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Sustainable System Solutions: RAK Research and Innovation Center

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Abstract

Achieving sustainable development requires collaboration between different sectors and institutions, as well as the participation of all relevant stakeholders and individuals. The major contribution of institutions of higher education and research centers to society's efforts at achieving sustainability is well recognized. RAK Research and Innovation center is a state of art research and development center specializing in sustainable system solutions. This center is the succession of research platform developed by the CSEM in 2007 when the Government of Ras Al Khaimah allocated to CSEM-UAE 87000 m2 of land in the industrial zone to build a world unique Solar R&D facilities open to co-operation with world leading academic, technology and industrial development centers. Recently, the center became one of the major research facilities of the American University of Ras Al Khaimah. Today this facility includes seven R&D test platforms focusing on Photovoltaic, Solar cooling, Solar Hybrid minigrid, Green building, solar water desalination, Solar Island and Concentrated Solar Power. One of the most promising applications of renewable sources, in UAE is to harness the energy required to supply fresh water. Water desalination using renewable energy technologies, such as solar is possible. Employing such new systems to produce fresh potable water in the future give solutions from feasibility, sustainability, environmental and safety issues to national economy, and social benefits. The need for sustainable approach to tackle the issue of bottled water has motivated us to develop an in-house water purification unit based on Membrane Distillation (MD) technology. MD is a novel process that could be adapted effectively for many water purification applications. A difference in partial pressure serves as the driving force, and the presence of a hydrophobic membrane ensures high water quality regardless of feedstock parameters. Hot-side temperatures below 90 C are suitable and this process has been proven ideal for exploiting waste heat or solar thermal resources for small scale applications. There is an acute increase in the energy utilization as well as its production in the world over in general and in particular in UAE. This is because of increase in population and economy. As a result of this there is an increase in global warming and CO2 emission. To reduce the generation and also to mitigate its effect on the climate, one has to reduce the utilization or need of the energy use in the society. Share of buildings in total energy consumption and its utilization is huge around 20%-40% depending upon country and it is used in cooling, heating, hot water, home appliances, lighting and cooking etc. In UAE 40% is the buildings share of total energy consumption of which Cooling is around 70% of building load, Lighting is the next and all the others will account for 20%. Hence, thermal insulation of building represents a big potential in Energy Saving in UAE. A theoretical study is done at site on different cost-effective and thermally efficient solutions, related to solar insulation materials for the buildings. To perform a real outdoor test for savings obtained with solar insulating materials, a solar calorimeter test facility has been designed and builds. The present design is aimed to determine the heat flux reduction and the energy savings of different measures with similar indoor conditions, with and without solar insulating materials for the same ambient conditions. RAK research and Innovation Center has one the world's first high precision solar tracking platform which can be used for concentrating solar panels. The platform floats on a cushion of air and is equipped with state of art rotating systems to track the movement of the sun in the order of 10-2. This platform has been tested for the load rotation test and it can take up to 150 tons of loads distributed over its top. This high precision structure is study various technology requiring high precision tracking for the optimum energy production. This platform has the potential to be deployed on land or offshore. Both versions are based on the principle of a torus floating on water and rotating to track the sun's azimuth, thus ensuring optimal use of primary solar radiation received on earth. Solar radiation being concentrated can be used in solar thermal processes or photovoltaic applications. This paper describes the basic research platforms at RAK Research and Innovation Center, and the main results that have been achieved.

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1. Introduction

Solar energy can be divided into direct and indirect categories. Most energy sources on earth are forms of indirect solar energy. Coal, oil and natural gas derive from ancient biological material which took its energy from the sun millions of years ago. All the energy in wood and foodstuffs also comes from the sun. Movement of the wind, and the evaporation of water to form rainfall which accumulates in rivers and lakes, are also powered by the sun. Therefore, hydroelectric power and wind and wave power are forms of indirect solar energy. Solar energy research and applications have been receiving increasing attention throughout the world as solar energy must play a much greater role in the energy mix in upcoming years [1-8].

Nivine Issa and Saeed Al Abbar [9] conducted an interesting research about different green buildings regulations and codes in Arab countries in general and in Qatar, UAE and Lebanon in specific, it also shed a light on what are the different challenges and constrains that faces the development and the implementation of the green building in these countries, this article shows how the Arab countries still have a long way in order that they reach their goals and visions towards a more environmental friendly buildings however, it also shows how a tremendous work is being done on both the governmental and the private sectors. Another interezsting study for developing countries in general and for Jordan in specific by Hikmat H. Ali and Saba F. Al Nsairat [10], this research focus on different international green building assessment tools such as such as LEED, CASBEE, BREEAM, GB Tool, and others, another outcome of this research was a computer based tool that matches the environmental conditions in Jordan for developing the implementations of green buildings. Another project held in RAKRIC (CSEM before) [11] the main idea of this project was to test different insulation materials using the exact same conditions in terms of the size of the rooms, the AC size used and using the same location.

