Green agriculture warehouse analysis in Yancheng, China

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Abstract

Mechanization level and informatization level have been improved through recent years, sustainability should be emphasized in response to the waste from the logistics process. Sustainable warehousing is integral to logistics processes, especially for perishable agricultural products. The sustainable warehouse focused on two areas: layout and energy application. The warehouse adopted the SLP method to minimize the construction cost and optimize the warehouse system and zone partition arrangement. Mechanization level and informatization level have been improved through recent years, sustainability should be emphasized in response to the waste from the logistics process. The sustainable warehouse focused on two areas: layout and energy application.

The research questions were “What is a suitable layout for a sustainable agricultural warehouse?” and “How to apply renewable energy to the warehouse system?” The first question is based on data analysis and estimation, the data is rearranged and estimated by Excel sheet. After a critical literature review from authoritative books and professional papers, multiple diagrams analysis, diagram drawings by Edraw, and charts by Excel, the warehouse adopted the SLP method to minimize the construction cost and optimize the warehouse system and zone partition arrangement. The second one is using PVsyst 7.3 to determine the tile angle and Excel for the solar panel’s parameter and final electricity calculation. The future will be combined with a designed algorithm to get more accurate results.

Keywords/tags (subjects)

Sustainable warehouse. SLP method. Solar energy. Sustainability. Warehouse layout.

Miscellaneous (Confidential information)

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1 Introduction

1.1 Yancheng agriculture analysis

Yancheng City is based primarily on agricultural production. This city produces 1.2 % national food, 1% meat, 2.1% vegetable, 1.9% aquatic product, and 2.8% eggs through only 0.61% of the country's arable land (Jiangsu Department of Agriculture and Rural Affairs, 2023). In addition, the previous year's data shows the total output of vegetables, melons, and fruits in the city was 15,111,000 tons (Municipal Bureau of Statistics office, 2023). Production of agriculture has been mechanized, and the city's crop cultivation and harvest comprehensive machinery rate reached more than 80 percent. Furthermore, digital agricultural rural construction has been utilized and big data platforms built in nearly 100 villages (Yancheng City Government Office,2021). Hence, the mechanization and intelligence level of Yancheng City has been paid attention to.

1.2 Background

Nevertheless, the environment has been neglected throughout the process. The environmental problems have been highlighted these years, land degradation and water storage in the ecosystems has been deteriorated. On top of this, climate change makes water scarcer and unpredictable. It could be a severe phenomenon that nearly 72 percent of freshwater has been consumed by agriculture and there is an existing problem setting in the imperfect supply chain, which causes the spoilage of these perishable vegetables in the warehouse and transport and exacerbate the environmental issues because of the scarcity of construction in the information of agricultural products system, the production always cannot fit the needs smoothly. The cooperation and information sharing will cut down the logistics cost and data can be analyzed and finally convert to manufacturing. The purpose of the thesis is to develop, optimize, design, and provide a sustainable warehouse for perishable agricultural products.

1.3 Purpose description

The scope of this research lies in how to build a warehouse sustainably, the sustainable agriculture warehouse will achieve sustainability from a basic description of a warehouse, scientific warehouse layout, and clean energy use to inside management philosophy. Here always comes the question of whether improperly designed warehouses will contribute to the loss of materials, square footage, and monetary expenditure. Moreover, energy utilization is a further question that exists in the warehouse system. This thesis wants to provide a viable and rational design for medium agriculture warehouses to meet the need of sustainability requirements and amend environmental issues existing in agriculture warehouses.

2 Research questions

What is a suitable layout for a sustainable agricultural warehouse?

How to apply renewable energy to the warehouse system?

3 Literature review

The thesis will design a sustainable warehouse based on status analysis and research; this chapter should provide a powerful theoretical and data basis for the results of my thesis.

3.1 Warehouse

3.1.1 Warehouse concept

As this research aims to build a sustainable agriculture warehouse, the first is to outline what is a warehouse. Storage has been introduced for the aspect of economic development. Richard (2022) described the surge of warehouse development and strategy like postponement that products are processing and packaging in the warehouse instead of in the manufacturing place, and the reasons are: “The introduction of concepts Just-in-time (JIT), efficient consumer response (ESR) and quick response (QR), companies are continually looking to minimize the amount of stock held and speed up the throughput” (p9). The origin of the warehouse could attribute to product storage altered from households to retailers, wholesalers, and manufacturers. The strategy of economic effectiveness of warehousing occurs when the integral logistics costs are reduced. At present, warehouses as an integral part of storing inventory in the logistics connection, which provides a bridge between production and marketing, and the important goal in warehousing are to maximize flexibility. Donald (2019) has described the four economic benefits of a warehouse are “(1) consolidation and break-bulk, (2) sorting. (3) seasonal storage, and (4) reverse logistics” (p.223). Overall, the warehouse should be an adding value process as a point in the line of the logistics, warehousing should be in anticipation and estimation responding to customer needs in the critical sales period.

3.1.2 Warehouse functions and activities

In warehouse design, functions and activities should be considered. When defined warehouse activities, according to Richards (2019), several studies have begun to examine warehouse activities. The literature has highlighted 8 main warehouse activities: “receiving, put-away, storage, order picking, packing, loading, stock counting, value-adding services” (p. 90). Figure 1 exhibits different main warehouse activities as a percentage of the total cost, the optimization of pick, pack, and dispatch operation processes tends to have relatively strong economic effectiveness.

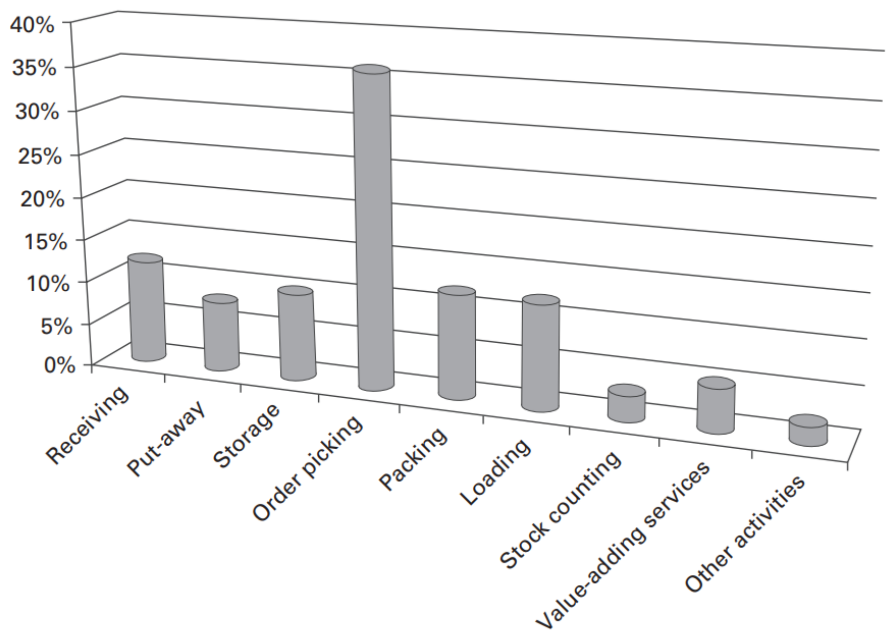


Figure 1: Warehouse activities Richards (2019)

