



## **INNOECOFOOD - Eco-innovative technologies for improved nutrition, sustainable production and marketing of agroecological food products in Africa**

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### **Deliverable D2.4**

#### **Design of innovative solar coolers and solar driers**

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## 1 Summary

The ECOHUBS in Ghana and Kenya will be equipped with a solar powered ice making machine and a solar multipurpose drier, each. The dimensioning of the equipment is resulting from the specific requirements and adjusted between the project partners. The energy demand of each application is analyzed, and the resulting energy supply is designed corresponding to the local situation. Photovoltaic for electricity production is considered as the simplest to install energy supply system, while providing heat for the drying processes is more challenging. Different approaches were followed for Ghana and Kenya: a solar thermal collector system will be installed in Ghana and heat pumps will be used in Kenya for heat production.

To support the farm to fork approach for fish and also spirulina production, chilling or drying processes will be used. Whole or filleted fish will be chilled using flake ice, produced with solar energy. The flake ice will be used to reduce spoilage and fish waste, either by local storage and/or to keep the cooling chain to the market.

Solar operation of the flake ice machine, which is an essential aspect, has a direct influence on the production capacity. Furthermore, different capacities were agreed upon the initiation of the project. Therefore, the ice production capacity in Ghana will be about 300 kg of flake ice within 8 h of operation per day and the capacity in Kenya will be about 650 kg for this operation time.

Following the specific demand and wish of the project partner CSIR-FRI in Ghana, the dryer will be split into a small dryer to be installed in the laboratory of CSIR-FRI and a large dryer to be installed at the ECOHUB. As the dryer manufactured and provided by the German partner INNOTECH consists of compartments, a scaling allows the split into one unit having  $\frac{1}{4}$  size and a large dryer with the  $\frac{3}{4}$  size. The dryer for the laboratory will be equipped with an electric heating while the dryer at the ECOHUB will be supplied with solar thermal heat from a solar thermal collector field.

The report of Deliverable D2.4 gives an overview on the applied technologies: the solar powered flake ice production, the multi-purpose dryer of the company INNOTECH and the dryer of the company SPARKY. Furthermore, the different energy production systems are analyzed and evaluated with specific regard to the local boundary conditions.

The report has been elaborated with contributions from:

- Alexander Morgenstern from the company Fraunhofer ISE
- Lawrence Eketayot from the company Sparky
- Albert Esper and Philipp Schüle from the company Innotech Ingenieursgesellschaft mbH
- Arnd Pietrzak from the company Asantys

## 2 Objective

One of INNOECOFOOD's aims is to establish innovative ECOHUBS with novel cooling and drying processes using renewable energies. The processes and technologies used help to optimize the production of eco-farmed fish, spirulina and insects, sustainable feeds and post-harvest processing.

The following aspects are considered and described:

- Solar production of flake ice using
- Innovative solar dryers



- Sustainable energy supply for heat (and electricity)

## 3 Solar production of flake ice

### 3.1 Technical solutions in general

In general, a solar operation of ice machines leads to different technical challenges which are usually not considered or do not appear if the machines are grid connected. One of the main issues is the high inrush current of the compressor of the ice machine when started. Values of up to 10 times of the nominal current can be measured. Furthermore, energy supply based on the sun strongly depends on the weather and the potential production capacity changes over the day. Therefore, oversizing of the photovoltaic (PV) systems helps to provide energy even during times with lower sunshine, but unfortunately not for each situation. The integration of batteries allows short term store of surplus of energy for weak production times. But most of the problems cannot be solved successfully without a modification of the control of the ice machine. Different system configurations and operation strategies are possible: direct solar operation, indirect solar operation and hybrid solar and grid powered operation.

Direct solar operation:

- Features
  - Off grid system
  - PV system with about double the electric capacity of the capacity of the ice machine
  - The ice machine is directly coupled on the direct current (DC) side
  - The ice machine has a build in control which allows the adaption of the operation frequency of the compressor and other mechanical components modifying the capacity following the solar energy production during the day
- Advantages
  - No solar inverters and not grid connection is required which leads to overall reduced system cost
  - Improved sustainability because of no included batteries, which have high prices and the shortest lifetime compared to the other components
  - High inrush current can be avoided or significantly reduced
  - Independent from the availability of an electricity grid and electricity shortages (black outs)
- Disadvantages
  - The ice production capacity is limited by the availability of solar energy and therefore limited to daytime and sunshine

Indirect solar operation:

- Features
  - Off grid system
  - PV system with solar inverters and batteries, providing a local 3-phase grid
- Advantages
  - Ice machine can be used without modification
  - The operation time can start earlier in the morning and be expanded into the evening depending on the battery size and the energy stored which leads to higher ice production capacity
  - Independent from the availability of an electricity grid and electricity shortages (black outs)
- Disadvantages
  - Depending on the configuration of the PV system already slight imbalances in the PV production in the strings can lead to an unequal phase generation and stop of the machine by the phase detection system
  - High inrush current can lead to system overload, if not oversized



- High system cost due to complexity and high number of system components

Hybrid configuration of PV and grid connection:

- Features
  - System as combination of PV and grid connection
- Advantages
  - In principle 24 h production possible
  - Reduced or no demand of power from grid during daytime
  - Machine start with support from grid possible
  - Feed of energy surplus into grid possible, but depends on the acceptance by the local energy provider
  - Lower system cost compared to the above mentioned solar off grid systems
  - Independency from weather and/or times with low energy production
- Disadvantages
  - Dependency from grid and rising electricity prices
  - Risk of lower production capacity production capacity if availability of grid fails

### 3.1.1 Specific situation in Kenya

Resulting from an evaluation of the demand for ice, carried out by the partner KMFRI during the elaboration of the project proposal and afterwards it turned out that a daily amount of about 650 kg ice should fit the local requirements at the ECOHUB. A daily operation time of about 8 hours with sunshine and therefore, energy provided by the PV system during this time, the required flake ice machine would have a production capacity of 2 tons related to 24 hours of operation. In general, the small flake ice machines are typically classified into 1 ton and 2 tons machines. It is considered that a 2 tons machine has an electric power demand of about 10 kW. This leads to the following technical requirements on the PV system, if the machine is powered directly solar:

#### Required PV system:

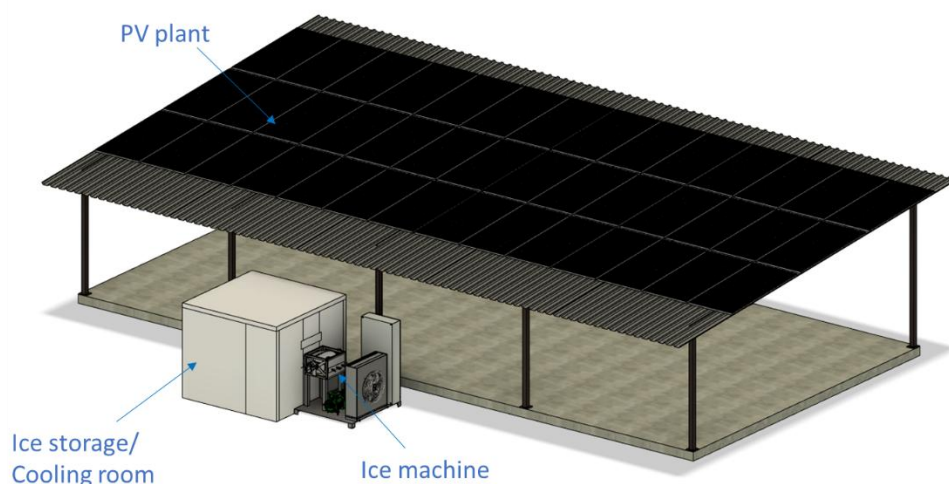
- 3 Strings with 13 solar modules each (resulting to together 39 modules)
- 580 Wp per module, minimum, (all PV modules have to fulfill Tier1)
- 38,0V MPP voltage, minimum
- Resulting to a PV system with 22.6 kWp with required voltage range of 520-540 V DC
- Additionally, a combiner box and DC circuit breakers needs to be installed

In the case of no PV system or as alternative solution (e.g. for night mode) a connection to the public grid is required with the following specifications:

- Grid electricity, 3-phase, 32 A, 400 V, 50 Hz

The following has to be noted: Beside the technical specifications, the water supply to the ice machine needs to fulfill the high hygienic requirements for drinking water.

