A STAND ALONE COMPLEX FOR THE PRODUCTION OF WATER, FOOD, ELECTRICITY & SALTS:

FOR THE SUSTAINABLE DEVELOPMENT OF SMALL COMMUNITIES IN REMOTE AREAS[1]

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ABSTRACT

This paper presents an autonomous and integrated complex presents a new concept for supporting the sustainable development of small communities in remote areas. The proposed complex utilises the abundant solar/wind energies to provide small community, living in remote areas, with water, food, electricity and salts. The proposed complexes consists mainly of (i) a set of solar stills with precipitation basins for fresh water and salts production, (ii) a group of photovoltaic panels and wind mills for electricity generation and (iii) a farm of greenhouses, partially self sufficient of irrigation water, for food production. A pilot complex will be installed in one of the villages in the North west coast of Egypt. The paper describes the complex conceptual design and its pre-economical feasibility.

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INTRODUCTION

Fresh water shortages threaten a large number of the world population and make water potentially a critical matter since it has no viable substitution. According to a recent report of the International Atomic Energy Agency (IAEA), estimated 1.1 billions of people have no access to safe drinking water and more than 5 million die from water borne diseases each year. Provisions are no better even for the future. It is estimated that more than 2.7 billion of people will face sever water shortage by the year 2025 if the world continues consuming water at the same per capita rate, and the real population growth fits the forecasted trend. The crisis is mainly due to the mis-management of existing water resources, population growth, and continuous climatic changes. On the other hand, the pollution of surface water (rivers and lakes) caused by industrial, agricultural and domestic wastes, limits the suitability of fresh water availability in many regions. Fresh water shortages and low quality became an international problem confronting human groups and countries. It is, therefore necessary that sincere effort be made to face the looming water crisis and conserve shrinking water supply against the rising demand. Egypt and Arabian countries are not to far from these confrontations.

The Arab world represents around 10 % of the world's total area and about 5 % of the world population. The renewable water resources of the Arab World, however, do not exceed 0.5 %, and the per capita water is among the lowest in the world, Fath [1]. Abu Zeid [2] summarizes the per capita of fresh water natural resources and shows the frightening values by the year 2025 for most of the Arab countries. The scarcity of water is very well appreciated in areas of no or very limited natural water resources as Gulf and North African countries. Most of these countries are arid desert with limited ground water supplies and dependable surface water sources. No rivers, streams or permanent fresh-water lakes. In addition, the rain fall is both scarce and infrequent and associated with high evaporation rate due to the harsh climatic conditions. These and other conditions, such as the difficulty of polluted water treatment, led to the decision of many governments on the region to adopt desalination as an alternative source of potable water for all major metropolitan areas.

Saline water desalination has already confirmed its potentiality to partially resolve the fresh water problem in numerous countries. According to IDA (International Desalination Association) inventory report [3], a world wide total of 13,600 desalination units of 25,909,000 m3/day have been installed or contracted in 120 countries around the world. The Arab countries (mainly, GCC) is the largest user of desalination technologies, with about 50 % of the world plants capacity. Saudi Arabia is the highest user of desalination with 21 % of the world capacity followed by Arab Emirates with 11.3 %, and Kuwait with 6.4 %. The main challenge is to produce fresh water at an acceptable cost as compared to other alternatives. Although it may seem to be more expensive in area of surface or ground water availability, it is not so in areas 300 – 500 km far from surface fresh water availability or of deep ground fresh water. For municipalities of large water demand, conventional desalination technologies as MSF, MED, RO, VC, etc. proved to be technically and economically suitable. For small communities living in remote areas (far from water and electricity network), renewable energy (RE) as solar/wind might be the only alternative for water and energy provision.