At the early stage, the function of the warehouse is storing and keeping products, the development of the warehouse is from a static state to a dynamic state, which simulates three basic functions, namely movement, storage, and information transfer. Yi’s comparative study described the movements in the warehouse “Movements can be divided into receiving, put-away or transfer, order picking selection, checking, and packing, shipping. and modern warehouses develop some new functions such as sortation, packaging, and cross-docking” (p.39, 2009). Storage is the physical storage of goods pending demand, which requires the goods in the warehouse to achieve the maximum storage rate. Information transfer is the accurate information in warehouse operating management such as storage level, cargo handling capacity, incoming and outgoing information, and space utilization (Yi, 2009). Information identification, estimation, and analysis will contribute to the warehouse area division and systematically consummate the rotative material flow of the warehouse inside and outside.

3.2 Sustainable warehouse

3.2.1 Sustainability

The essence of a sustainable warehouse is sustainability. Understanding sustainable warehouses requires the foundation theory of sustainability and the sustainable standard in the specific warehouse industry.

CSR (Corporation social responsibility) may be seen as a cushion measure in social sustainability by which a business delivers its commitment to sustainable development before restriction from forming laws in sustainability. Thiele (2016) pointed out CSR has become a mainstay of business activities; large corporations emphasized environmental sustainability and sustainability report has become the measure of shareholders and consumers. The trend of laws and executive standards in the EU may make corporations give attention to closed-loop and sustainable economic models and some of these are compulsory.

In circular economy studies, the resource flow is turning from the traditional linear process to a closed-loop process. Examples of environmental responsibility in CSR are to impede or minimize the adverse impact of environmental issues through precautionary approaches or develop and diffuse environmentally-friendly technologies (Thiele, 2016). Unlike CSE giving an overview of environmental stewardship, SDGs give a more detailed description of sustainable constructions. SDGs are addressed by ISO standards based on three pillars: economic, environmental, and societal dimensions. SDG list consists of 17 ISO standards to achieve sustainable objectives. Sustainable cities and communities describe how to make constructions and human settlements inclusive, safe, resilient, and sustainable. High energy consumption, carbon dioxide emission, and material consumption are emphasized in the construction sector. The standards have regulated sustainable constructions, propose an overall framework for construction sustainability, and given the foundation of the sustainable warehouse.

3.2.2 Sustainable warehouse

Net-zero warehouse can be achieved by these approaches: one is to gather the acquisition from solar, wind, or other types of renewable energy, and one is to improve the energy efficiency in the warehouse's electricity and machinal system, eliminating or prohibiting the waste of electricity utilization. Sustainable warehouses can be qualified by different criteria by organizations and institutions. Chinese green warehouse requirements and evaluation declared by the China Warehouse Association organization and put forward by the Chinese Ministry of Commerce gives the specifical acquirements through these aspects: warehouse site selection and planning of reservoir area; land saving and use; energy saving and energy utilization; water saving and water resources utilization; saving and utilization of materials; environment; technology progress and innovation. (Li, 2016) Also, layout and site selection should be considered as important environmental factors and the waste of it can be reducible or avoidable at the early conceiving phase of the warehouse. When assessing the impact of the environmental balance, it consists of two levels: the emissions from construction and the operational emissions (Alexander, 2017). The most used standards are BREEAM, the Building Research Establishment Environmental Assessment Method by Building Research Establishment (BRE) based in the UK. A framework of assessment for developing sustainability in warehouses studied by Peter & Clive is separated from the individual firm and economic features from a micro-level perspective to environmental and social responsibility from a macro-level perspective (p68, 2015). In addition, the systems approach draws from the life cycle analysis widely used in supply analysis, and stages toward sustainability in the warehouse are derived as baseline energy efficient warehouse, low-emission and green energy warehouse, and sustainable warehouse. Peter & Clive have set up some criteria for the sustainable warehouse including water recovery and management; local sourcing of materials; achieving BREEAM excellent standards; solar and thermal recovery; low-energy materials; exceeding minimum standards; generating green energy; managing supply chain sustainability; focus on total lifetime emissions and costs. These standards are significant components of warehouse assessment and evaluation basis.

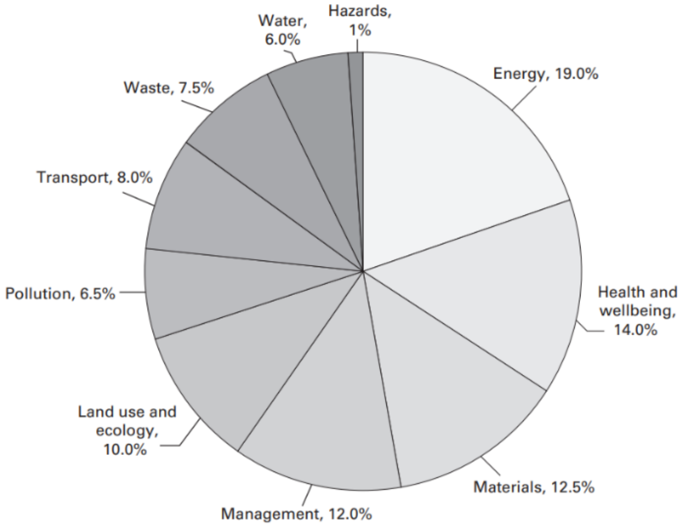


Figure 2: BREEAM weighting factors for new constructions, Alexander (2017)

3.2.3 Energy

As the industrial system was gradually improved, “Renewable sources include wood, plants, dung, falling or gravity-fed water for hydroelectric or mechanical energy, geothermal sources, solar, off-shore, and onshore wind, biomass or biofuels, and tidal and wave energy” (David, 2017). China is one of the world’s largest carbon emission countries, the chart made by the Chinese renewable energy report indicates the total trend of renewable energy use in China is increasing and the volume of renewable energy generation has quadrupled in a decade.