Based on the first assumptions and discussions, a proposal for the setup of the power supply for the flake ice machine has been elaborated and is shown in Figure 1. If anyhow possible, the flake ice machine as well as the ice storage room should be placed in a shaded place to lower the energy demand by a higher efficiency in colder environment and reduce the thermal influence of the sun and to avoid accelerated melting of the ice.



**Figure 1.** Proposal for the setup of a flake ice machine with ice storage room and electricity supply via PV system nearby [PS2024].

### 3.1.2 Specific situation in Ghana

Resulting from an evaluation of the demand for ice, carried out by the project partners during the elaboration of the project proposal and afterwards it turned out that a daily amount of about 300 kg ice should fit the local requirements at the ECOHUB. A daily operation time of about 8 hours with sunshine and therefore, energy provided by the PV system during this time, the required flake ice machine would have a production capacity of 1 ton related to 24 hours of operation. It is considered that a 1 ton machine has an electric power demand of about 6 kW. This leads to the following technical requirements on the PV system, if the machine is powered directly solar:

#### Required PV system:

- 2 Strings with 13 solar modules each (resulting to together 26 modules)
- 580 Wp per module, minimum, (all PV modules have to fulfill Tier1)
- 38,0V MPP voltage, minimum
- Resulting to a PV system with 14.56 kWp with required voltage range of 520-540 V DC
- Additionally, a combiner box and DC circuit breakers needs to be installed

In the case of no PV system or as alternative solution (e.g. for night mode) a connection to the public grid is required with the following specifications:

- Grid electricity, 3-phase, 16 A, 400 V, 50 Hz

The following has to be noted: Beside the technical specifications, the water supply to the ice machine needs to fulfill the high hygienic requirements for drinking water.

## 4 Drying systems to be realized within the project

In this chapter, the different concepts of the dryers in the project are considered and described at first. Afterwards, heat supply concepts are analyzed, and pros and cons of the different technologies are described.

Usually, drying systems are classified following the construction type and the heat supply concept:

### System concept

- Solar tunnel dryer
- Cabinet dryer

### Heat supply concepts

- Direct solar
- Indirect solar or alternative

### 4.1 Sparky Smart Solar Dryer

The following information on the Sparky Smart Solar Dryer was provided by Lawrence Okettayot from the company Sparky [LO2025] (Figures 2 and 3).

The Smart Solar Dryer is an energy-efficient, IoT-integrated drying system designed to reduce postharvest losses and improve the quality of dried agricultural produce in rural and off-grid communities. Traditional solar drying methods often suffer from inconsistent drying, contamination, and vulnerability to weather conditions. This innovative dryer addresses these limitations by combining natural solar heating with automated climate control, night-time thermal support, and real-time monitoring. The system uses a dome-shaped structure covered with UV-treated polycarbonate sheet for passive heat collection, reinforced by a solar-powered electrical system that drives DC fans, temperature/humidity sensors, and night-time silicone heating elements. The drying process is continuously monitored using an ESP32 microcontroller with GSM communication, transmitting data to an online dashboard for analysis and optimization. This approach enhances drying speed, product safety, energy efficiency, and scalability, making it ideal for use by farmer cooperatives, agro-processors, and institutions working to improve food security and value addition.

#### 4.1.1 Detailed Description of the Smart Solar Dryer Structural Design

The dryer structure measures 3 meters in length, 2 meters in width, and 2.5 meters in height at its highest point. It adopts a dome or tunnel-shaped profile to enhance passive solar heating and promote natural airflow. The frame is built using RHS steel sections (42×1.2mm and 32×1.2mm) for strength and durability, and it is covered with UV-treated greenhouse polythene, which is more affordable and thermally efficient compared to polycarbonate.

The floor is constructed with compacted earth layered with sand, concrete, and finally 30cm × 30cm clay tiles, which retain solar heat during the day and slowly release it during cooler hours to maintain a stable drying temperature.

#### 4.1.2 Drying Capacity and Tray System

The interior houses 10 drying racks, 5 on each side of a central walkway. The trays measure approximately 1.3m × 1.2m and are made from 20×20×1.2mm RHS steel frames fitted with coffee tray food-grade mesh for safe and efficient airflow.

At full capacity, the dryer can process up to 100 kg of fresh produce, including fruits, vegetables, and fish.



### 4.1.3 Power System and Energy Storage

The Smart Solar Dryer is powered by an integrated off-grid solar system:

- 4 × 600W mono-crystalline solar panels (2.4 kW )
- 4 × 12V 200Ah lithium batteries (LiFePO<sub>4</sub>) configured into a 48V, 200Ah battery bank (9.6kWh total storage)
- 120A MPPT charge controller (PV max input: 200V)

This setup ensures full system autonomy, enabling day and night operation with minimal maintenance.

### 4.1.4 Active Heating and Ventilation

To maintain consistent drying conditions:

- 4 industrial 12V DC fans (30cm × 30cm) are installed, 2 as air inlets and 2 as exhausts to regulate internal airflow.
- 10 silicone rubber heaters (180W each, 12V) are installed under the trays and powered from the battery bank at night. These maintain internal temperatures between 35°C and 45°C when solar radiation is insufficient.

### 4.1.5 IoT and Automation

The Smart Dryer integrates advanced monitoring and automation features:

- ESP32 GSM-enabled microcontroller (A7670G) controls the fans and heaters.
- DHT22 sensors (two inside, one outside) continuously monitor temperature and humidity.
- The system uses reinforcement learning logic to adjust fan speed based on real-time conditions.
- All data is sent to the ThingSpeak cloud platform, allowing remote monitoring and performance tracking via dashboard.

### 4.1.6 Key Results & Performance

- Maintains drying temperatures of 45–60°C (day) and 35–45°C (night)
- 30–40% faster drying time compared to traditional systems
- Supports continuous 24-hour drying
- Internal climate is automatically regulated for optimal drying efficiency
- Real-time monitoring improves data visibility, performance analysis, and troubleshooting

### 4.1.7 Innovative Features

- Hybrid solar + electric drying system for all-weather reliability
- IoT-based monitoring and control with GSM communication
- Fan automation using reinforcement logic for airflow optimization
- Night drying enabled by silicone heaters powered by solar-charged battery bank
- Structural design supports modular scaling, easy repair, and cost efficiency
- Designed for low-cost construction using locally available materials



*Figure 2. Photos of the Sparky Smart Solar Dryer [LO2025].*



*Figure 3. Photos of the Sparky Smart Solar Dryer with PV panels and fans for ventilation [LO2025].*

## 4.2 Multi-Purpose Dryer from Innotech

The following information on the Multi-Purpose Dryer was provided by the project partner Innotech [PS2025] (Figure 4).

### 4.2.1 Innovative drying concept

The drying process is a fundamental component of the value chain in an ECOHUB. In addition to aquaculture catfish and tilapia, spirulina and insects must also be dried as efficiently as possible under optimal conditions to produce a high-quality product. The prerequisite for this is an innovative drying concept that enables flexible operation of the drying facility, while simultaneously consuming minimal resources and creating optimal conditions for the drying process. Within the project, the same dryer concepts are being developed for the Kenya and Ghana sites, although they differ in their capacity.

#### 4.2.1.1 Flexible Operation

The use of different dryers for each specific product is not economically viable, so a concept was developed that enables the simple processing and drying of all products. The use of trolleys, into which the trays are later inserted, offers several advantages for flexible operation and handling. The trolley can be transported to the various processing sites for each product and loaded directly with the respective product there. Furthermore, the use of a removable trolley enables easy cleaning, which is particularly important when handling different products, allowing a high level of hygiene and quality to be maintained with minimal effort. In addition to the trolley, the entire dryer must also be easy to clean for flexible operation, which is also taken into account during the dryer's development.

Depending on the product type and the current product volume, more or less drying space is required for a drying process. Therefore, the dryers are designed so that only individual sections or modules of the dryer can be specifically activated for drying, thus significantly saving resources. The flexible control system and modular design of the dryer could also be used to dry two different products simultaneously under different conditions.