ADIRA PROJECT & COMPLEX DEVELOPMENT

1. ADIRA Project

ADIRA project (Autonomous desalination system concepts for sea water and brackish water in rural areas with renewable energies) aims at the development of optimum concepts for fresh water supply in rural areas derived from salty water (sea water and brackish water). Units powered by autonomous, renewable energy supply systems with fresh water output in the range of 100 Lit/day to 10 m³/day are in the focus of ADIRA project. Instead of development of new desalination technologies, the adaptation of existing concepts from various suppliers for the use with renewable energies is targeted by evaluation of the potential and the optimum solution. This will be implemented in areas of the countries involved in the project (Morocco, Egypt, Jordan, Cyprus and Turkey) taking into account the technical, economical, environmental, and organizational and the socio-technical and the socio-economic aspects. This integrated, multi-disciplinary and border crossing problem solving approach will contribute to the improvement of the sustainability of water management projects. The project is coordinated by Fraunhofer Institute for Solar Energy Systems (ISE), Germany.

2. Present Complex Development

The motivation for the present complex development arises from the fact that desert Land, Seawater, Solar and Wind Energies are all available and almost for free in many regions in Egypt (and other MENA countries). Lack of developments of small communities living in remote areas (as fishers, Bedouins, and tourists serving communities, for example) leads to their migration to the larger cities. This internal migration creates the crowd ness mass negative behaviour of increasing the percentage of un-employment, crimes and the pressure on utilities …etc. A basic question arises, could we develop a system to produce the basic needs of these small communities (as food, water, and electricity) for their sustainable development?. The answer should always YES. The system to be developed should be of simple, of well known, and available technologies, that could locally be developed, manufactured, operated and maintained. The system should also have positive impacts on the local society development as creating an area of investment and manufacturing as well as job creation.

COMPLEX DESCRIPTION

Fath & El-Shall [4] proposed the construction of a stand alone and integrated complex that can provide the community with the main life necessities; water, food, energy and salts. The proposed complexes utilize the abundant solar/wind energies for domestic water & salts production, electric power generation, and agriculture crops. The proposed autonomous and integrated complex presents, therefore, a new concept for supporting the sustainable development of small communities living in remote areas. The proposed complexes consists mainly of; Figure (1):-

(i) a set of solar stills with precipitation basins for fresh water and salts production.

(ii) a group of Photo Voltaic (PV) Panels and wind mill(s) for electricity generation, and,

(iii) a farm of greenhouses, partially self sufficient of irrigation water, for agriculture crops production,

Detailed description of the stand alone and integrated complex, proposed for ADIRA project in Egypt, can be summarized as follows:-

i- Set of Land Solar Stills with Salts Precipitation Basins

Background

Solar energy is the major un-depletable source of renewable energy. Egypt enjoys an abundant incidence of solar irradiation of 3000 – 3500 hours of sunshine per year and receive about 4-6 kWhr/m^2 per day. The annual mean of solar energy varies between 150 to 250 W/m^2.

Solar desalination presents a promising alternative, that can partially support the small community's needs for fresh water with renewable, free and environmentally friendly energy source. The development of solar desalination systems has demonstrated its suitability when the weather conditions are suitable and the demand is not too large (ADIRA target small population communities living in remote areas). The problem of the relative higher water production cost of solar desalination, over conventional energy, triggered scientists and engineers to investigate various means to improve the system productivity, reliability and thermal efficiency, in order to reduce water production cost. Detailed technical and economical assessment of direct solar desalination (solar stills) has been discussed by Fath and others [5-17]. At present, direct solar desalination may not economically challenge the lower cost of large conventional units. However, solar stills seem to be a competing alternative for; very small communities living in remote areas (far from water and electricity net work), of un available technical capability. Fath et. Al. [13] presented the cost calculations of 1.0 m^3/day of water production by the still farm and shows that 1.0 m^3 of water costs 9 $. However if the still cost is reduced to 20 $ (through mass production and cheaper material), the 1.0 m^3 fresh water will cost only 3.0 $, which is a challenging cost for very small desalination units. This cost could further be reduced for larger water production unit.