In their study, Mutasim Nour and Golbarg Rohani [12], aim for studying the feasibility of connecting a stand-alone PV-diesel hybrid power system for a village located in in the western region of Abu Dhabi in UAE, the research presents how a conventional power source such as a diesel generator can be used to support a solar based power system to compensate in case of any power shortage from the solar system, the system is first simulated using HOMER software in order to check for the feasibility of the system's configuration and to check whether it can meet the electrical demand of the system or not. Another research that was implemented in RAKRIC (CSEM before) by Zaki Iqbal, Gorkem Soyumer, Waqarullah Kazim [13] this research shows how before connecting the stand alone system with the mini grid the power produced in one center was either consumed there or wasted, and how after implementing the mini grid these grids are effecting in a positive manner on the overall energy bill.

Hussain [14] developed multiple hybrid poly-generation systems for Kuwait based on requirements in the region. System is designed to produce power, fresh water and cooling simultaneously. The poly-generation systems are developed by integrating combined power cycle, desalination system and cooling unit. Two different type of desalination and cooling technologies are considered in the analysis. Reverse osmosis (RO) and multi-stage flash (MSF) are considered for desalination purposes, absorption refrigeration (AR) and vapor compression air conditioner (VC) for cooling. The combination of Power-RO-AR configuration provides higher fuel savings compared to all other combinations. Calise et al. [15] modeled a solar energy based tri-generation for CCCWP applications. Multi-effect desalination unit and vapor absorption chiller are integrated together with PVT collector for combined production of cooling, desalination and power. The transient simulations for different operational and design parameter were conducted and optimized in terms of energetic efficiency and economic viability -19- Kullab [16] experimentally and numerically analyzed the performance of air gap membrane distillation system developed by SCARAB Development AB for utilization cogeneration power plants.

Calise et al. [15] dynamically simulated a solar tri-generation system and analyzed energetically and economically for production of cooling, fresh water and electricity. The system is modeled with PVTs (Photovoltaic/thermal collectors) integrated with absorption chiller and multi-effect desalination system for providing tri-generation. We experimentally analyzed the performance of a flexible solar thermal poly-generation system (STP) to produce simultaneous cooling, pure water and domestic hot water (DHW) for the weather conditions of UAE. The system is operated for providing cooling for the office cabins in CSEM-UAE during the summer season.

Picinardi [17] analyzed the performance of cogeneration system for production of cooling and desalination by integrating a single stage absorption chiller and humidification desalination process. Burrieza et al. [18] experimentally investigated the performance of AGMD modules for different flow rates and temperatures on the hot and cold side. The potential of solar thermal driven MD technology as an alternative to the conventional desalinations systems has been researched by several authors.

2. Solar Island

The Solar Island project is a feasibility study and a prototype realization for a new kind of solar energy power plants. This project is sponsored by the Ras-al-Khaimah Investment authority (RAKIA) with partners in UAE, Switzerland and France. The platform and the tracking structure has been successfully implemented and tested in the UAE condition and now the part of American University's RAK Research and Innovation Center Lab.

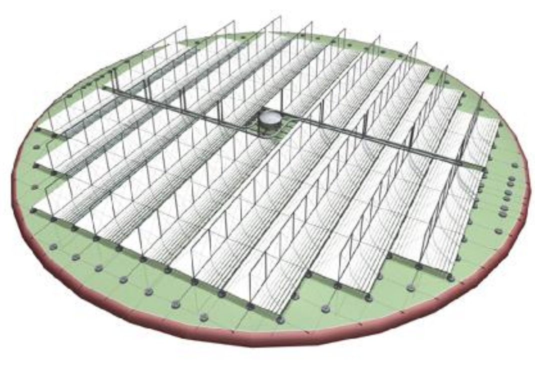

Figure 1: Solar Island project concept

The island has been placed approximately in the middle of the field to leave space around for the other entities such as: the power plant, the water pond, the office, the workshop and a viewing dune. Also, the power plant – tunnel – island – viewing dune are aligned on a North – South axis permitting to visitors to have the best view of the project with the Sun always in the back when standing on the viewing point.