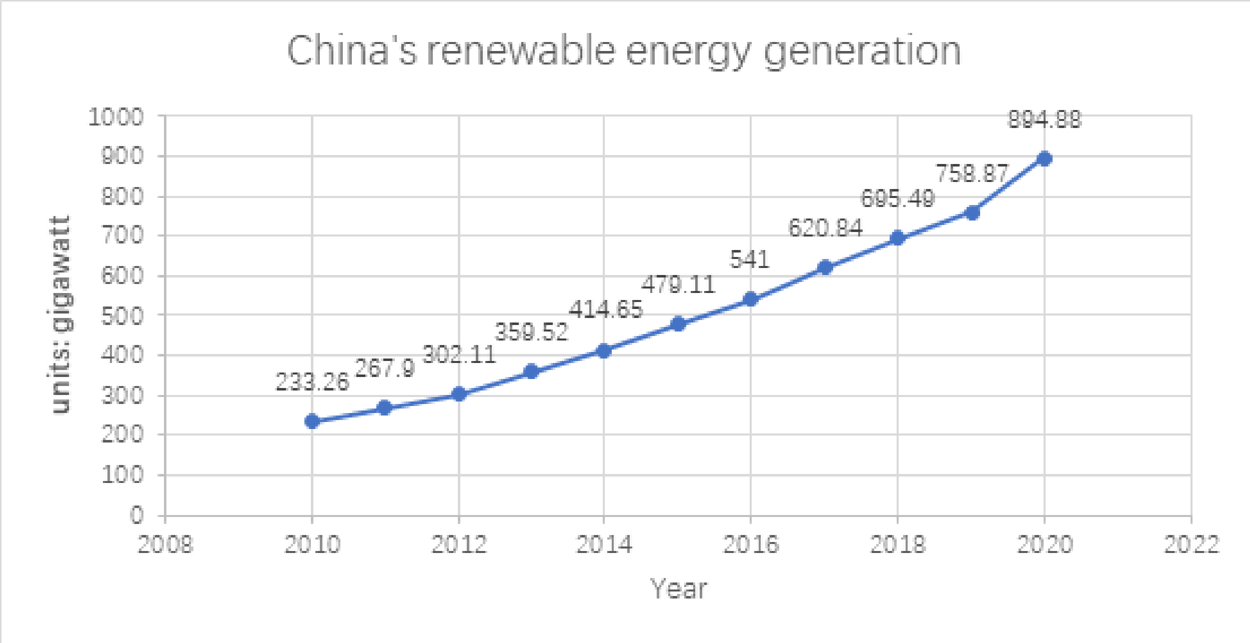


Figure 3: China's renewable energy generation (Data sources from the 2022 Chinese renewable energy report)

3.2.4 Solar energy for green warehouse

With the solar photovoltaic technology developed and manufacturing costs declining, solar energy has evolved into a renewable generation alternative for fossil fuels, which reduces greenhouse emissions and contributes a sustainable way of energy use.

Solar panel working theory

Sun generates huge energy in the form of electromagnetic radiation from thermonuclear fusion and solar energy is harnessed by solar panels from the solar photovoltaic and solar thermal. Photovoltaic is one of the various technologies available for harnessing the sun's energy, and solar cells or PV cells are made of semiconductor materials and convert them into electricity. Lewis & Larry defined three types of solar modules or alternative PV module types, "(a) standard silicon single-crystal module fabrication, crystal to ingot to the wafer to module; (b) concentrator module fabrication, smaller single-crystal cells with mirrors or lens array; and (c) thin-film module, spray-on successive nanocrystalline films" (p.8, 2010). The photovoltaic effect is the principle behind solar power generation, when light shines on the semiconductor PN junction, the semiconductor PN junction absorbs light energy and generates electromotive force at both ends. This phenomenon is called the photovoltaic effect. Due to the strong built-in electric field in the depletion region of the PN junction, electrons and holes in the depletion region are generated. Under the action of the built-in electrostatic field, electrons and holes in the depletion region move in opposite directions and leave the depletion region. As a result, the potential in P-zone increases and the potential in N-zone decreases, and photoelectromotive force is formed at both ends of the PN junction, which is the photovoltaic effect of the PN junction (Zhou & Ji, 2013).

The application of solar panels in warehouses

The application of solar panels is about the electricity system in the warehouse. Chiras & Daniel described the solar electricity system which applies to homes or other buildings, illustrated, and analyzed two systems that are efficiently used in building systems: the batteryless utility-tied PV system (aka grid-connected PV systems) and the gid-connected systems with battery backup. The sustainable warehouse requires a refrigeration and ventilation system, which means high electricity consumption and constant power supply, it is a better option to choose gid-connected systems with battery backup as our warehouse system (p. 87, 2020).

In their designed grid-connected system, it will cut down the cost of wired modules that can be in very short series strings and more efficient if wire series strings are in much higher voltages. Additionally, maintaining a fully charged battery bank required a cost of 5% to 10% of the PV system efficiency. What is described in the schematic of a grid-connected system with battery backup, “batteries are not called into duty unless there is a power outage.” (p. 102, 2020). Our sustainable warehouse panel system will apply a batteryless utility-tied PV system for easy application and efficient cost. We should consider if it is possible to parallel the waste disposal circuit system with the accumulator, in this way, the waste disposal area will also provide a part of the electricity in the whole system.

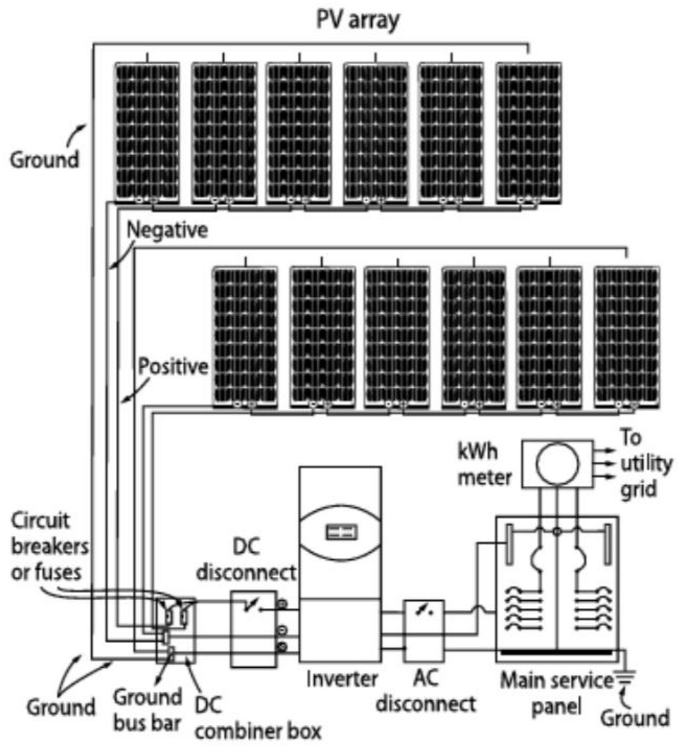


Figure 4: Schematic of batteryless utility-tied PV system, Chiras & Daniel, 2022 p.103

When we consider our choice of the type of solar panel. Jianhong Z. (2017) studies the application of solar energy photovoltaic power generation technology in low-temperature storage in Hainan province. He gives the method how to choose the panel, the performance of monocrystalline silicon cell is stable, and the photoelectric conversion rate is 15% and generally used in areas with rainy weather; by contrast, Polysilicon cell photoelectric conversion is about 12%, which has cheaper manufacturing costs with less silicon material consumption and can be applied to areas that have ample sunlight. Yancheng is a city located in the middle of the east coast of China, it is typically subtropical monsoon climate and rainy in summer, we can choose solar panels with a higher photoelectric conversion rate.

