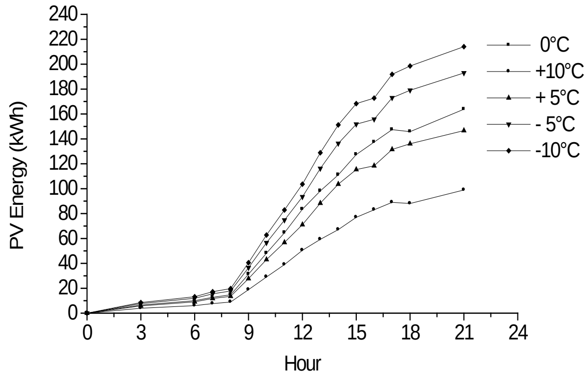

Figure 15: Hourly variation of PV energy for evaporating temperatures of 0°C, +10°C, +5°C, -5°C and -10°C on 1st April 2012

Figure 16 shows the evolution of the output of the PV panels and that absorbed by the compressor on April for an evaporating temperature of 0 °C. It could be seen that the energy provided by the PV panel is greater than that consumed by the compressor; it has a minimum value of *9.93 kW* and a maximum value of 12.77 kW, while the power absorbed by the compressor varies from 4.8 to 6.18 kW.

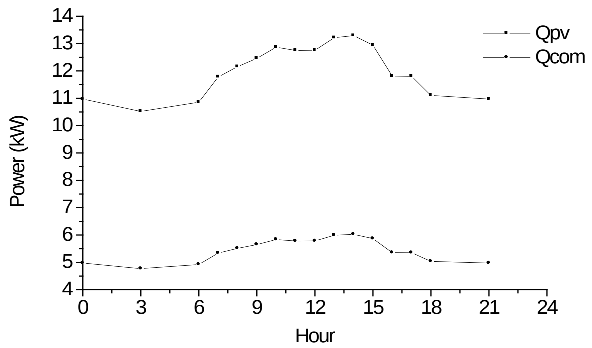

Figure 16: Comparison between the hourly power consumption of the compressor and the PV power generated on April 1st, 2012 for an evaporating temperature Te= 0°C

Figure 17 presents a comparison between the energy absorbed by the compressor and the energy of PV panels in April for an evaporating temperature of 0 °C. It could be checked that, between 4 pm and 9 pm, energy exceeds consumption. So the excess energy could be stored in batteries for latter uses at operating hours of low energy such as 8 am, 9 am, 4 pm, 5 pm and 6 pm.

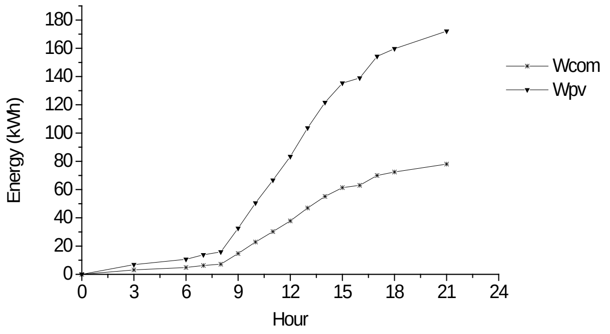

Figure 17: Comparison between hourly energy consumption of the compressor and the PV energy generated on April 1st, 2012 for an evaporating temperature Te= 0°C

4.6. Evaluation of the overall efficiency of the system

Considering the values of the total heat load and PV power calculated from March to October the overall monthly efficiencies of the system are presented in table 10. It could be seen that the overall performance of the plant also varies with season. In the warmer months, we have higher values. We can therefore conclude that, our SE-VCR system will have better returns for the months of March, April and May, with a maximum value of 35%.

5. Conclusions and Recommendations

The overall objective of this work was to contribute to the improvement of thermal comfort in living environments by using a cooling system coupled to a solar installation. An evaluation of the hourly cooling load was done by the means of heat balance due to walls, solar radiation, air renewal, occupants, lighting and electrical appliances. The variations of the various parameters were calculated as well as the minimum area of the photovoltaic panel to satisfy the power demand of the compressor. The results showed that the effective power of the compressor varies between *5.33 kW* and *6 kW*; the coefficient of refrigerating performance varies from 3.28 to 3.74 while the efficiency of the installation varies from 17 % to 35 %. Finally, the proposed SE-VCR system can successfully be operated in dry tropical areas to improve thermal comfort. The results obtained in this paper could be used in some other areas like Niamey in Niger; Ndjamena in Chad; Ouagadougou in Burkina Faso and other regions with same climatic characteristics. However, further investigations should be made to see the possibility of using adsorption refrigeration systems in the Sudano-Sahelian areas.