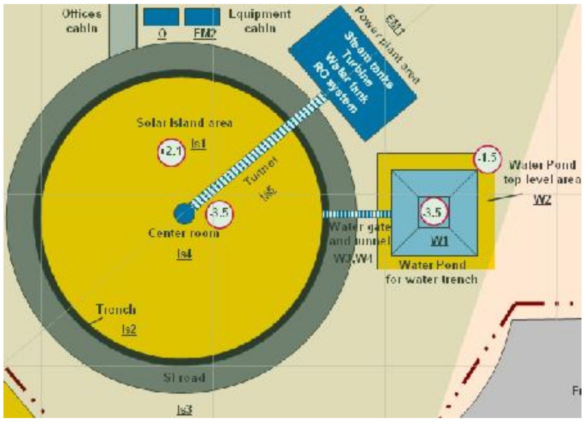

Figure 2: Solar-Islands layout of water system elements

The main element of the moving platform is, without any doubts, the torus. This polygonal structure, the torus, is made out of 36 straight elements, each of them 7.5 m long. Themselves, they are an assembly of 4 tubular pieces made out of a plain and flat 6 m long plate of steel which have been rolled and welded together. The trench is a circular concrete structure of 3.2m wide between 2 walls of 2.016m (inner) and 1.4m (outer) high forming a channel of approximately 84m of average diameter shown in figure 3 below.

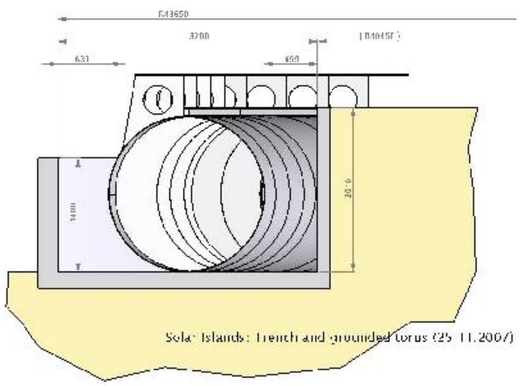

Figure 3: Solar-Islands trench with torus and without water

The torus works comprises also of elements such as the internal croissant-shaped reinforcements and the external 'flat ring' with its supports welded on the torus. This flat ring reinforces the structure and holds the steel cable anchors which are welded horizontally, all with their unique angle.

The whole rotating structure consists of a circular platform of 84m diameter delimited by a metallic torus of 2m diameter floating on the water in the trench, 50cm above its floor. An airtight membrane is attached to the torus and covers the whole inner surface. Pressurized air below the membrane permits the structure to hover. In operation, the whole structure rotates to follow the Sun. Guiding and driving wheels are placed on the torus to realize the rotation.

The control of the rotation of the island is done using the floating/hovering of the entire structure. The control parameter for the rotation is based on the solar azimuth angle with which the platform corresponds. The one for the floating/hovering is based on its height given by the level of the water in trench and the amount of air under the platform. These control is taken care by PLC using in-house software algorithm, dedicated sensors and actuators to ensure its height is maintained and it can precisely track the sun.

3. Solar Hybrid Minigrid

Solar Hybrid mini grid project was envisioned to develop a green energy initiative to power up the solar lab also known as RAK Research and Innovation Center (RAKRIC). Previously the electricity in Solar lab was produced majorly by the 50 kVA diesel generator which was connected to each center through the cabling network. There also existed stand-alone solar PV and battery systems at 4 research centers (desalination, cooling, photovoltaic and calorimeter). It is worth noting that diesel generator was manually integrated into the network which means that an automated contactor did not exist for the previous configuration. To bring the eco-friendly concept into reality there was a need to calculate the load that existed at each center at the solar lab. Load profiling algorithm was generated to precisely calculate the effective working of each center.

Modeling of the electricity generation in Solar lab was conducted using HOMER which is the power supply optimization software developed by US National Renewable Energy Laboratory. It has been featured to model and compare multiple power generation systems in terms of technical and financial basis. The annual modeling of power generation was created at hourly resolution in order that the system efficiency, reliability and cost effectiveness are assessed with high accuracy. Varying the sizes of components that influences the net present cost (NPC) and levelized cost of electricity generation were taken into consideration. Multi-parametric simulation has been done on each component to minimize the cost.

As can be seen, 3 units of 8 kWp hybrid inverters available in SMA's product catalog are selected to meet the minimum 20 kW size. Utilization of the existing charge controllers connected to 20 kW PV standalone system (DC-coupled) were done into the integration into the mini-grid. 3 kWp and 36 kWp PV system which are AC-coupled we additionally integrated through 2 units of SMA STP 17000TL three phase grid-tie inverters to meet the demand for the solar lab. Eventually, battery bank was formed by using 72 batteries with the total capacity of 172.8 kWh. This system is successfully implemented in our lab and we are now powering our center 24X7 with eco-friendly 59kWp solar hybrid mini-grid.