3.2.5 Water saving

Agriculture is a water-consuming industry. Water saving not only brings less freshwater use but also for the agriculture warehouse water saving, some scholars state that warehouses are ideal for harvesting rainwater and re-using it in greywater areas of warehouses (Trautrims, 2017). The study proposed by Zhang (2022) illustrates the application of warehouse water saving can be given as the optimization of the overall layout of water supply and drainage, and some technology like recycling of the water in the foundation pit and application of variable frequency energy-saving water pump by frequency converter and pressure sensor. Design a rainwater collection and apply this technology to recycle water.

3.2.6 Waste utilization and green packaging

Waste disposal should be indispensable in sustainable warehouses and form the part of circular economy. Vegetables, fruit, grain, and meat should be recognized and classified as biomass energy. Biomass can be converted into electricity and is one of the carbon-neutral renewable energy sources and the process of generating electricity is stable and continuous. Anaerobic digestion could be an appropriate approach for biomass energy generation.

Packaging is integral to protecting the goods from supporting production, storage, supply chain, and transportation activities. Green packaging also means biodegradable packaging, these compostable packages are made by multiple mixtures of plants and finally break down to nature. PLA plastic is made from corn, starch, and sugar cane. (CarePac, n.d.)

3.3 Agriculture warehouse

3.3.1 Warehouse layout

In the chapter on warehouse layout, Richards & Kevin (2022) systematically analyzed the historic evolution of modern warehouses from the form of retailing to informational inconsistent, competitive, and versatile market and 8 elements when designing the warehouse, continually evolving products and annual changing order and intricated market connections require the warehouse to be more flexible. Donald et al. (2019) described the basic warehouse layout, they think that the key to an efficient layout is a well-developed slotting plan and introduce a method called product-mix analysis design their warehouse space, design, layout, handling equipment, operating procedures, and controls based on the total size, cube, and weight of the average order. In addition, the layout of the storage area should comply with product flow and layout design should be in alignment with internal logistics and the flow of handling equipment. Richards et al. (2022) have described warehouse design should be concentrated on data analysis, flexibility for the warehouse, and cubic capacity of the building. Alan et al. (2017) systematically studied steps in warehouse design using the method of utilizing Pareto (80/20 rule), flow diagrams, operational principles such as order lead time and cut-off times, and high-level procedural and information systems requirements.

The principle of warehouse layout is to fit the production process of warehouse production. According to Liu and Wang (2013), the general layout of the warehouse should be adapted to the production process of the storage enterprise, which is conducive to the normal production of the storage enterprise. The arrangement between the unloading, receiving, and storage locations of goods in the warehouse must be adapted to the storage production process and flow in one direction. It should minimize roundabout transport, the arrangement of special lines should be in the middle of the depot area, and according to the operation mode, storage commodity varieties, geographical conditions, etc., reasonable arrangement of depots, special lines, and main roads should correspond to each other. The fewer activities of handling and processing of goods in storage contribute to the warehouse efficiency, and the integration of unloading, acceptance, and stacking of goods will bring less labor wastage.

Shen & Wang (2021) analyzed the warehouse layout and planning, the conditions of the warehouse can be outlined as adaptability of the storage process, economic efficiency, maximization of storage space utilization, efficiency of equipment use, and safety and employee wellness.

Three ways to show different types of layouts. The U-shaped layout shows the compactness of output and input, which means the shared dock utilization area will improve handling efficiency. L-shaped layout is designed to expand storage to the back of the warehouse and the other areas are combined into an ‘L’ shape. The I-shaped layout inside indicates the product flow is linear and is the operation for mass production or high-volume storage.

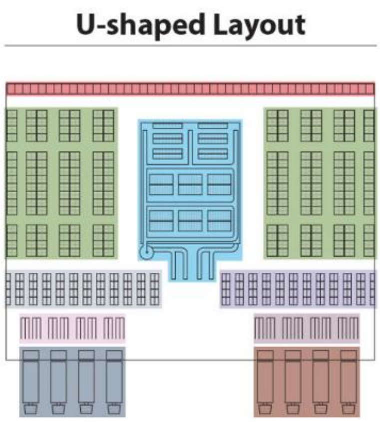


Figure 5: U-shaped layout, Laceup solutions, n.d.

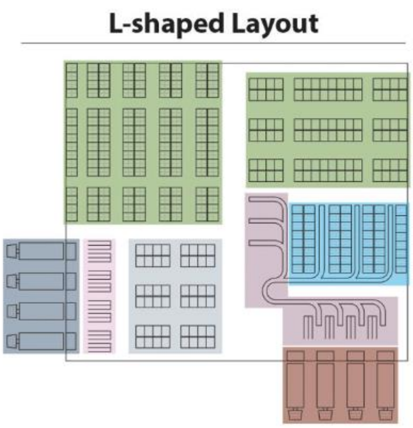


Figure 6: L-shaped layout, Laceup solutions, n.d.

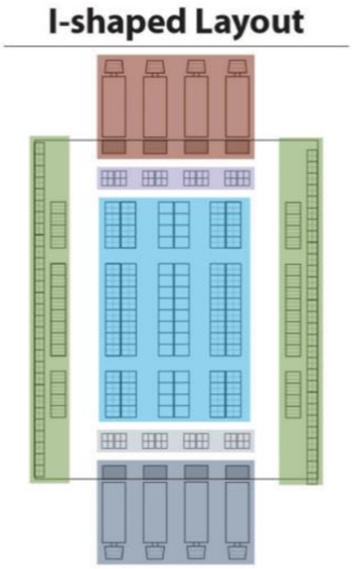


Figure 7: L-shaped layout, Laceup solutions, n.d.

SLP method

The systematic layout method, found by Richard, is commonly used in factory layouts. The starting point of the SLP method is the closeness of interrelationships between operational units is quantified to assess the degree of relevance between departments. This theory is based on 5 elements including product, quantity, routing, supporting service, and time. According to Richard and Lee (2016), a reasonable approach to tackling general warehouse layout could be divided into the following steps and each step has a key document or must-do need to be completed, which includes product-quantity analysis to determine the division of various products, materials, or items involved and types of layout; the flow of materials analysis through the operation process chart, nested process chart; determine the relationship between each activity through the relationship chart and draw flow or activity relationship diagram; space determinations, draw space relationships on layout make templates for block layout planning, and record the alternatives; evaluate alternatives and find the best layout.

According to Richard & Lee (2017), the primary purpose of any plant layout is to facilitate the manufacturing process, what is the similarity of the warehouse The purpose of using an SLP layout is to accelerate logistics processes. An additional objective in a warehouse system should be considered: Minimizing material handling especially on time and travel distance; the flexibility of the warehouse when the storage changes; how to promote a high turnover rate; Economical use of floor space; promoting effective utilization of labor; consideration of employee's safety, convenience.