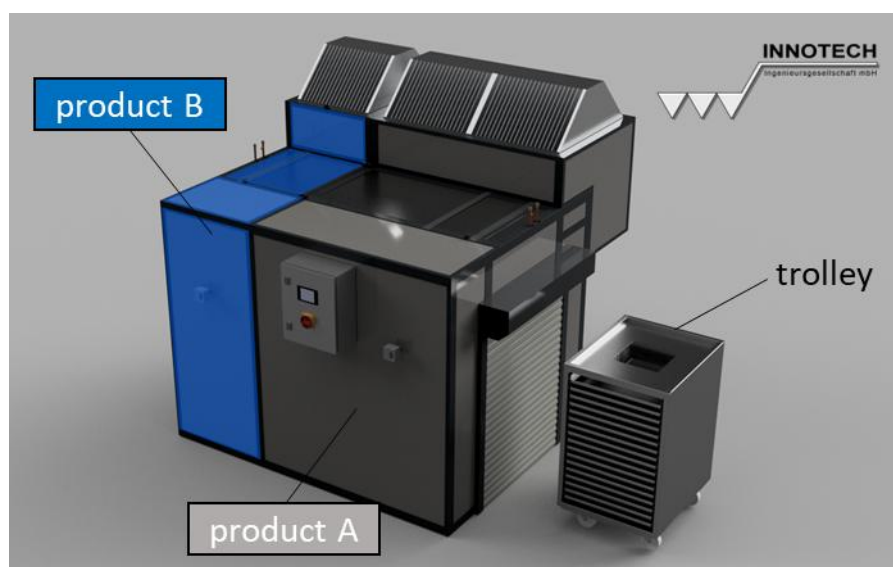


Figure 4. Design of the multi-purpose dryer (HWT3) in Ghana [PS2025].

#### 4.2.1.2 Energy efficient system

Due to the high investment costs of renewable energies, efficient operation of the dryers is essential to ensure cost-effective operation. In addition to the thermal energy required for drying, the electrical energy required for air circulation is also crucial for energy consumption. The dryer is therefore designed using flow analyses to achieve low air pressure loss. The use of controllable and efficient axial fans also ensures low energy consumption.

Thermal energy consumption accounts for the largest share of the total energy required for drying, accounting for over 90%. While sufficient solar energy is usually available for drying during the day on sunny days, it is particularly important at night to reduce energy consumption sufficiently so that the drying process can continue smoothly. The heat recovery unit with a cross-flow heat exchanger built into the dryer ensures energy savings of up to 30% compared to traditional solar dryers, as the energy in the warm exhaust air is reused.

#### 4.2.1.3 Optimized drying

With the help of intelligent control and monitoring, energy consumption can be significantly reduced, especially during periods of low energy availability, such as cloudy days or at night, through optimal humidity and temperature control, as well as air flow control. The dryer also features high-quality sensors (temperature sensors, humidity sensors, etc.) that enable precise online data recording of the drying process and make it traceable, allowing it to be continuously optimized at any time (Figure 5).

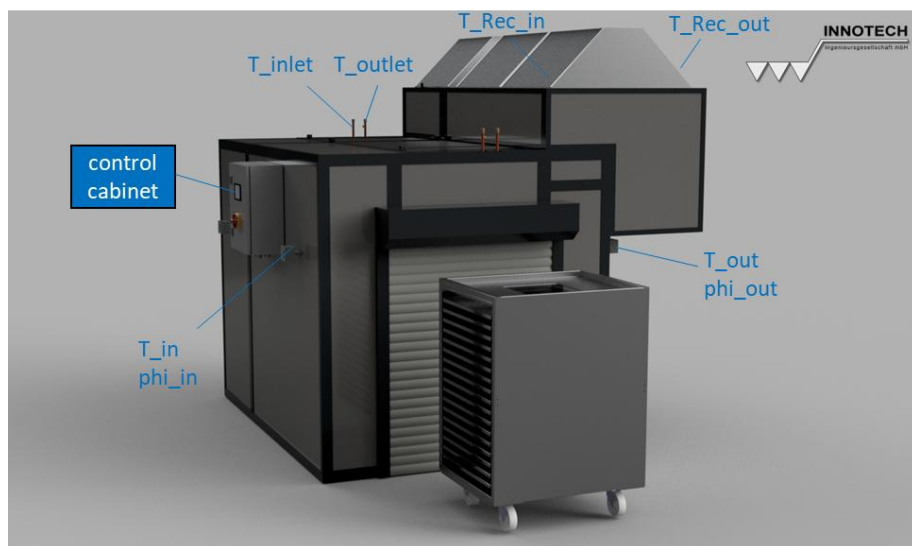


Figure 5. System of control and data acquisition (sensors) [PS2025].

The temperature and humidity sensors upstream and downstream of the product ( $T_{in/out}$ ,  $\phi_{in/out}$ ), together with the volume flow, which is determined using the characteristic curve and speed of the axial fans, enable air-side balancing of the drying process. The sensors also serve to regulate the drying process according to various control variables, such as temperature, humidity, water content, and specific energy consumption. The amount of thermal energy used for the drying process can also be determined directly via the water-side balancing of the installed air-water heat exchanger. For this purpose, the  $T_{inlet}/T_{outlet}$  temperature sensors are attached to the heat exchanger together with a waterflow meter.

The measured values are recorded and controlled by a Jumo PLC installed in the control cabinet. This PLC controls all components involved in the drying process, such as fan speeds, circulation pump performance, hydraulic valves, recirculation dampers and heat pumps.

Central storage of the data in a shared database also enables the use of AI-based control concepts. Depending on the respective framework conditions such as drying progress, product or ambient conditions, it is then possible to intervene specifically in the drying process and optimize it in terms of efficiency, product quality or speed.

#### 4.2.2 Locations for HWT drying concept

The HWT dryer concept presented here will be used in both Ghana (region of Accra) and Kenya (region of Siaya) ECOHUBS. The systems at each location differ slightly in terms of design and energy source, which will be explained in more detail below.

##### ECOHUB Ghana (HWT3)

The HWT3 dryer comprises a total of three trolleys with a total drying area of 24.5 m<sup>2</sup>. Each trolley can accommodate 17 stainless steel trays, each measuring 800x600 mm and spaced 50 mm apart. The dryer consists of two units (a double unit and a single unit), which can be separately controlled and regulated. For efficient operation, all units are equipped with a recuperator that allows the ambient air to be preheated using the moist exhaust air. To generate an air flow of up to 60-65 °C, each unit uses an air-water heat exchanger, which is supplied by a 4000 L buffer tank. The tank is coupled with an 80 m<sup>2</sup> solar thermal system (24 kW) and is designed to operate the dryer entirely with solar energy (Figure 6).

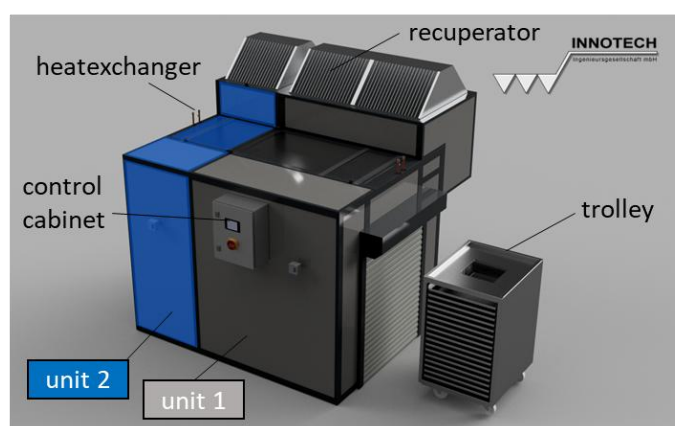


Figure 6. Components of HWT3 dryer in ECOHUB Ghana [PS2025].

The maximum electrical requirement is specified as 2,5 kW (Table 1). In addition to the fans, this also includes the electrical power for all other electrical components such as actuators, control valves, pumps, and the control unit.

Table 1. Parameters of the HWT3.

Dimensions dryer (L*W*H)	2,6*2,7*2,5 m
Number of trolleys	3
Drying area	24,5 m <sup>2</sup>
Heating-system	Solar thermal water heaters, 24 kW (80m <sup>2</sup> )
Total electrical power demand	2,5 kW

For a purely solar supply of the electrical components, a PV system with 5 kWp and 5 kWh of electrical storage is suitable, or these should be provided as resources by the overall PV system of the ECOHUB.

### Ghana laboratory (HWT1)

At CSIR-FRI in Accra, Ghana a single dryer unit is being set up with a trolley. Unlike the dryer installed in the ECOHUB, this one has a purely electric heating element, eliminating components such as circulation pumps, storage tanks, and valves in this system. The dryer is equipped with the same measurement technology, allowing the data obtained to be compared (Figure 7, Table 2).