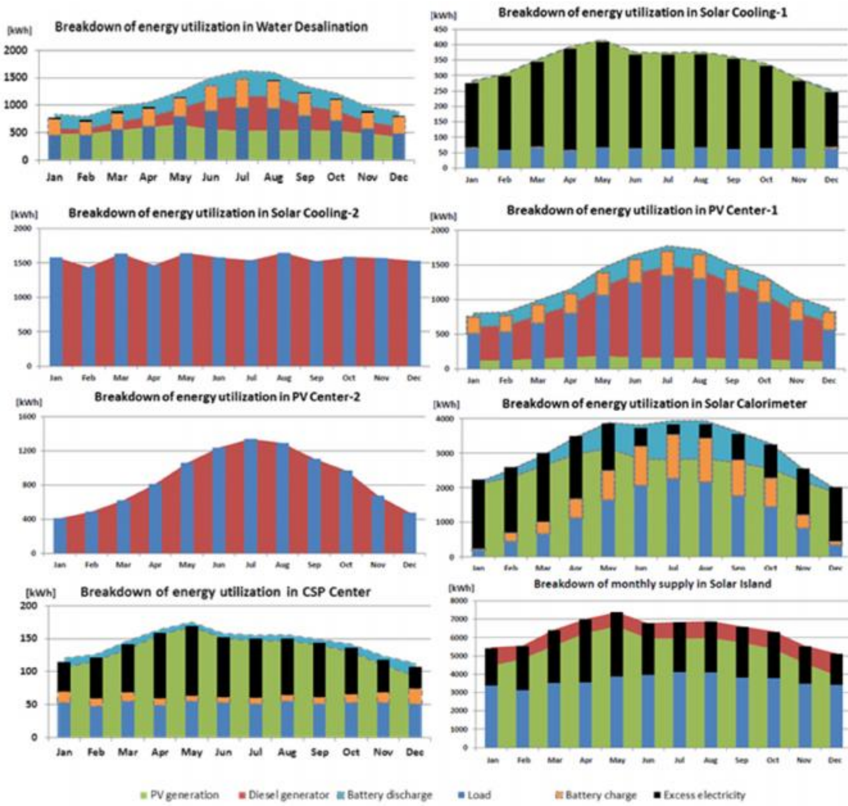

Figure 4: Energy utilization based on load profiling for each center at the solar lab

The line diagram of the mini-grid that has been implemented at RAKRIC and is demonstrated in Figure 5 below:

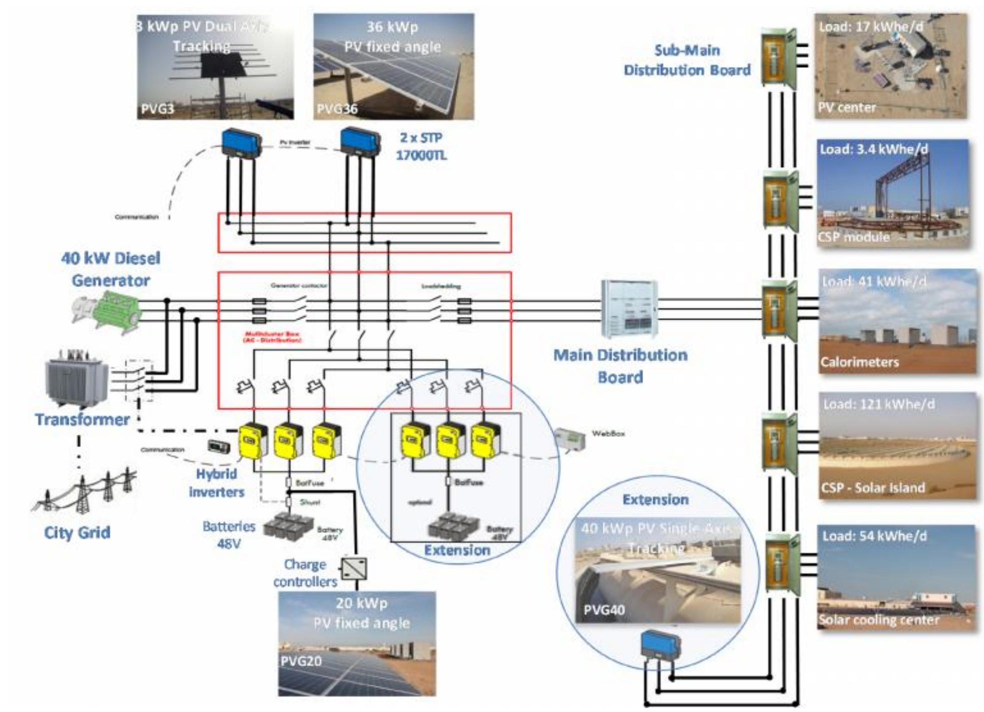

Figure 5: Line drawing of the mini-grid final design

4. PV Center

The significant increase in Atmospheric carbon emissions is the biggest threat to our environment and it is believed that the only way to halt the rise of airborne CO2 is for 80 percent of the world's fossil fuel emissions to stop or reduce, most of the power produced in this region is with Fossil fuel with ample amount of solar available in the region there is a high need to utilize that in shape of renewable, when we talk about the renewable energy production that is the most efficient for this region when compared to other available technologies Photovoltaic tops them all so at RAKRIC we decided to build a facility that is capable of testing the performance of different types of available PV solutions for their performance in the UAE climatic conditions.