In the application of the SLP method, Fan (2022) offers the SLP method in designing the layout of an agriculture warehouse through the logistics relationship analysis, operation relation analysis, and operation area arrangement; the SLP method is based on 5 elements: product categories, production, operation route, auxiliary department, and technology. In this dimension, the area division of agricultural warehouses is determined by the connection and operational flow in receiving, storage, picking, packing, and dispatch area of this main logistics function area. In the foundation of SLP, Li (2017) combined IQ analysis and ABC storage space optimization classification and optimizes the layout in LS company and addresses the problems of distant operating areas, low space utilization, and insufficient storage capacity. These applications provide different views on the SLP method.

4 Solution

4.1 SLP warehousing layout

4.1.1 Basic structure of SLP method application in agriculture warehouse

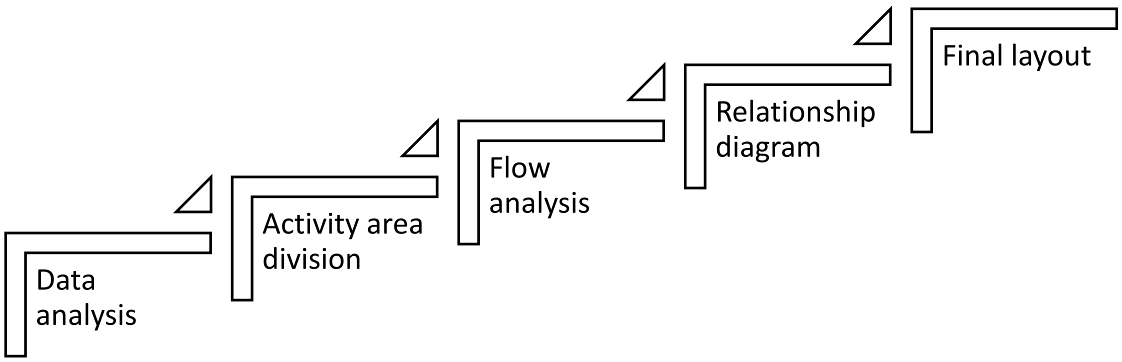


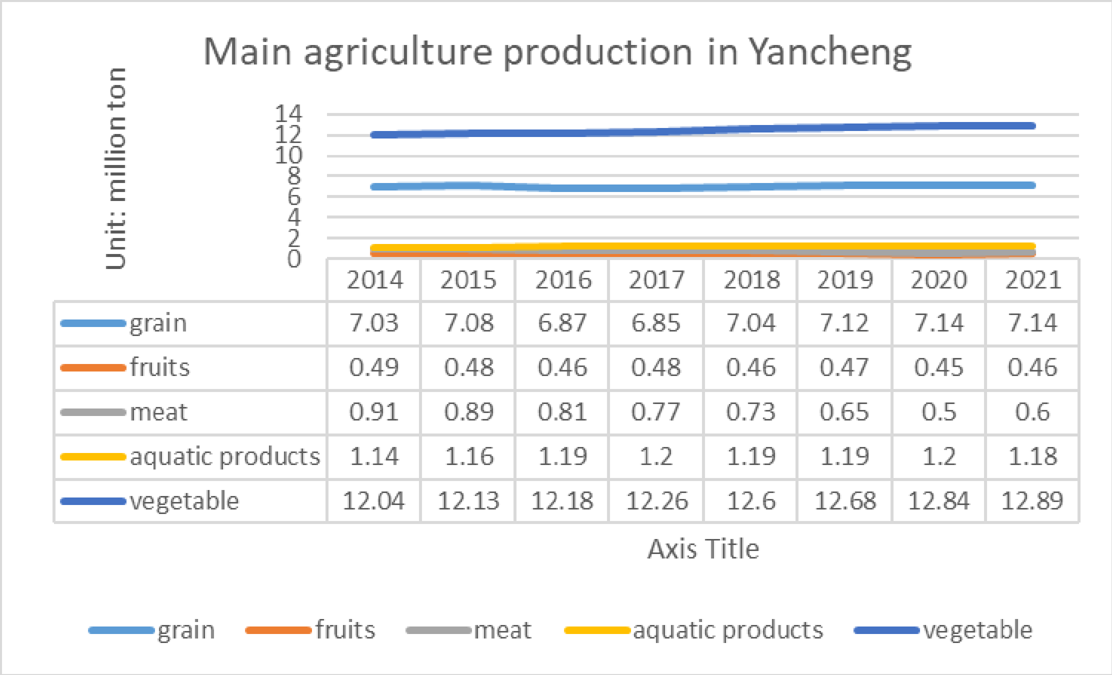
Figure 8: General steps of the SLP method

4.1.2 Data analysis

P-Q chart

According to Richard & Lee (2016), product-quality analysis takes the form of division of grouping of the various products. In this description, agriculture products including meat, grain, fruits, and vegetables basically can be divided into three groups from their storage temperature: normal temperature area, low-temperature area, and frozen temperature area.

However, because different agriculture products have different storage methods, a possible approach to tackle this issue is estimating the data and using a P-Q chart to analyze the quantities of relatively few products or varieties, and then deciding the storage area division through P-Q analysis and storage methods. The P-Q chart shows the fundamental relationships to the planning layout. Product-quality analysis takes the form of the division of the various agricultural product, it visualizes the findings, arranges the order of count, and the results plotted on a graph.



	2014	2015	2016	2017	2018	2019	2020	2021
grain	7.03	7.08	6.87	6.85	7.04	7.12	7.14	7.14
fruits	0.49	0.48	0.46	0.48	0.46	0.47	0.45	0.46
meat	0.91	0.89	0.81	0.77	0.73	0.65	0.5	0.6
aquatic products	1.14	1.16	1.19	1.2	1.19	1.19	1.2	1.18
vegetable	12.04	12.13	12.18	12.26	12.6	12.68	12.84	12.89

Figure 9: Main agriculture production, Yancheng Statistical Yearbook 2015-2021

To estimate the warehouse storage, different estimation methods are applied for different agricultural products considering different data distributions. The tool is Excel.

Moving average and optimized by MSE: $S_t = aY_{t-1} + (1-a)S_{t-1}$

The formula of a simple linear regression model: $y = \beta_0 + \beta_1 + \varepsilon$

The formula of the multiple linear regression model: $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \varepsilon$

Moving average for egg and fruit, because of its slight fluctuation.

Table 1: Estimation for eggs

		α	0.5172		
Year	Egg	Forecast	Eorror	Eorror^2	Estimation value
2014	0.72	0.72	0	0	0.9061
2015	0.71	0.74477	-0.0348	0.00121	MSE
2016	0.71	0.75241	-0.0424	0.0018	0.00506595
2017	0.64	0.75636	-0.1164	0.01354	
2018	0.71	0.7222	-0.0122	0.00015	
2019	0.74	0.74074	-0.0007	5.5E-07	
2020	0.92	0.76584	0.15416	0.02376	
2021	0.88	0.87192	0.00808	6.5E-05	

Table 2: Estimation for fruits

	α(smoothing coei		0.56899		
Year	Fruits	Forecast	Eorror	Eorror^2	Estimation value
2014	0.49	0.49	0	0	0.459153193
2015	0.48	0.49	-0.01	0.0001	MSE
2016	0.46	0.48431	-0.0243	0.00059	0.000174458
2017	0.48	0.47048	0.00952	9.1E-05	
2018	0.46	0.4759	-0.0159	0.00025	
2019	0.47	0.46685	0.00315	9.9E-06	
2020	0.45	0.46864	-0.0186	0.00035	
2021	0.46	0.45804	0.00196	3.9E-06	

Multiple linear regression for grain and aquatic products for one or two inflection points.