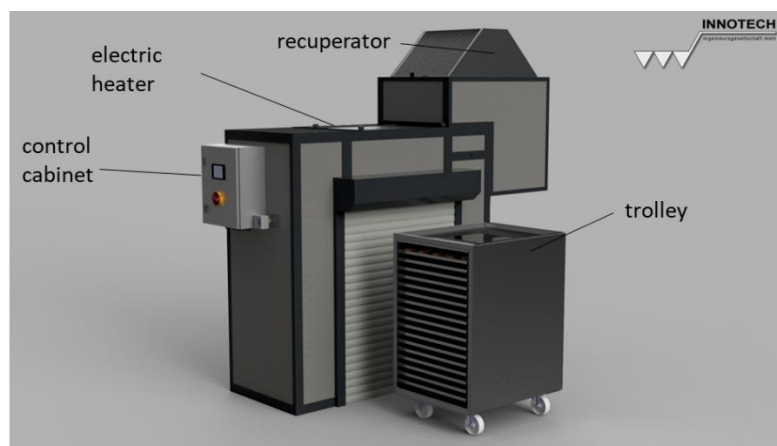


Figure 7. Design of HWT1 dryer in laboratory Ghana [PS2025].

Table 2. Parameters of the HWT1.

Dimensions dryer (L*W*H)	2,6*1,1*2,5 m
Number of trolleys	1
Drying area	8,2 m <sup>2</sup>
Heating-system	Electric heater, 10 kW
Total electrical power demand	11 kW

### ECOHUB Kenya (HWT2\_plus)

The HWT2\_plus dryer will be installed at the ECOHUB in Siaya, Kenya. Unlike the HWT3 (ECOHUB Ghana), it consists of two separate tall units, each of which can be controlled and operated separately. Due to higher capacity of a trolley (30 trays per trolley), the dryer's dimensions are also larger in height and width (Figure 8).

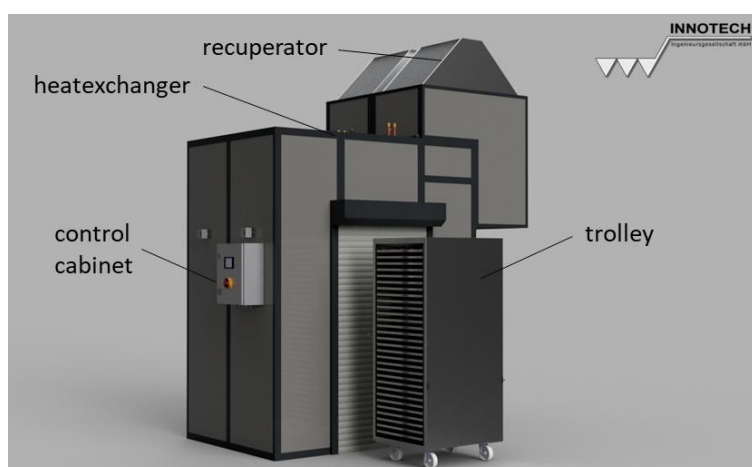


Figure 8. Design of HWT2\_plus dryer in ECOHUB Kenya [PS2025].

Each unit is equipped with an air-to-water heat exchanger connected to a 4000-liter storage tank. The hot water required for drying in the buffer tank is produced by two heat pumps, each with a thermal output of 16 kW (Table 3).

**Table 3.** Parameters of the HWT2\_plus.

Dimensions dryer (L*W*H)	3,1*1,5*3,7 m
Number of trolleys	2
Drying area	28,8 m <sup>2</sup>
Heating-system	Heat pump (2*16 kW)
Total electrical power demand	9,5 kW

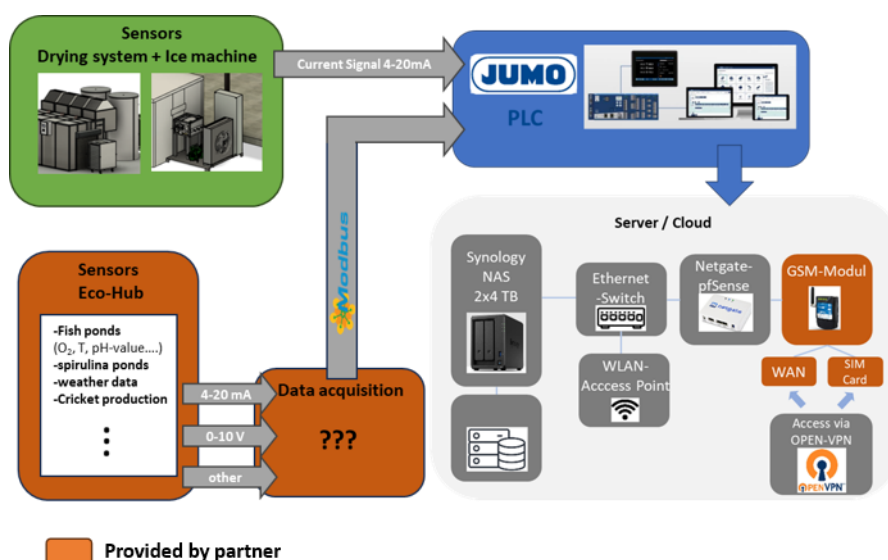
A purely solar-powered system requires an installed PV capacity of 15 kWp with a 10 kWh electrical storage system. A variable-speed heat pump also offers the advantage of being able to generate hot water at lower power levels during periods of low solar yield, thus conserving battery resources.

### 4.2.3 Data acquisition

A separate data acquisition and processing system will be set up for each dryer. All sensor and process data generated during drying will be stored by the Jumo PLC on a local Synology server in a MariaDB database. The system is designed so that data from other systems in the ECOHUBS and Living Labs can also be stored on the servers using various IoT protocols.

A GSM module enables communication with the other locations. A VPN solution allows all authorized project partners to query and process the data. Furthermore, remote operation of the dryers and the sending of notifications and warnings to users are possible.

Using a dedicated local server offers several advantages over a commercial cloud solution: The consortium retains control over the data generated in the project and its data protection measures. There are also no ongoing costs that could burden the ECOHUBS in the future. Furthermore, a dedicated system guarantees complete freedom over the software used. Data from different areas of the ECOHUB can be easily combined and used to train AI models because they can be stored centrally and uniformly (Figure 9).



**Figure 9.** Overview of the data collection concept in the ECOHUBS [PS2025].

## 5 Heat production systems for drying applications – a comparison of the technologies

Drying is a preservation method that removes water from food to extend its shelf life. By extracting moisture, the growth of microorganisms such as bacteria, yeasts, and molds is inhibited. At the same time, it preserves taste, color, and nutrients as much as possible. Furthermore, the drying process reduces weight and volume which is advantageous for easier storage and transportation.

Within the project, only the hot air-drying method is used:

- Warm air is passed over the goods to absorb and carry away moisture.
- Typical temperatures range between 40–80 °C.

In the hot air-drying method heat is applied to goods in the following way and with the following results:

- Warm air flows over or through the food.
- The heat transfers from the air to the food's surface.
- This increases the temperature of the food, supplying energy for evaporation.
- The warm, moisture-laden air is constantly removed to maintain a moisture gradient, speeding up drying.

The choice of heat source and temperature depends on the type of food and desired drying speed and quality.

In the following, a comparison and evaluation of different heat production systems is carried out to derive the best and most reliable solution for the heat supply for the dryers in Kenya and Ghana.

From the technical side, different options exist for the heat production at a temperature level of 70°C for about 10 h per day and around the whole year.

### 5.1 Evaluation of options for heat supply using renewable energy sources

#### 5.1.1 Heat pumps in combination with photovoltaic (PV) electricity supply

- Advantages
  - Relatively cheap components for the PV installation
  - Moderate prices for the heat pumps
  - All components are market available in Kenya and even in Ghana (e.g.: <https://daisyheatpumps.com/why-heat-pumps/>)
  - The installation know-how and the maintenance / service are meanwhile available in Kenya, but mainly limited to the capital only. In case of installation or maintenance requests technicians have to travel to the specific locations
  - Typical refrigerants are mainly available in Kenya and refilling for maintenance is possible
- Disadvantages
  - Especially, for the heat pumps regular maintenance is required, especially for cleaning/dust removal from heat exchanger.
  - Most locally available heat pumps still use traditional refrigerant with a high GWP, the use of R290 (propane) as refrigerant is not yet common in general, but the numbers are slowly increasing

#### 5.1.2 Solar thermal hot water systems

- Advantages
  - Worldwide used, available and well-known technology
  - High efficiency in use of solar heat for direct water heating



- No conversion losses and direct storage of heat
- Disadvantages
  - Complex hydraulic installation effort
  - Drain back systems required for stagnation safe installation
    - increased installation effort and not common in every region/country
    - stagnation would lead to high thermal stress because of system overheating and therewith to an accelerated aging of components
  - large systems not common so far in Kenya (Africa), without small solar hot water heaters (thermosyphon systems)
    - Nearly no providers of large collector systems (without <https://krystalsolutionsea.com/the-best-solar-heating-systems-in-kenya/>) and maintenance is not guaranteed
    - Import from Europe would be required

Situation in Ghana: Only a few companies are offering solar thermal collector systems in Ghana. The call for tender resulted in one quotation only.