In PV test center we are capable of testing multiple types of PV panels for their performance, the performance of different types of mounting structures fixed angle and variable angle to check the performance on different tilts and tracking systems is also conducted at our center, we are also equipped with single axis tracking systems and dual axis tracking system so that we can test efficiency of the given PV panel on fixed as well as tracking solutions. The performance of these systems in then monitored and documented with the help of our multiple IV curve tracer from Raydec which is a 16 channel IV curve tracer that is capable of data logging the yield, current, temperature and traces the IV curve for 16 different PV panels simultaneously along with the eight separate channels for temperature and radiation both so as to support the results. To help our center to perform diverse testing we are also equipped with the FLUKE thermal imager, and when it comes to the testing of complete PV systems we are also equipped with sophisticated instruments like FLUKE Power quality analyzer and Spectrum Analyzer, all of that data is then synchronized with the Solar radiation weather station data at RAKRIC to support the results.

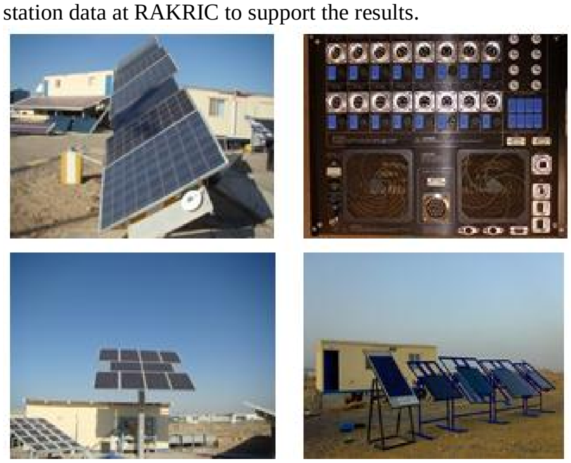

Figure 6: Single and dual axis tracking systems

The performance of this test facility is enhanced with the help of our software lab which helps with the simulation and design using TRANSYS, Polysun and sombrero.

5. Solar Calorimetric Test Center

Solar calorimetric test center is one of the seven test centers at RAKRIC, UAE produced a total of 109,979. GWh in 2013 out of the total energy produced in UAE 40% is consumed in residential and domestic purpose and out of total domestic energy consumed 70% is used in cooling which is a huge share, there are three major solutions to counter this problem and first is the passive design of buildings in this method you reduce the thermal conduction of your building material which eventually results in reducing the energy needs of that building second solution is to reduce the consumption by choosing efficient loads this way you reduce losses and improve conversion efficiency the third is the active design in which you generate your own electricity, out of these three the passive design is the most effective way of reducing energy consumption that is to consume less.

Figure 7: Solar Calorimetric Testing Facilities

Considering passive design as the most effective way to reduce energy consumption we developed a solar calorimetric test facility to test the different insulation materials for their characteristics in UAE climatic condition, this concept turned in to reality in 2012 when we developed four cubicles at our research center for testing different insulation materials and their behavior in Ras-Al-Khaimah UAE to reduce the energy consumption.

The four cubicles are identical in size and shape and one wall of each cubical is facing south, the south wall and roof of each cubical is our test facade, in first stage we developed and tested the south walls of four cubicles (3x3x3m3) as 50% of the thermal load contribution is from south wall and roof, one building is reference, others for testing different materials as energy consumption of each building is measured and compared to that of reference.

Test facility before (a) and after adding insulation (b).

- B1 is our reference building, U value: 3.25W/(m^2K)
- B2 is Solar reflective coating test building, same as B1, but coating added on test façade,
- B3 is Retrofitting insulation test building: same as B1, but 5cm PIR board added on test façade, U-value: 0.391W/(m^2K)
- B4 is Innovative construction test building : same but test façade by new technology (EIFS), U-value 0.175W/(m^2K)

We measure multiple parameters like Heat flux through testing facade, Indoor temperature and Relative Humidity (RH), Energy consumption, facade surface temperature and ambient conditions (Temperature, RH, Global radiation etc.,).

The results that we achieved were very overwhelming as the reduction in heat flux of different materials is Compared to reference B1 (Standard technology) The heat load reduction is 23% in B2 (coating), 70% in B3 (external retrofit) & 76% in B4 (EIFS).