On the other hand, disposal of rejected brine is an integral part of the desalination process, and for inland desalination plants, this poses a serious challenge. There are several means of disposal handling that are practiced worldwide. Fath [6] summarizes the disposal options, their environmental concerns and possible mitigation methods. Another alternative is to process the brine in order to extract the dissolved salts (zero discharge solution). This has the advantages of being environmentally friendly and producing valuable commercial salts.

Recent large scale pilot trials and public demonstrations have confirmed the capabilities of the technology for the recovery of saleable chemical products, while achieving zero discharge. These chemical products have many application areas including; animal dietary needs, fire retardants, manufacture of magnesium metal, manufacture of light-weight and fire-proof plaster boards and other building products, manufacture of salt-tolerant building footing, wall panels and other construction products, various applications in food and chloral kali industries, applications in tanneries, production of quality paper products, manufacture of plastics, paints, ink and sealant products, soil conditioners for remediation of sodic and acidic soils, sealants for irrigation channels and earthen ponds, premium stabilisers for road base construction, flocculating agents for water/wastewater treatment, dust suppressant, Ahmed et. Al. [18]. In table salts industry, for example, the process is carried out in series of cascaded basins such that each basin is selected for the precipitation of one typical salt. The basins are divided into three groups; (i) the concentration basins, (ii) the crystallization basins, and (iii) sour brine basins. The crystallization process of salts production is carried out through different steps; (1) sedimentation of suspended solids and impurities, (2) sedimentation of Calcium carbonate and bi carbonate, (3) sedimentation of Calcium sulphate, (4) sedimentation of Sodium Chloride (Table Salts), and so on, Fath et. al. [19].

Set Description

A set of conventional and economical land solar stills will be used for fresh water and salts production using direct solar distillation. Distilled water is collected in the stills troughs and passed, by gravity, to the distilled water tank. The rate distilled water production will be designed for the production of 1 - 2 m^3/day, as the pilot complex target. This should satisfy the community basic demand of drinking water (after specification adjustments) and to supplement greenhouses irrigation water requirements. Different types of solar distillation system will be tested for technical and economical assessment. This includes; (a) the conventional single and double slopped basin stills, (b) humidification – dehumidification distillation system, and (c) newly developed “Tube Stills”.

The brine of these solar stills will be fed to a larger salts precipitation basins. Different chemical salts will precipitated in each basin so that the accumulated salts can be collected separately, after a scheduled period, and supplied to the corresponding industry as raw material, or partially used for animal feeding.

ii- Set of Photo Voltaic (PV) Panels and Wind Mill(s)

Background

Photo Voltaic (PV) panels (or solar cells as they are often referred to) are semi conductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays, can be used to charge batteries, operates motors, and to power a number of electrical loads. With the appropriate power conversion equipment, PV system can also produce AC compatible with any conventional appliances. PV panels are available in the market of different power sizes. As a rule of thumb, the cost of PV power is about 3.0 $/Wp. However, the PV power cost is reducing with time and 1.0 $/Wp is the target of manufacturers for the coming few years.

On the other hand, wind mills (or wind turbines) are devices that taps the inexhaustible, cheap renewable kinetic energy of blowing wind and convert it to useable mechanical or electrical energy. Wind mills have the advantage of it's technical availability and well developed and practiced in many countries. Egypt, for example, installed 65 MW wind power plants at Al-Zafaranah site, west of read sea, and can locally manufacturer small units. Some of wind mill disadvantages are the dependability of the site conditions and, as most of renewable energy, its not uniform and may needs energy storage system.

Set Description

Electrical power is required for driving the complex rotating and other components (as pumps, fans, lighting bulbs) and is also required for the small community basic needs (such as lighting, appliances -Radio/TV-, and summer fan). Photo Voltaic (PV) panels will be installed to generate 75 % of both the complex and community electrical power requirements, see complex component number (5) of Fig. (1). Similarly, more than one wind mills will be installed as a second electrical power generation system, for generating another 75% of both the complex and community requirements, see complex component number (6) of Fig. (1). A total of 150 % of the required power is installed.