### 5.1.3 Solar air collectors

- Advantages
  - Simple components: flat plate or evacuated tube collectors
  - Stagnation safe
  - No refilling required
  - Small leakages in the air circuit do not influence the efficiency
- Disadvantages
  - Heat transfer to water as storage operation medium for dryer required
  - Short air channels required to avoid heat losses
  - Dust soiling of air collectors may raise problems after longtime operation, therefore enhanced filtering of the air is required
  - Systems not common in Africa, no local providers found in Kenya or Ghana
    - Import from Europe would be required

### 5.1.4 Hydrogen-fuel cell

- Advantages
  - Production of electricity and heat at the same time
- Disadvantages
  - Over innovative, not for rural applications
  - Fuel cells mainly developed for power production, waste heat is by-product
    - Relation of power production to heat production about 1:2
  - Hydrogen-supply infrastructure in Africa not realistic within the project time
    - Local electrolyzer expensive, neither broad market availability in Europe nor in Africa, any technical support in Africa is not realistic
  - Low conversion factor for the whole chain: PV – electrolyzer – fuel cell – electricity
  - Safety regulations and safe behavior in Africa might raise problems. A realistic evaluation of the safety risks is not possible.
  - Regularly maintenance is required
- Further information as calculation example:

- A team of researchers has analyzed the energy demand to provide the heat for heating a single-family house with a hydrogen fuel cell, in the framework of the German project “Norddeutsches Reallabor”, assuming a yearly heat demand of 40.000 kWh. To produce the therefore required amount of hydrogen a yearly electricity demand of 67.000 kWh is required. In comparison, a heat pump requires 12.000 kWh of electricity [HP2024].
- In comparison, a drying process with an annual heat demand of 52000 kWh (operation 52 weeks and 5 days the week) would lead to about 87.000 kWh electricity for hydrogen production only.
- The therefore required PV system to provide the electricity corresponding for the production of the hydrogen for the fuel cell would need an 8.8-times larger area compared to a system using PV in combination with a heat pump.

Resume:

Applying a hydrogen-based fuel cell system for the ECOHUBS in Kenya and Ghana is not recommended for different reasons, especially because of the so far too low efficiency compared to a system with heat pump which uses about 80% of environmental energy for the heat production, especially under the boundary conditions in Africa. Furthermore, hydrogen fuel cells so far need regularly maintenance, and a hydrogen infrastructure is also not available. To guarantee a sustainable, reliable and long-lasting heat and power supply for the drying system at the ECOHUBS technical solutions available locally should be applied.

5.1.5 Optional consideration: Could be a photovoltaic PV system in combination with a heating rod be an alternative solution?

- Advantages
  - Simple concept
  - Cheap components
  - Components market available in Kenya
  - Installation, Maintenance / service in Africa available
- Disadvantages
  - A 3 to 4 times larger PV area compared to PV with heat pump would be needed because of no use of environmental energy which leads at the end to a significant higher material demand and is therefore less sustainable

## 5.2 Concept development for the ECOHUBS in Kenya and Ghana

The installation sites in Kenya and Ghana are not laying at the same latitude, but very similar in relation to the equator. A similar available solar radiation is expected. After discussion with the project partner INNOTECH and manufacturer of the multi-purpose dryer, it has been jointly decided to prioritize a solar thermal collector system for the heat supply at the ECOHUB in Ghana and a heat supply solution based on heat pumps for the ECOHUB in Kenya, which are mainly supplied with electricity from the locally installed PV system. The installation of two different heat supply systems in the two ECOHUBS will allow a comparison of the system performance and an evaluation of both concepts against each other.

### 5.2.1 System concept for the ECOHUB in Ghana

The dryer to be installed in Accra, Ghana has an energy demand of 24 kW at a temperature level of 65 to 70°C. In average it will be operated 10 hours per day and 25 days each month. This results in a monthly heat demand of 6000 kWh and the yearly heat demand of 72.000 kWh. A solar thermal system combined with a hot water storage tank is analyzed against this demand.

#### 5.2.1.1 System Specifications

The system consists of 40 flat-plate collectors, each having a gross area of 2 m<sup>2</sup>. Excluding the frame, casing and other construction elements the net absorber area of each collector is around 1.8 m<sup>2</sup>. For maximum efficiency, the tilt angle is set to 5 degrees, and the storage tank has a volume of 4000 L.

Polysun software was used to evaluate the performance of the proposed system. To allow setting up a simulation model of a solar thermal system a simplified system concept has been used corresponding to the schematic in the Figure 10. Instead of a dryer a “consumption” of hot water at 60°C is implemented in the simulation model, having a corresponding flow rate. The return temperature is assumed to be at about room temperature.

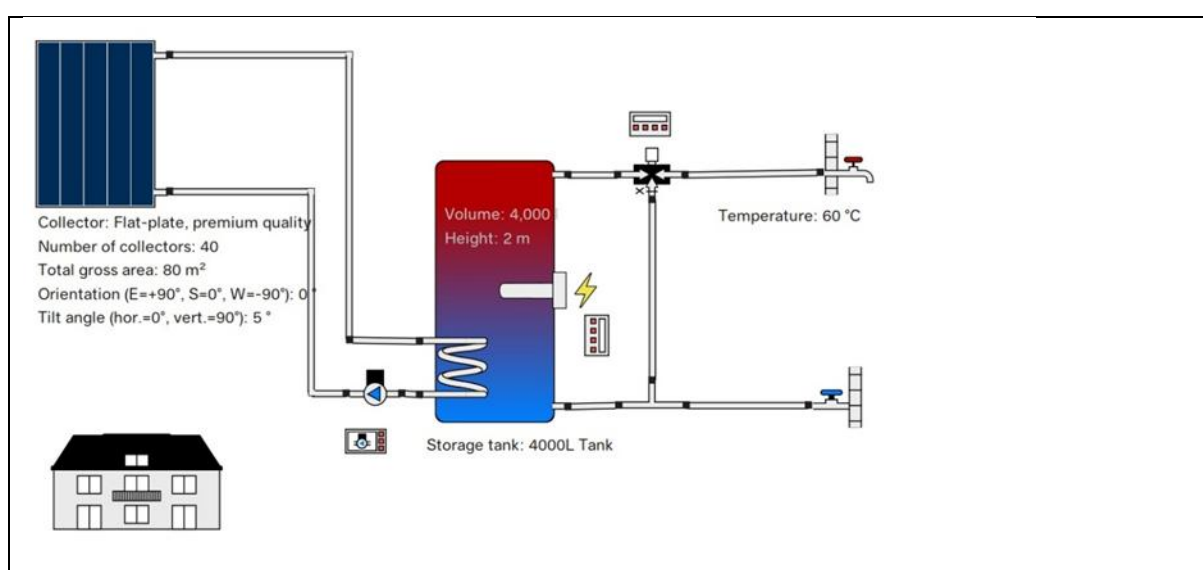


Figure 10. Simplified system concept of a solar thermal system, used for the simulation analysis.

### 5.2.1.2 Performance Analysis

After running the simulation, the useful heat delivered by the system (Qsol) results to 71.444 kWh per year. The total yearly irradiation onto the collector is 131.591 kWh. An efficiency of 54 percent is assumed for the collectors.