Acknowledgements

Authors are grateful to the Meteorological service of the airport of Maroua-Salak for providing them with data necessary to the realization of this work.

References

[1] Maalouf Chadi (2006). Étude du potentiel de rafraîchissement d'un système évaporatif à désorption avec régénération solaire. PhD Thesis, Université de la Rochelle, France, 220P.
[2] Noël Djongyang, René Tchinda and César Kapseu (2012) A Review of Solar Technologies For Buildings. African Journal of Science, Technology, Innovation and Development 4 (4): 11-36
[3] César Kapseu, Noël Djongyang, George Elambo Nkeng, Maturin Petsoko, Daniel Ayuk Mbi Egbe (2012). Energies renouvelables en Afrique Subsaharienne, Harmattan, 370 p.
[4] Mastrullo, R., Renno, C., (2010). A thermoeconomic model of a photovoltaic heat pump. Applied Thermal Engineering 30: 1959–1966.
[5] Adnene Cherif, Ahmed Dhouib (2002). Dynamic modelling and simulation of a photovoltaic refrigeration plant. Renewable Energy 26: 143–153.
[6] Mehmet Bilgili (2011). Hourly simulation and performance of solar electric vapor compression refrigeration system. Solar Energy 85: 1-12.
[7] Fong, K.F., Chow Tai Tai, Lee, C.K., Lin, Z., Chan Lung Sang, (2010). Comparative study of different solar cooling systems for buildings in subtropical city. Solar Energy 84:227–244.
[8] Todd Otanicar, Robert A. Taylor, Patrick E. Phelan (2012). Prospects for solar cooling-An economic and environmental assessment. Solar Energy 86 (5) 1287–1299.
[9] Dai YJ, Wang RZ, Ni L (2003). Experimental investigation and analysis on a thermoelectric refrigerator driven by solar cells. Solar Energy Mater. Solar Cells, 77: 377-391.
[10] Abdul-Wahab SA, Elkamel A, Al-Damkhi AM, Al-Habsi IA, Al-Rubai'ey' HS, Al-Battashi AK, Al-Tamimi AR, Al-Mamari KH, Chutani MU (2009). Design and experimental investigation of portable solar thermoelectric refrigerator. Renewable Energy, 34: 30-34.
[11] Kaplanis S, Papanastasiou N (2006). The study and performance of a modified conventional refrigerator to serve as a PV powered one. Renewable Energy, 31: 771-780.
[12] Dieng AO, Wang RZ (2001). Literature review on solar adsorption technologies for ice-making and air conditioning purposes and recent developments in solar technology. Renewable Sustain. Energy Rev., 5: 313-342.
[13] Fan Y, Luo L, Souyri B (2007). Review of solar sorption refrigeration technologies: Development and applications. Renewable Sustain. Energy Rev., 11: 1758-1775.
[14] S.M. Xu , X.D. Huang ,R.Du (2011) An investigation of the solar powered absorption refrigeration system with advanced energy storage technology. Solar Energy 85: 1794–1804.
[15] [15] K.F. Fong, C.K. Lee, T.T. Chow, Z. Lin, L.S. Chan (2010). Solar hybrid air-conditioning system for high temperature cooling in subtropical city. Renewable Energy 35:2439- 2451

[16] Axaopoulos PJ, Theodoridis MP (2009). Design and experimental performance of a PV Ice-maker without battery. Solar Energy, 83: 1360-1369.

[17] Ewert MK, Agrella M, Frahm J, Bergeron DJ, Berchowitz D (1998). Experimental evaluation of a solar PV-refrigerator with Thermoelectric, Stirling and Vapor Compression Heat Pumps. Proceedings of Solar' 98, ASES. http://solar.nmsu.edu/publications/pv_direct_refrig.pdf

[18] Papadopoulos AM, Oxizidis S, Kyriakis N (2003). Perspectives of solar cooling in view of the developments in the air-conditioning sector. Renewable Sustainable Energy Rev., 7: 419-438.