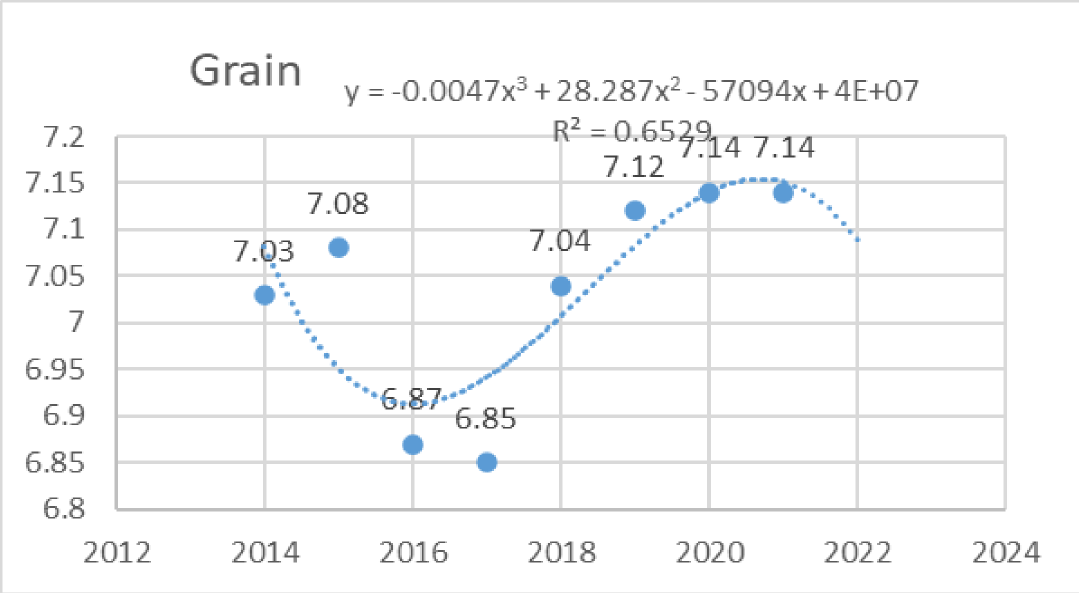


Figure 10: Estimation chart for grain

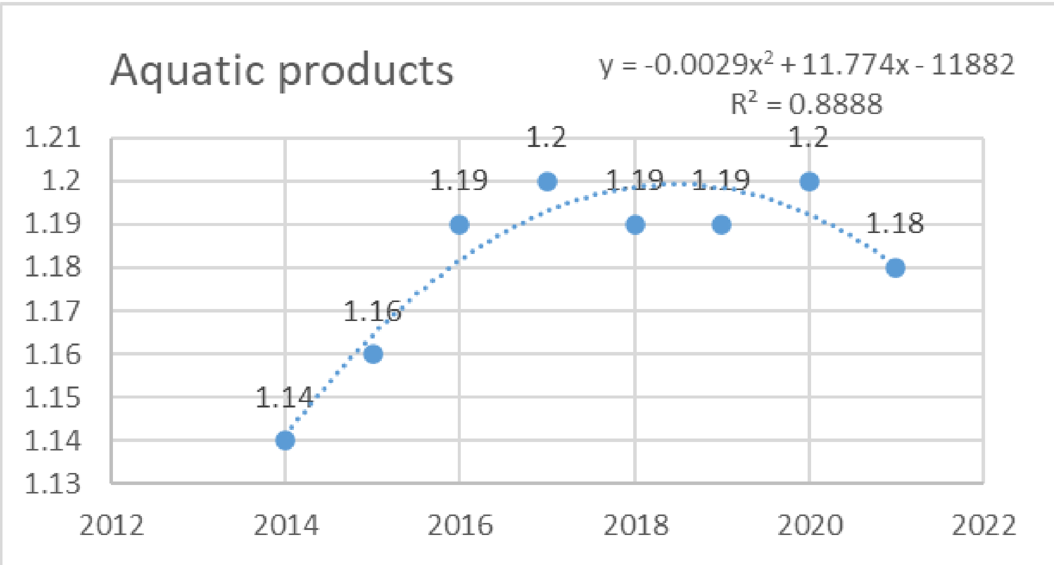


Figure 11: Estimation chart for aquatic products

Meat has a linear decrease trendline and the R square is near to 1, which means it fits the trend very well.

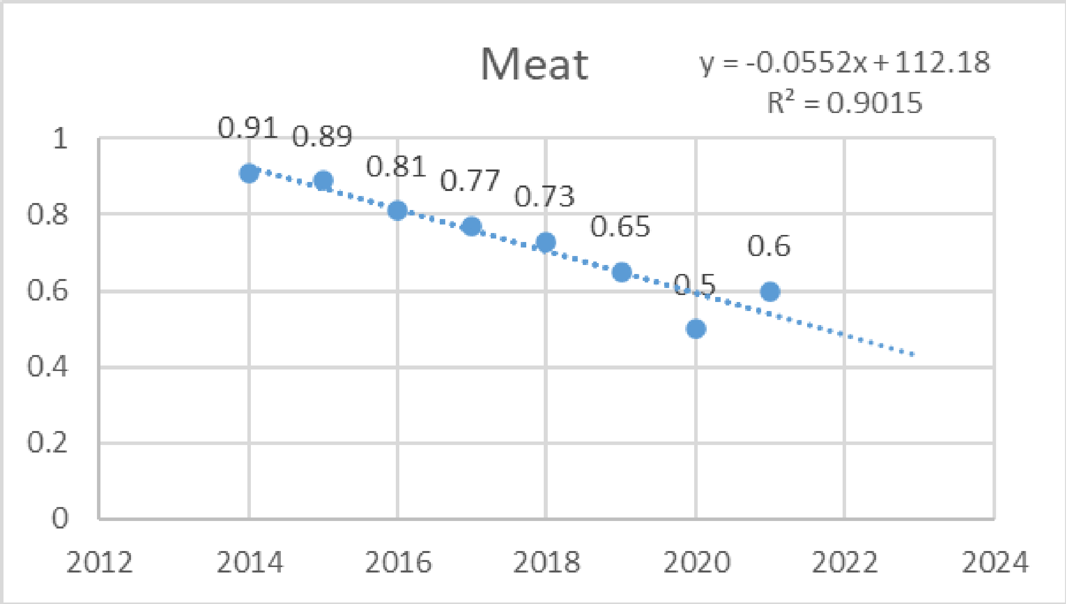


Figure 12: Estimation chart for meat

The number of oil plants remains the same for nearly four years, so the result continues.