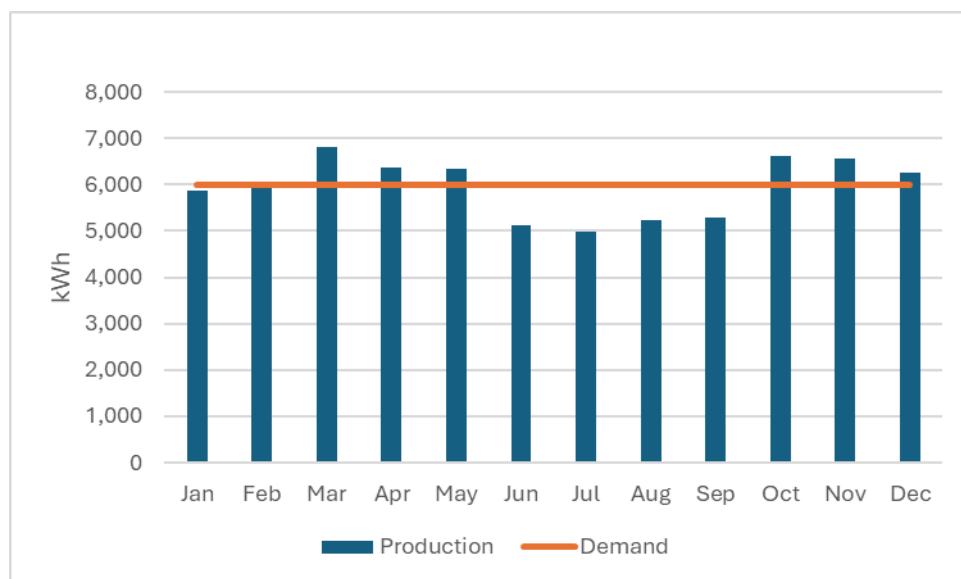


Figure 11. Monthly demand and energy production of the solar thermal system in Ghana.

The simulation results show that for the majority of the months the system can effectively meet the monthly heat demand of 6000 kWh (Figure 11). However, from June to September, there is a slight decrease in the production, which can be attributed to reduced solar irradiation due to the rainy season and increased cloud covers.

### 5.2.1.3 Conclusion and Recommendations

While adding more collectors could cover the decrease, this would incur additional costs and require more space for the collector system. Also, there will be a wastage of surplus energy in the remaining months. During the rainy season, to align with the heat production level, an adaption of the schedule for using the dryer or at a slightly lower temperature could be an option.

The proposed solar thermal system with 40 collectors is the optimal design to meet the requirements without causing a significant financial burden. This solution supports sustainable practices while fulfilling the energy demand.

### 5.2.1.4 Evaluation of roof mounted vs. ground mounted solar thermal collector system

The installation of solar collectors on the roof of buildings requires a specific structure and strength of the roof. This and the following aspects had been discussed with the installation company GNP Engineering Services in Ghana.

Roof mounted systems:

- Advantages

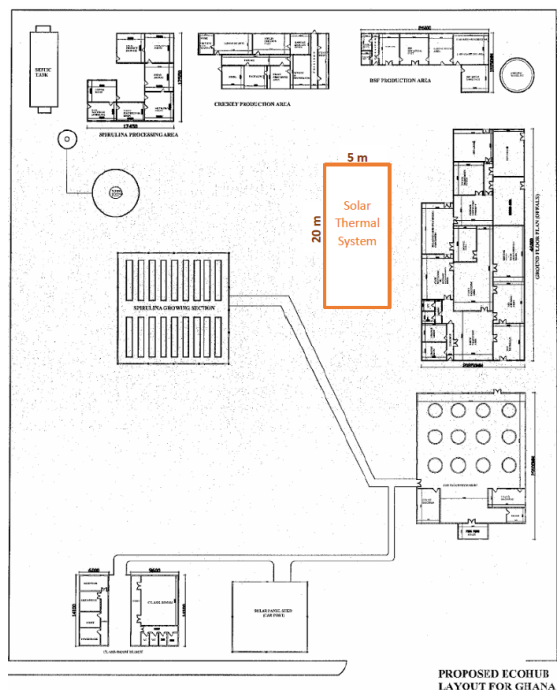
- Efficient use roof space
- lowers system cost
- Shorter pipes
- Less risk of damages because of missing accessibility
- Disadvantages
  - The maintenance is more difficult because safe access to the roof is needed
  - To guarantee an optimized orientation towards the sun is more difficult

Ground mounted version:

- Advantages
  - Easier and better orientation towards the sun for maximum energy harvest
  - Allows easier maintenance
- Disadvantages or requirements
  - availability of land
  - occasional risk of damages
  - slight fencing might be required

The project partners CSIR-FRI in Ghana have decided for a ground mounted version. The main reasons are the disadvantageous roof construction and an easier maintenance.

It has been proposed by the installation company GNP Engineering Services to apply the design of a drain back system to guarantee a robust and reliable system. Because of the local availability, two 2000 L hot water storages will be installed instead of the initially proposed storage of 4000 L (Figure 12).



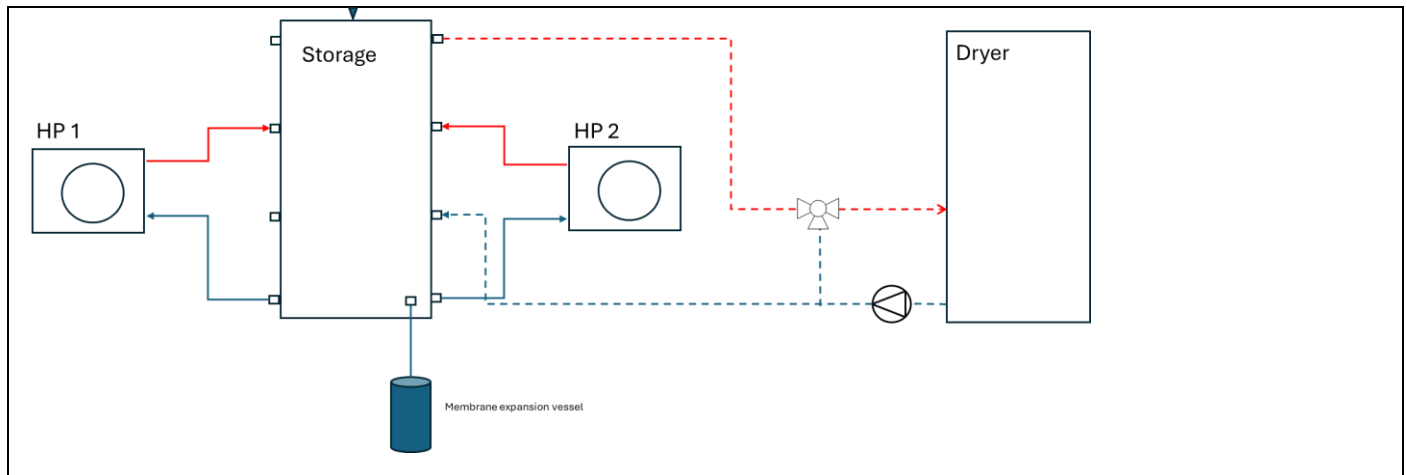
**Figure 12.** Master plan of the ECOHUB in Ghana (status of July 2025) with marked installation site for the solar thermal collector system [BM2025].

## 5.2.2 System concept for the ECOHUB in Kenya

The selected cabinet dryer requires water at 70°C at the inlet, with an overall energy demand of 32 kW. To ensure a steady and reliable supply, a 4000 L storage tank is proposed, which will act as a buffer against any fluctuations.

### 5.2.2.1 System Design and Technical Approach

As already described above, heat pumps are selected over traditional water heating methods due of their higher efficiency and reduced environmental impact. The system is configured to use two heat pumps, each with an output of 16 kW, so that their combined capacity meets the total energy requirement. This setup also improves overall system reliability in case one heat pump fails or requires maintenance. The proposed hydraulic schemes are shown in the Figure 13 and Figure 14.



**Figure 13.** Simplified hydraulic scheme of two heat pumps with a storage tank and the connected heat consumer (dryer).