Electrical Batteries system will also be used for electrical energy storage in order to smoothen the electricity supply and to guarantee continuous demand loads, in case of part of the PV or wind mills systems failure, malfunction, or being under maintenance, see complex component number (8) of Fig. (1). In case of larger electrical power demand, these power generation and storage systems can be expanded by adding more units.

iii- Farm of Greenhouse, partially self sufficient of irrigating water

Background

In hot and sunny desert regions, as in Egypt's summer, it is difficult to grow plants in the open field due to the harshness of land and climates and the high rate of irrigating water requirements. To overcome these difficulties, the use of agriculture greenhouses GH can provide a proper environment to plant growth and to conserve irrigating water. Use of GH has many advantages, as compared to open field cultivation, including; (i) off-season crops can be grown throughout the year, (ii) higher production per unit area, (iii) high value and high quality crops can be grawn, (iv) consumption of irrigating water and wastage of fertilizers and nuitrants is minimized, (v) infestation of pests and diseases is reduced, and (vi) suitability for tissue culture cultivation.

The successful operation of GH depends on maintaining the climatic conditions of the GH within specified desired range and the continuous supply of irrigating water. In areas of high solar intensity, however, the GH inside temperature can reach a high value that prevents its utilization or, otherwise, a costly mechanical air conditioning system should be used. Fath [19 to 22] proposed a system to decrease the greenhouse cooling load and utilize the surplus solar energy during the day for natural ventilation of the GH and irrigation water production. Fath [21], for example, proposed placing a group of saline water basins on the top of the GH roof for irrigation water production. Several solar stills GH combination has also been presented in literature see Malik et. Al. [17] and Radwan & Fath [23]. The suitability of such systems for remote areas arises from the fact that:- (i) Solar distillation can, in most cases, provide the rather modest demand of the greenhouse for fresh water (about 10 % of water requirement for irrigation in an open field). Thus, in remote areas where fresh water for irrigation is not available or costly to obtain, the GH-distillation system can partially support local agriculture activities. No water transport or storage are required since distillate can be fed directly into the GH (after fertilizers adjustments), (ii) The diurnal and seasonal fluctuation in solar distillation productivity are intrinsically linked to the fluctuating water demand, and (iii) Direct solar stills involve simple technology that does not need high technical capabilities for design, manufacturing, operation and maintenance,

Complex GH Farm

Three types of agriculture greenhouses can be used in the present complex, see Fig. (1);

- Type (1), Fig. (2), is a long term (glass/fibreglass/polycarbonate) type GH's, with roof solar distillation basins, for planting high cost value agriculture products. GH dimension of 12 m long, 6 m width, and 3.0 m height, with triangle roof of 30 degree from horizontal (to act as vapour condensing surface) is shown,
- Type (2), Fig. (3), is an economical polyethylene GH's, with roof solar distillation basins, for vegitables planting. GH dimension of 3.0 m wide and 1.0 m height and 3.0 m diameter half cylindrical dome is shown, and
- Type (3), Fig. (4), is also an economical polyethylene GH's, however, with land solar stills (and possibility salts concentration basins). This GH type suits plants growing in hot or hot/humid environment. GH dimension of 3.0 m diameter half cylindrical dome is shown. (*Note: GH dimensions will, however, be flexible to suits the market standard dimensions for cost reduction*).