Then, the result of the PQ chart.

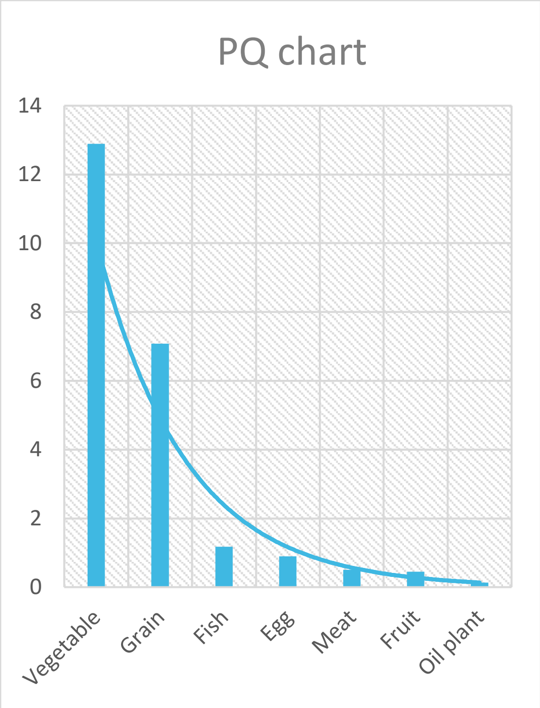


Figure 13: PQ chart

The P-Q chart demonstrates the storage of vegetables and grain is high volume low-variety ’fast movers’, which is justified by a high degree of mechanization, handling equipment, and storage equipment. Fish, eggs, meat, fruit, and oil plant, on the other side, are low-volume, high-variety ’slow movers’, which calls for general-purpose machinery, and low investment in handling equipment.

Activity area division

The storage area is the dominating area of an agriculture warehouse, the subdivision of storage facilitates the storage of agricultural products. According to ‘Processing and Storage of agricultural products’ (Liu et al., 2019), grain storage needs to control moisture, remove impurities, grade storage, air cooling, prevent pests, and confine grain heap. Rice, wheat, and barley are all used in low-temperature and low-humidity confined storage. Considering the warehouse should apply mechanization level for the modern warehouse, we can use grain drying silos to store the grain. As to vegetables and fruits, Liu et al. (2019) gave some methods like trench storage, cellaring, and well cellar. These traditional methods cannot fit the modern mechanization requirements, it can be applied by small-scale farm owners instead of a large-scale modern warehouse. There could be a definite need to have an air conditioning cold storage room. In addition to the function of cold storage, there are nitrogen generators to reduce oxygen, carbon dioxide remover, and other equipment to Inhibit the respiration intensity of vegetables and prolong the storage and freshness period.

During storage, the goal of preservation of food is both quantitative and qualitative. Monitoring the change in temperature and humidity should be carried out systematically. According to the data from the Department of primary industries and regional development (2016), storage conditions for vegetables can be divided into two parts, one is storage by 0°C for most leaf vegetables such as artichoke, asparagus, bean, beetroot, broccoli, brussels sprout, cabbage, carrot, cauliflower, celeriac, celery, collard, endive, garlic, greens, lettuce, mushroom, onion, radish, shallot, spinach, turnip greens. Another one is stored at 10°C which is fit for beans, capsicum, cucumber, eggplant, ginger, marrow, honeydew melon, pepper, potato, pumpkin, squash (hard shell), sweet potato, and tomato. Relative humidity can be 90-100% which is fit for every vegetable except garlic, ginger, marrow, and onion which can be stored in a sealed container inside the part. (Soonchye, 2016)

Fruit and vegetables should be stored separately because most fruits produce a gaseous compound called ethylene which affects all surrounding produce that changes the texture, color, and flavor of the produce, and speeds up the ripening process considerably. (University of Maine, 2023) For the fruit part, Yancheng City only produces apples, pears, grapes, and persimmon. (Yancheng statistical yearbook, 2022) 0°C and 90-95 humidity are suitable for each kind.

When it comes to meat and fish, to fit the market demand and follow the storage method, can be divided into fresh meat areas and frozen meat areas. According to Singapore Food Agency, it can be divided into two separate areas for meat storage: refrigerator (4°C) for fresh meat and freezer (-18°C) for freezing meat. Eggs can be merged into fresh meat areas and oil plants can be merged into vegetable areas. To sum up, six cells to store agricultural products include vegetable Ⅰ(0°C), vegetable Ⅱ(10°C), fruit area, grain area, fresh meat area, and frozen meat area. The storage area can be divided into three main districts (vegetable and fruit district, grain district, and meat district) based on the production estimation and agriculture warehouse layout requirements.

In this green warehouse layout, in contrast to the main floor space areas within the warehouse provided by Richard et al. (2022) and blend agriculture warehouse properties, this warehouse consists of receiving area, reserve storage area, processing area, storage area (vegetable and fruit district, grain district, meat district), packing area, dispatch area, security area, equipment area, waste disposal area, warehouse office.

4.1.3 Flow analysis and relationship diagram

Process analysis

This warehouse's activities include receiving, incoming inspection, receiving storage, processing, a main storage package, and delivery, and the process chart was established to make the whole process understandable.

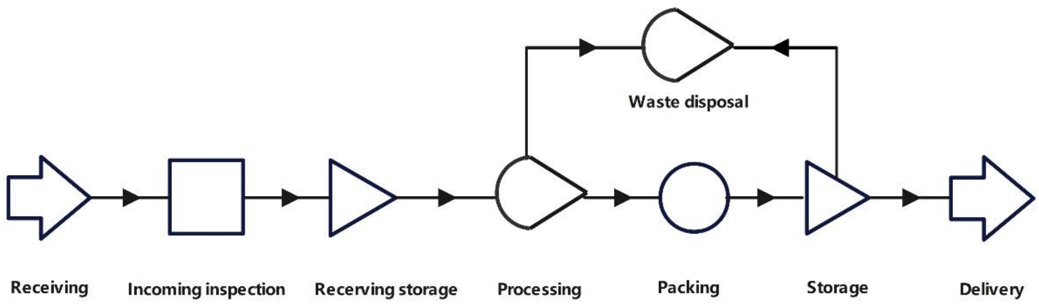


Figure 14: The process chart

The majority of agri-products arrive at warehouses by bulk trucking shipments. Good unloading is the first handling activity. In this case, our cold storage trucks, which are pallet loading with high productivity, get the freshest stock from farmers' precool and ship it in recyclable folding fruit and vegetable trays, precooling of agricultural products refers to a series of technological means to quickly cool the temperature of agricultural products after picking to the optimal storage temperature. Accurate receiving and shipping of goods are imperative for inventory management, and receiving checks is essential for accurate inventory management. Inspection is at the beginning of the warehousing process, items can be assessed instantly at this point and the order problems can be found through the process with vendors, shippers, and other handlers. Furthermore, Inconsistent packaging and order delays can be resolved here. Before warehouse picking, receiving storage is an indispensable process that influences the effectiveness of stock management in the warehouse. Inventory storage management can strengthen the inventory storage system and handle the warehouse in an efficient and cost-saving way which can directly enhance the reduction of crop spoilage. In this warehouse, the picking process has two missions: picking out the defective products and sorting the Agri-products based on size, quality, etc. The defective products will forward to waste disposal for material recycling. The packaging process should use green packaging which refers to package material that can be recycled and regenerative and eco-friendly to human health, then to the stockroom in anticipation of the order.