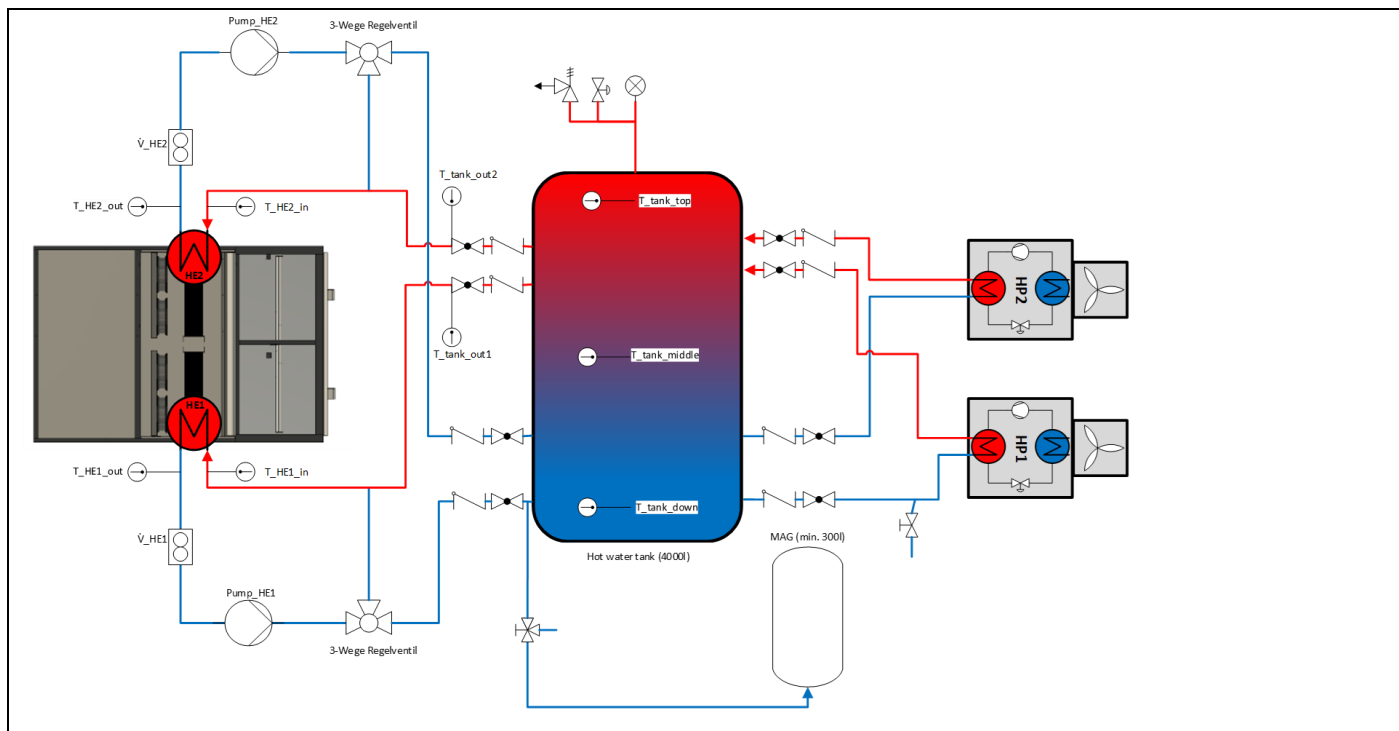


Figure 14. Complex hydraulic scheme of the system configuration for the ECOHUB in Kenya [PS2025].

The heat pumps will gradually increase the water temperature inside the tank to the required range of 70–75°C. The hot water will then be supplied to the multi-purpose dryer, where air is heated up to the required temperature in the range of about 65°C to be circulated through the trays to dry the fish. The size of the buffer tank will also reduce the frequency of heat pump cycling, which will ultimately improve system longevity and reliability.

As always, environmental impact and sustainability are key considerations. Therefore, heat pumps using R290 refrigerant were prioritized, as it has a very low global warming potential and zero ozone depletion potential.

### 5.2.2.2 Simulation and Analysis

To evaluate the system's performance, the entire setup was simulated using Polysun software. The initial water temperature was set to 30°C, representing the average site conditions throughout the year, and the target water temperature was set to 75°C, which also serves as the cut-off temperature for the heat pumps. Hot water was scheduled to be withdrawn after 6 hours to allow sufficient time for the heat pumps to reach the target temperature. The time for the calculation doesn't need to be considered as the time of a real day – it is an example - as the heat pump should be in operation during daytime when sun is available and the PV system produces electricity.

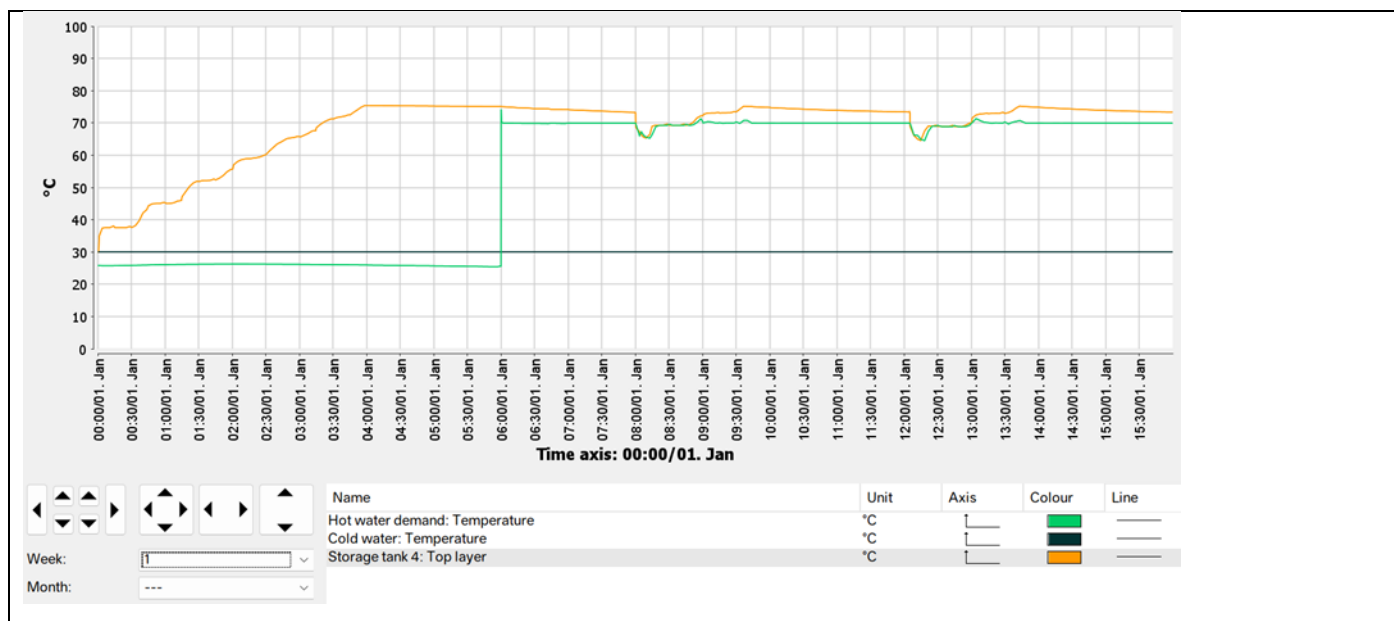


Figure 15. Simulation results of the temperature of the hot water in the dryer.

The simulation showed that the system can heat the water in approximately 4–5 hours, depending on ambient conditions (Figure 15). Once water was supplied to the dryers (temperature drops in the graph), the heat pumps were able to maintain the outlet temperature with only minor fluctuations. This demonstrated that the system can reliably meet the dryer’s requirements under typical operating conditions. However, if only one heat pump is running, the heating time will increase, and the system may need to operate at reduced capacity.

### 5.2.2.3 Conclusion

The system successfully met the requirement of a reliable, efficient, and environmentally friendly hot water supply for the drying machines. By using heat pumps with R290 refrigerant and a large buffer tank, the system can consistently provide hot water at the required temperature.

The use of two heat pumps ensures operational reliability, even in the event of equipment failure. Simulation results confirmed that the system meets performance expectations, making it a robust solution for fish preservation needs. It also sets a strong foundation for scaling up or integrating renewable electricity sources in the future.

## 6 Electricity demand and considered photovoltaic based power supply

### 6.1 Example Ghana: Electricity demand of the dryer and flake ice machine

Multipurpose dryer WHT3 for Ghana:

The electric power demand of the dryer is the sum of the power of the fans, the of the hydraulic pumps and the control. For the HWT3 it results to 2.5 kW and 25 kWh/daily batch, considering an operation time of 10 h.

Ice machine:

Considered is an ice machine with a production capacity of 1000 kg/24 h corresponding to about 300 kg/8h of daily operation. The expected maximum power demand of the ice machine is about 6 kW.

#### 6.1.1 Derived and recommended power of the PV system for dryer and ice machine

Depending on the concept of the power supply of the two consumers the following values need to be considered:

- For the dryer only, a PV system of about 7.5 kW<sub>peak</sub> installed capacity would be required, if a separate system is used. If the electric power is provided by a large general PV system, only 5 kW<sub>peak</sub> should be considered.
- If the ice machine is directly powered from a separate PV system on the DC side, a PV system nearly 15 kW<sub>peak</sub> DC-power is needed. In such a case a system configuration without battery and inverters would be possible. If the electric power supply is provided by a general and large PV system, the specific PV power demand can be considered as lower.

#### 6.1.2 Analysis of the energy demand and recommendations for the design of the PV system for the EcoHub in Ghana

In summary and resulting from the above-mentioned information a simulation-based calculation with the following results has been elaborated.