Test facility has been developed to characterize all kinds of insulation methods like coating, retrofitting and new walls, the average heat load savings for few months are following similar trend to that of TRNSYS predictions, the heat load reductions are highly dependent on season as the savings are always relative, based on the results, the best insulation method is EIFS for thermal comfort as well as energy performance. However, the cost effective method is Reflective coating, retrofitting insulation (PIR Board of 5cm) also shows promising results and it can be used as immediate solution to existing townhouses and villas along with coating.

6. Solar Desalination and Co-generation of Heat

Conventional desalination processes employed in Middle East region are powered by fossil fuel resources and highly energy intensive. However, this region is fortunate to receive some of the highest levels of solar irradiance on the planet. Therefore, many countries in the region have been exploring the potential of solar energy as a solution to their energy challenge, especially for water desalination. Solar energy is a clean renewable energy source and can reliably complement conventional energy also ensuring that greenhouse-gas emissions are kept to a minimum. Despite the advantages, less than 1% of total desalinated water is produced in the Middle East using renewable sources.

Recent increase in attention towards solar driven desalination technologies in Arab nations and the remarkable ability of Membrane Distillation (MD) technology to couple with solar system has motivated the development of a novel solar combi MD (SCMD) system at solar outdoor laboratory of RAKRIC. A semi-commercial single cassette Air-Gap MD module was integrated with solar domestic hot water system having flat plate and evacuated tubular collectors as shown in Fig.8. Pure distillate flow is varied from 1.5 to 3 l/h, with higher values achieved at higher hot and cold side temperature difference of MD module. System simulations has been carried out using TRNSYS in order to obtain optimum operating conditions for producing 20l/day of pure water and 250 l/day of hot water for a single family household of 4-5 members in UAE region [18].

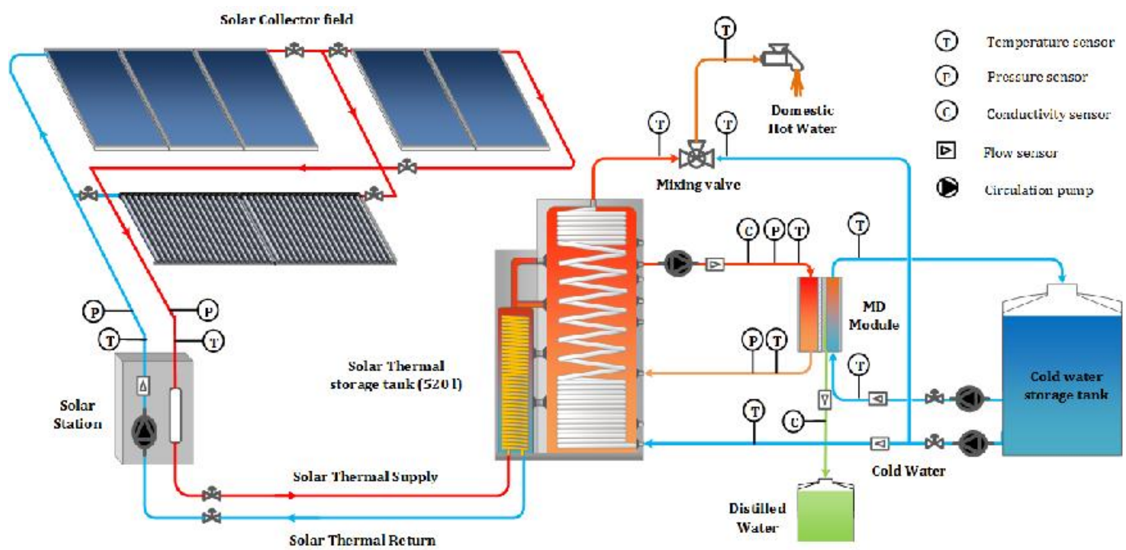

Figure. 8: Schematic representation of Solar-combi MD system

Another large AGMD module with 10 cassettes having total membrane area of 2.3 m^2 was also integrated with evacuated tubular collector field solar thermal collectors. Key area of research is to evaluate the performance of the cogeneration system with different system integration techniques. The cogeneration system for production of pure water and heat was successfully installed at RAKRIC research facility in UAE. Detailed experimentations were conducted in order to investigate the merits and demerits of all these integration modes e.g. Thermal store integration (TSI), Direct solar integration (DSI) and combination of direct solar and thermal store integration (DSTSI). Based on field experiments conducted in the months of September and October 2014, operational performance of solar cogeneration system gets maximum output in DSTSI mode. A maximum distillate productivity of 43 kg/day was achieved with this configuration, whereas only 29 kg/day and 39 kg/day of potable water are produced with TSI and DSI respectively. In terms of domestic heat production, DSTSI configuration efficiently uses 277 kWh of thermal energy for production of DHW at a rate of 80 L/min. DSTSI mode has improved energy efficiency with reasonable Net cumulative savings and with better payback period of 6.4

years with inflation and discount rates of 10% and 5% respectively. Thus, integrating a cogeneration system in DSTSI mode proved to be viable technology in terms of energy efficiency and economic benefits. Rooftop installations of this cogeneration system could be potentially applicable to hotel industry in which large amounts of hot water is required along with little amounts of complimentary drinkable water.