For GH types (1) and (2), a group of transparent saline water basins are placed on the GH roofs to absorb the excess solar thermal energy, above that required for plants photosynthetic process for irrigating fresh water production using solar distillation. GH top covers will act as the vapor condensation surfaces. The roof basins will reduce the heat load on the greenhouse cavity and, therefore, reduce the ventilation/cooling requirements. It will also reduce the temperature of GH walls and land so that additional condensation of ventilation air vapour takes place on the colder surfaces for more irrigating fresh water production. The greenhouse could, therefore, be partially self sufficient of irrigating water.

iv- Supporting and auxiliary systems and components

The above main set of components (land stills, PV panels, wind mills, and GHs) needs additional supporting and auxiliary systems and components. For example, roof and land basins/stills require salty water feed, distillecwater, and brine drain systems. GH requires irrigation, ventilation and lighting systems. These systems requires many components such as pumps, fans, evaporative coolers pads, tanks, piping, valves, lambs, switches, …etc.. Electrical power generators (P.V. Panels & wind mills) require supporting systems and components as power rectifiers, stabilizers, electrical cables,..etc. Complex to surrounding community requires supply of water and electricity transmission systems with tanks, bottles, pumps, electrical cables, ….. etc.

The electrical auxiliary components (as batteries, spare parts and other storage inventory) are placed in the electrical service room, complex component number (7) of Fig. (1). Mechanical auxiliary components and spare parts are placed in the mechanical service room, number (9). A separate space will also be allocated for the complex operator(s) resting.

ECONOMICAL PRE-FEASIBILITY

For the proposed pilot complex installation, the economical pre-feasibility study, including capital cost, running cost and annual profit, will be summarized below.

i- Complex Capital Cost

The total capital cost of the proposed pilot complex is about 150,000 $. Table (1) shows the breakdown of the estimated complex capital cost. Details of this table calculations are given in Fath & El-Shall [4]. For complex average ten years life time and 0.0 % interest (owner is the investor or with government support), the annual payment is 15,000 $.

Table (1) Complex Capital Cost Break Down

No	Component	Total Cost ($)	Remarks
1	Greenhouses	32,400	
2	Solar Stills	45,000	
3	P.V. Pannels	25,800	
4	Wind Mills	9,000	
5	Battaries	4,600	
	Sub-Total	116,800	
6	Auxilaries	23,360	20 % of Sub-Total
	Total	**140,160**	**Take 150,000 $**
	Annual Payment	**15,000**	**10 years life time, 0.0% interest**

ii- <u>Complex Operation and Maintenance Costs</u>

The estimated Operation and Maintenance (O & M) cost of the complex is 17,800 $/year. Table (2) summarizes the O & M cost break-down of the complex main components

Table (2) Complex O & M Cost Break Down

No	Component	Annual Cost $/year	Remarks
1	Labor	10,800	3 operators x 300 $/month x 12 month
2	Energy	---	In house Generation
3	Spare Parts	2,000	Estimated*
4	Others	5,000	Chemicals, Fertilizers, cleaning materials, …etc
	Total Annual Payment	**17,800**	

* for example, GH polyethylene sheet replacement every 2-3 years, stills glass cover break, …etc.

iii- Complex Return Income

Table (3) shows the complex total annual payment while Table (4) shows the annual return from the complex main products.

Table (3) Complex Annual Running Cost

No	Component	Annual Cost $/year	Remarks
1	Capital Annual Payment	15,000	Table (1)
2	O & M Annual Payment	17800	Table (2)
	Total Annual Payment	**32,800**	

Table (4) Complex Annual Return Income[(a)]

No	Component	Annual Return	Remarks
1	Agriculture Products	32,400	
2	Water	27,375	
3	Electricity	1825	
4	Salts	2,393	
	Total Annual Income	**63,993**	**Say 63,000 $**

(a) Fath & El-Shall [4]

From Tables (3) and (4), the annual income is higher than the annual running cost. The difference is the annual profit.