[19] Sözen A, Özalp M (2005). Solar-driven ejector-absorption cooling system. Appl. Energy, 80: 97-113.

[20] Desideri U, Proietti S, Sdringola P (2009). Solar-powered cooling systems: Technical and economic analysis on industrial refrigeration and air-conditioning applications. Appl. Energy, 86: 1376-1386.

[21] C. Sanjuan, S. Soutullo, M.R. Heras (2010). Optimization of a solar cooling system with interior energy storage. Solar Energy 84: 1244–1254.

[22] Anyanwu EE (2003). Review of solid adsorption solar refrigerator I: an overview of the refrigeration cycle. Energy Conversion Manage., 44: 301-312.

[23] Anyanwu EE (2004). Review of solid adsorption solar refrigeration II: An overview of the principles and theory. Energy Conversion Manage., 45: 1279-1295.

[24] Noël Djongyang, René Tchinda, Donatien Njomo (2012). Estimation of some comfort parameters for sleeping environments in dry-tropical sub-Saharan Africa region. Energy Conversion and Management 58:110-119.

[25] Mehmet Azmi Aktacir (2011). Experimental study of a multi-purpose PV-refrigerator system. International Journal of Physical Sciences Vol. 6(4), pp. 746-757

[26] Noël Djongyang, René Tchinda (2010). An investigation into thermal comfort and residential thermal environments in the intertropical sub-Saharan Africa region: Field study report during the Harmattan season in Cameroon, Energy Conversion and Management 51: 1391-1397.

[27] Belhadj Mohammed (2008). Modélisation d'un Système de Captage Photovoltaïque Autonome. Master Thesis, University of Bechar, Algeria.

[28] Noël Jabbour (2011). Intégration des systèmes à absorption solaire de petites puissances aux bâtiments - approche multifonction solaire: chauffage, ECS et rafraîchissement. PhD Thesis, University of Lyon, 163 pages.

[29] Butti K. and Perlin J (1981). A Golden Thread (2500 Years of Solar Architecture and Technology). New York: Van Nostrand Reinhold.

[30] Weiss W. Bergmann I. and Faninger G (2006). Solar Heating Worldwide: Markets and Contribution to Energy Supply 2004. Paris: International Energy Agency Solar Heating and Cooling Program.

[31] Mamadou Adj (1987). Etude et réalisation d'un prototype de réfrigérateur solaire a réserve de froid destiné à la conservation des vaccins. PhD Thesis, Cheick Anta Diop Universiy, Senegal, 136 Pages.

[32] Weiss W.W (2003). Solar Heating Systems for Houses - A Design Handbook for Solar Combisystems.s.l.: Earthscan 9781902916460.

[33] Jacques Bonnin, P.J. Wilbur and Susumu Karaki (1980). Réfrigération solaire, SCM Paris.

[34] N. Medini, B. Marmottant, ES. Golliet Ph. Grenier (1991). Study of a solar icemaker Machine. International Journal of Refrigeration 14: 363-367.

Author Profile

Armand Noël Ngueche Chedop received a Msc Degree in Electronics, Electrotechnics and Automatics from the University of Ngaoundere and a Master of Engineering in Renewable Energies from the Higher Institute of The Sahel of the University of Maroua in 2012 and 2014, respectively. He is now preparing a PhD Degree in Energy Systems and the Environment at the University of Maroua in Cameroon.

Noël Djongyang received a PhD Degree in Energy systems from the University of Yaounde I in 2010. From 2007 to 2013, he was a senior lecturer at the Faculty of Science of the University of Ngaoundere. He is since 2013, the Head of Department of Renewable Energies at the Higher Institute of the Sahel of the University of Maroua in Cameroon.

Zaatri Abdelouahab graduated as an Electrical Engineer from the Université Catholique de Louvain-la-Neuve, Belgium in 1981. He got a Magister on Electronics from the Electronics Institute of the University of Constantine in 1993.He received a PhD Degree from the "Flamish University", Leuven, Belgium. He is now a full professor at the Faculty of Engineering Science of the University of Constantine 1 in Algeria.