7. Solar Absorption Cooling

The abundance of solar radiation in UAE makes solar cooling a sustainable approach to fulfill the cooling demands which accounts for 70% of total domestic energy need. The performance of a 10TR solar cooling system was simulated and analyzed experimentally at RAKRIC outdoor facility in terms of meeting the cooling requirements for office cabins of SOLAB. The transient performance of the system was modeled using TRNSYS [11]. Results of the simulation indicate that the system can operate with an average thermal COP of 0.70. The chilling capacity of the currently installed system (with 128 m^2 gross collector area, and no auxiliary heater) meets cooling requirements for whole year except the summer months (Jun – Sep). Simulation results shows that the average Solar Fraction Cooling (SFC) for the months of June – September can however, be improved by; increasing the total gross area water flow to the collector arrays in the range 150 – 200 l/h, maintaining a chiller start temperature of 78°C by incorporation of a controller for that purpose, and/or incorporation of an auxiliary heater in the stratified tank. This study shows that solar driven air – conditioning systems in UAE stand a very huge potential for replacement of the conventional fossil powered air – conditioning systems.

Simulation system developed at RARIC needs improvement to exactly mimic physical phenomena and components considering transient behaviour, more accurate pipeline heat loss and gain coefficients, storage tank stratification system and estimation of cooling load etc. Optimized simulation studies and detailed experimentation has been carried out to analyze the technical potential of solar absorption cooling technology in UAE conditions [13]. Figure 9, shows the pictures of installation having solar collectors, absorption chiller and thermal stores. It was observed that the thermal coefficient of performance varying in the range of 0.46 - 0.67 having worst values in peak summer months of July to September. Optimized design and selection of hot water storage tank and the maintenance of stratification in hot water storage tank through-out the operation period of chiller, are very important aspects to get maximum benefit with longer operation period of solar cooling system. Efficiency of the collector improved during later hours of the day indicating possibility of sustained normal operation of chiller when radiation level decreases in evening hours.

Figure 9: Solar absorption cooling installed at RAKRIC

8. Solar Driven Polygeneration

Literature shows that, several combinations for integration of solar cooling and different conventional desalination technologies like RO, MED and MSF were investigated. However, the possibility of solar thermal polygeneration system integrating absorption chillers and membrane distillation together is not been studied and hence solar thermal driven polygeneration system for simultaneous production of cooling by absorption chiller, fresh water by membrane distillation (2 Modules in series) and domestic hot water by heat recovery has been designed, developed and experimentally tested at RAKRIC. Dynamic simulations were carried out using TRNSYS for the weather conditions of Ras-Al-Khaimah, UAE. Simulation results of the solar polygeneration system prove that cooling demands of office buildings considered in the study is completely fulfilled with all three collector types (FPC, ETC and CPC) having different collector areas. Optimization of the design parameters are conducted for maximizing the energetic performance and economic benefits. System performance of the polygeneration system was maximized with following parameters (i) Tilt angle of the collector at 15° (ii) Flow rate to the collector at 300 kg/h (iii) Storage volume of 1 m^3. In terms of required gross collector area to achieve 100% SFC, 216m^2 is required for ETC compared to 276m^2 needed for FTC and CPC configurations [14].