Annual Profit = Annual Return – Annual Payment
= 63,000 $ - 32,800 $
= 30,200 $/year (say 30,000 $/year)

Pay Back Period = Capital cost / Annual Profit
= 150,000 ($) / 30,000 ($/year)
= 5 years

CONCLUSIONS

1- A stand alone and integrated complex that utilises the abundant solar/wind energies to produce water, food, energy and salts is presented. The proposed autonomous and integrated complex presents a new concept for supporting the sustainable development of small communities in remote areas.
2- The complex consists mainly of (i) a set of solar stills with precipitation basins for fresh water and salts production, (ii) a group of photovoltaic panels and wind mills for electricity generation and (iii) a farm of greenhouses, partially self sufficient of irrigation water, for food production.
3- The pilot complex will be installed at the North West coast of Egypt, for a small community village, suffering from water & energy shortages.
4- The paper presented the complex conceptual design and its economical pre-feasibility, which shows an annual profit is about 30,000 $ with project pay back period of 5 years. The profit can be increased and as the complex size increases or multi-complexes are constructed.

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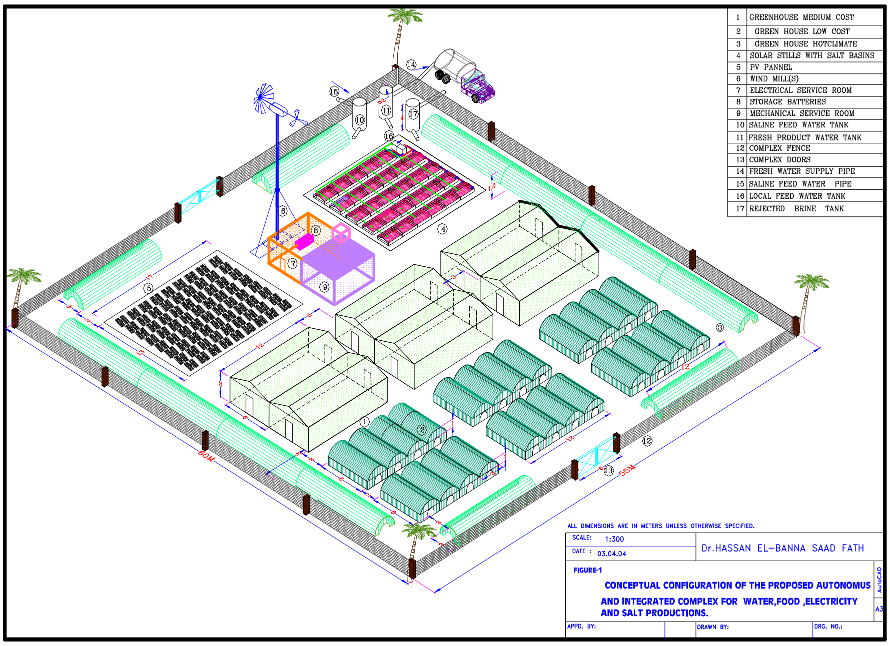