#### *Solar Energy System Analysis and Recommendation*

The ECOHUB fish farming system is partially powered by the photovoltaics modules therefore a brief analysis was conducted with the aim to assess production capabilities of different configurations and to recommend an appropriate one for the project.

Polysun software was used to perform the analysis, and the geographic location was set to Accra, Ghana. Two different configurations of solar PV systems were evaluated, one with 2 strings (26 PV modules) rated at 14.56 kW and the other with 3 strings (39 PV modules) at 21.84 kW.

#### **2 Strings Configuration**

As per the data provided on 20<sup>th</sup> March 2025 (by CSIR-FRI), the daily energy demand of the plant is 109 kWh, and this system has the capacity to cover half of it. The monthly energy production values varies between 1400 kWh and 2000 kWh (Figure 16). Due to rainy and cloudy season the production is lowest in the months of June, July and August. The yearly production results to 20,476 kWh and the average daily production are estimated to 56 kWh.



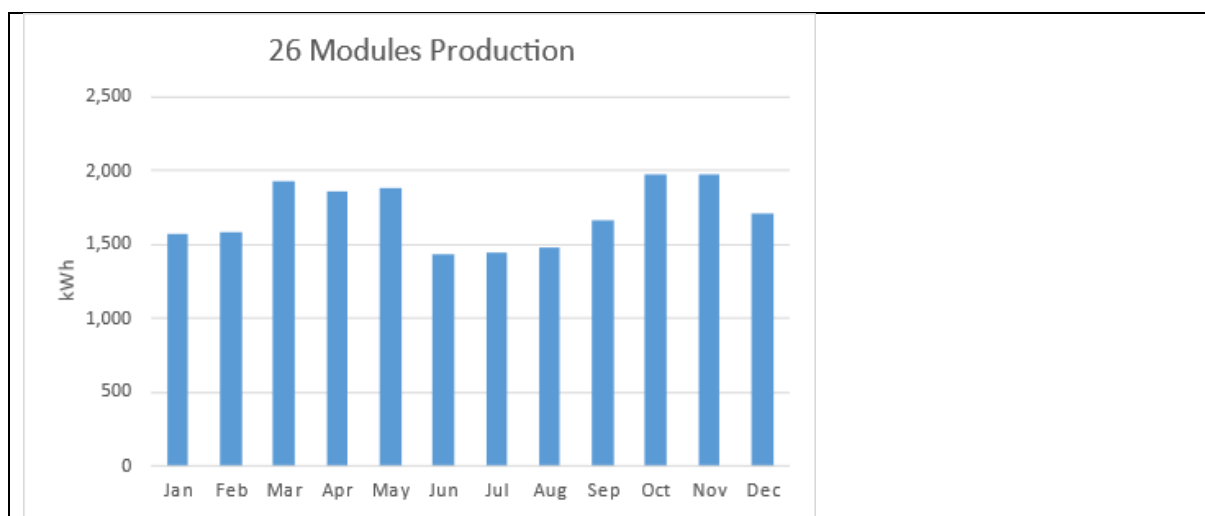


Figure 16. Monthly energy production of a 2 string PV system.

### 3 Strings Configuration

Figure 17 provides a visualization of monthly production output for 21.84 kW system. The yearly production went up by 10,000 kWh. Seasonal trend is still the same and the production varies between 2100 kWh and 3000 kWh per month. The yearly production results 31,028 kWh with an estimated average daily production of 85 kWh.

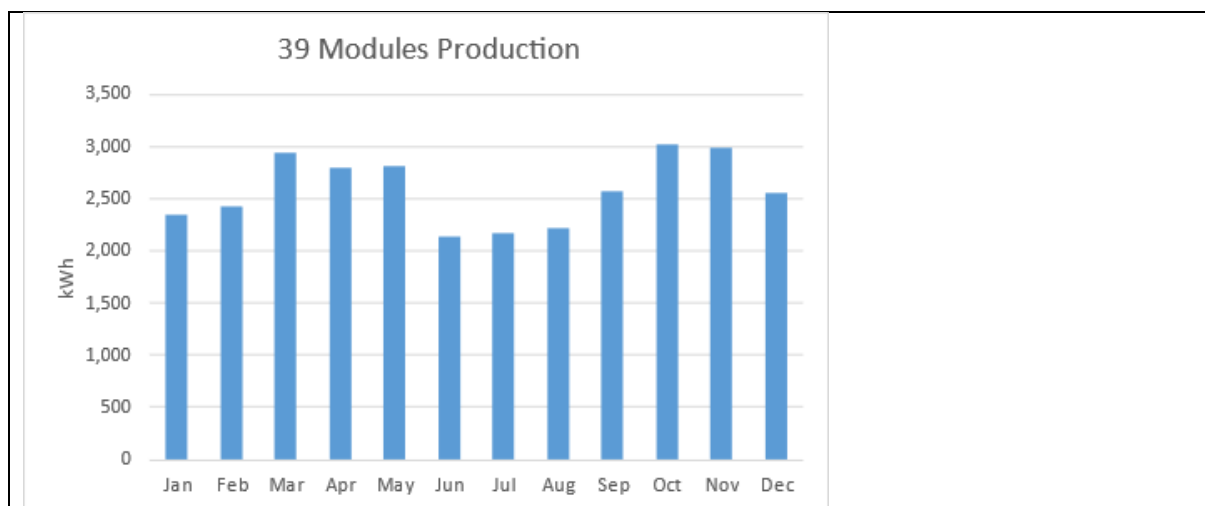


Figure 17. Monthly energy production of a 3 string PV system.

### Side by Side Comparison

Energy production data for both configurations is depicted against each other in Figure 18, and the monthly demand is plotted as a constant line. In both cases, additional electricity is required which will be supplied by the local grid. The electricity tariff in Ghana is €0.10 per kWh, meaning over €1,000 per year can be saved if we increase the capacity from 2 to 3 strings.

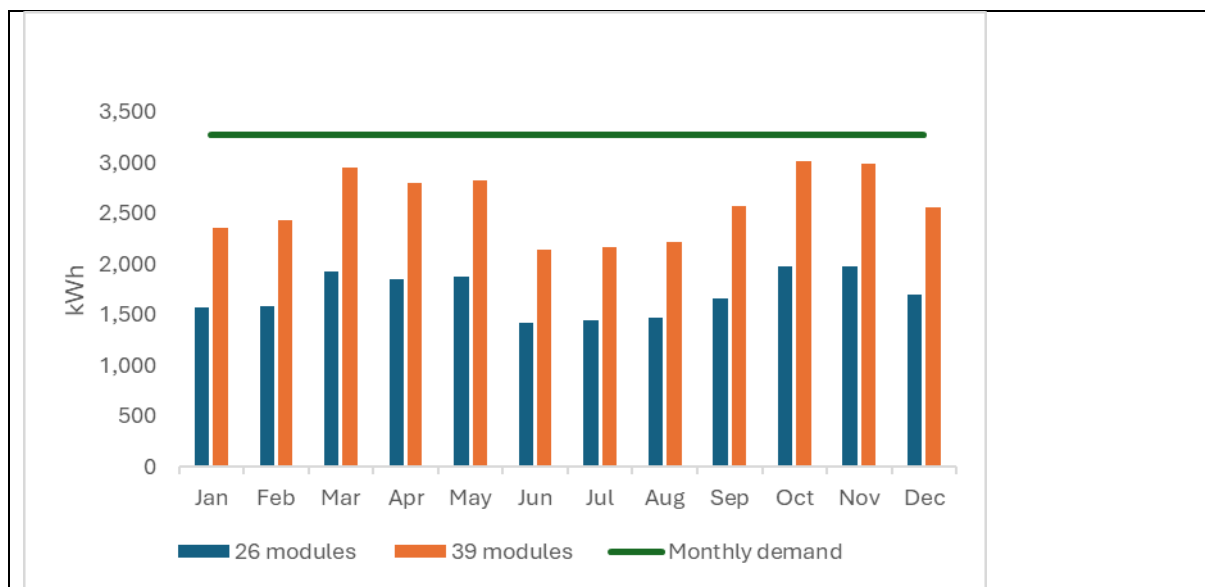


Figure 18. 2 strings vs 3 strings configuration.

### 6.1.3 Considerations and Recommendations

The three strings configuration is recommended for the project as it offers considerably higher energy production and potential savings. But it is also very important to factor in the additional costs linked with extra modules, battery and a large capacity inverter. With continuous operation and timely maintenance, the long-term benefits of a bigger PV system will outweigh the initial investment.

## 7 References

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