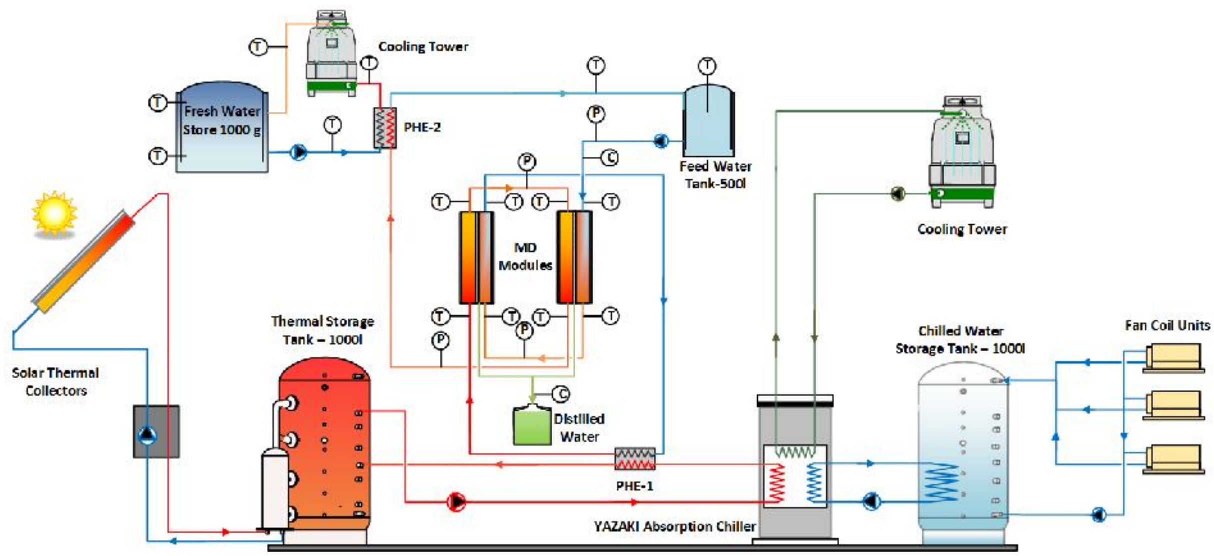

Figure 10: Schematic representation of Solar Polygeneration system

In terms of distillate performance, around 90 liters of fresh water is produced during daily simulation. Reduction in productivity prevailed during winter, which is majorly influenced by lower hot water supply temperatures. During the peak summer day, 34 kW of chilled energy produced by the single stage absorption chiller at an ideal COP of 0.7. Annual daily productivity varies between 114 and 370 kWh/day across different months, which is influenced by cooling demand requirements of the office buildings. Overall system performance varies between 60% and 67% throughout the year, higher system efficiency is achieved during winter due to lower ambient temperature. Whereas combined efficiency lies between 30% and 38%. Economic analyses shows that ETC achieves the lowest payback period of 9 years and highest net cumulative savings of $450,000 compared to other two configurations. With roof top installation, payback period is further reduced to 6.75 years and net cumulative saving is increased by $520,000 due to reduction in investment cost. In terms of global warming potential, 114 tons of CO_2 emission is avoided every year. CO_2 emissions avoided also provide cost saving through the implementation of carbon credits, which leads to reduction of payback period by 8% and improved net cumulative savings by 14%.

Experimental validation of the solar polygeneration shown in Fig.10 was done using the system installed in RAKRIC with 60% of designed collector area and with flexibility of operating in different configurations. Sea water with TDS of 40,000mg/l is desalinated in the STP system to a salinity level less than 30mg/l. Membrane distillation system is operated with internal and external heat recovery technique in which around 75% of energy is recovered for production of DHW at 55°C. A detailed numerical case study was also performed for real scale tri-generation application using waste heat recovery from Gas turbines for the implementation in Al-Hamra area, Ras Al Khaimah, UAE [23]. The tri-generation system is modeled for maximizing the utilization of waste heat by driving four thermal cycles. The absorption chiller plant is optimized based on cooling energy requirement of duplex villas in the region. The simulation results show that energetic efficiency of tri-generation system maximizes up to 85% in summer due to lower fuel consumption and full scale operation of absorption chiller.

9. Weather Station

All Solar related R&D work requires weather and solar related database for both modeling and experimental work, at RAKRIC multiple R&D activities, solar thermal, solar PV, CSP, solar cooling, building energy efficiency, solar desalination. RAKRIC Weather station continuously records the weather database since 2007, Recorded data needs to be reduced and make ready for subsequent analysis according to the requirement of different R&D projects, the parameters that we monitor includes, Global Radiation, Diffuse radiation, Beam radiation, ambient temperature, humidity, wind velocity, wind direction etc, these are the basic weather variables for all solar related projects.

The location of our weather station is Latitude: 25^0 5ʹ N, Longitude: 55^0 5ʹ E, AMSL: ~8 m, Local time GMT+4, Type/Class: Research, In Operation since 2007. RAKRIC consists of one main solar radiation weather station and three dedicated weather stations for certain tests.

Table 1: Weather Stations

Station 1	**Measured data**	**Sensor Model**	**Supplier**
Radiation	Direct Beam	NIP	EPLAB
	Global-Horizontal, Diffuse-Horizontal	CMP 11	Kipp & Zonen
Other Meteorological data	Ambient Temperature-Shaded and Unshaded	AD 592CNZ	
Station 2	Radiation: Global-Horizontal		
Other Meteorologica l data	Ambient Temperature, Pressure, Wind Direction and Speed, Relative Humidity, Ultraviolet Index (UVI)	Davis Vantage Pro 2, model no 6162	Davis

Figure 11: Line drawing of the mini-grid final design

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