Fig (1) A Stand Alone Complex - Conceptual Design

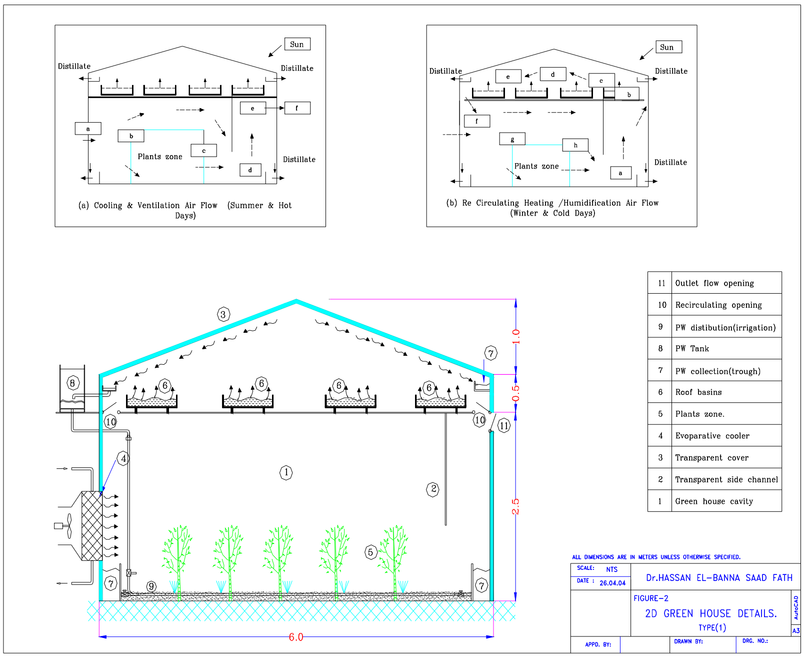

Fig (2) Type-1 GH with Roof Solar Basins

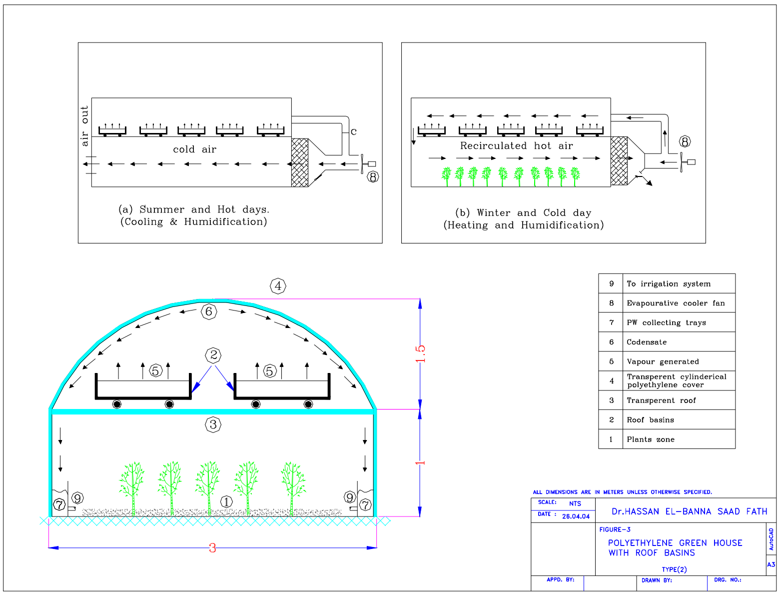

Fig (3) Type-2 Polyethylene GH with Roof Solar Basins

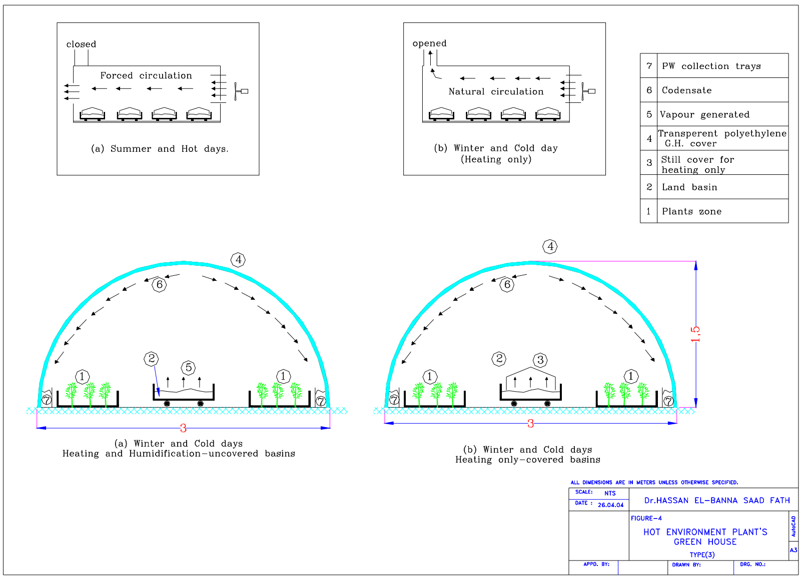

Fig (4) Type-3 Polyethylene GH with Floor Solar Stills