Logistics flow analysis

From-to chart: A chart indicates the relationships from different dots and is a matrix containing numerical figures representing the metrics (units, unit loads, etc.) of material flow between machinery, departments, buildings, etc. In warehouse logistics, "entries in the chart may represent several material handling trips made between departments in each day, the total material movement represented by weight, cost, quantity, etc." (University of Cambridge, n.d.).

In this case, the from-to chart is to express the process and relative operational quantities. Assuming the daily entrance is 20 trucks, 25t/ truck, the percentage of defective products required to be returned is 0.1%; 8% of waste generated from processing areas; 2% of waste generated during packaging; 4% of waste generated during storage.

		To department							
From department		A	B	C	D	E	F	A	Receiving
	A		478					B	Processing
	B			449	29			C	Packing
	C				9	440		D	Waste disposal
	D							E	Storage
	E				18		422	F	Despatch
	F								

According to Li (2017) and Richard & Lee (2015), they divided the logistics level into five grades: A, E, I, O, and U, the specific division is indicated in the following tables.

Logistic flow level		
Symbol	Meaning	Percentage
A	Very strong logistics level	30%-100%
E	Strong logistics level	20%-30%
I	High logistics level	10%-20%
O	Normal logistics level	5%-10%
U	Unimportant	0%-5%

Operation	Logistics flow	Percentage	Grade
A-B	478	25.89%	E
B-C	449	24.34%	E
B-D	29	1.55%	U
C-D	9	0.48%	U
C-E	440	23.85%	E
D-E	18	0.95%	U
E-F	422	22.90%	E
Total	1843.72-	100%	_

The logistics flow can be described as the logistics relationship chart below.

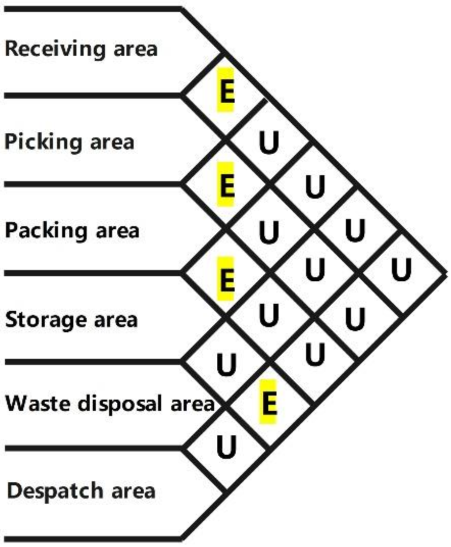


Figure 15: The logistics relationship chart

Area calculation

This warehouse is constructed based on the data and design for village use. According to interview data and official webpages from Yancheng, an estimated one farmer can work for 50 acres and 500 farmers in one village can produce 300 tons of vegetables per day in the peak season. Considering the perishable properties, high turnover cycles, no more than a two-day turnaround, and the aisle area, the warehouse should have more room for the vegetable area, and it can be anticipated by its production ratio according to P-Q analysis.

	Vegetable	Grain	Fish	Egg	Meat	Fruit	Oil plant
P-Q analysis Unit (Mt)	12.89	7.08	1.18	0.9	0.51	0.45	0.13
Estimation Unit (t)	300	164.77	27.46	20.94	11.86	10.47	3.02

Note: This is an overall estimation, and the exact layout is subject to analysis in conjunction with the practicalities and reality.

By the data from companies Xue Yi refrigeration and Kairan refrigeration, meat takes up approximately 5 m³ of space per ton of goods stored, vegetables and fruit take up approximately 6m³ of space per ton of goods stored and grain takes up approximately 2 m³ for one metric ton of cargo stored. The tonnages of the commodity types are added up and divided into three parts. The vegetable, grain, and meat sections weighed 313.49, 164.77, and 60.28 tons respectively, and multiply by respective storage density, which can get a rough estimation.

Depending to data from a company called Hua Xue Refrigeration, meat, fish, frozen meat, etc.: 1 ton 2.5 cubic meters of storage space required, with approximately 4 cubic meters of cold storage space required. Fruits, vegetables, and other fruit and vegetables: 1 ton per 4 to 5 cubic meters of storage space required, with approximately 6 cubic meters of cold storage space required. The concluding remarks of the research are 1 ton of meat or fish: 4 cubic meters of cold storage required (if 2.5 meters high, area approx. 1.6 sq. m). 1 ton of fruit and vegetables: 6 cubic meters of cold storage (if 2.5 meters high, area approx. 4 sq. m). From the measures for the administration of government reserve grain Storage (National Food and Strategic Reserves Administration), the grain bin design capacity is calculated according to the theoretical reference value of the standard wheat bulk weight 0.8t/m³, which means 1 ton of grain need 1.25 cubic meters (if 2.5 meters high, area approx. 0.5 sq. m).

According to Li & Wang (2020), the warehouse area calculation method first calculates the practical area of the warehouse, then determines the total area of the warehouse.

The practical area of warehouse calculation formula:

$$S = Q/q$$

S—Practical area of the warehouse

Q—Maximum storage capacity of the warehouse

q—Storage capacity per unit area

The practical area should be a vegetable area of 1253.96 m², a meat area of 96.448 m², and a grain area of 83.88 m².

The total area of the warehouse formula:

$$A = \sum S / i$$

A—Total area of the warehouse

S—Sum of the practical area of the warehouse

i—Warehouse area utilization coefficient

Considering the cross-aisle width, we estimate i=0.7 The final area size can be roughly estimated as vegetable area (1791.37 m²), grain area (119.82 m²), and meat area (137.78 m²), the total storage area is 2048.97 m².

According to Shen & Wang (2021), the modern warehouse has been transformed from the traditional reserve warehouse to the circulation warehouse which mainly receives and sends. They give approximate area division based on modern warehouse layout, “Modern warehouse general storage area accounts for 40% ~ 50% of the total area; Channel area accounts for 8% ~ 12% of the total area; The receiving and delivery area accounts for 10% ~ 15% of the total area; processing area and processing area account for 10% ~ 15% of the total volume; The return area and waste area account for 5% ~ 10% of the total area.” Based on this, the main area of sustainable warehouse can be estimated as a storage area (2000 m^2), receiving area (600 m^2), processing area (400 m^2), packing area (400 m^2), waste proposal area (400 m^2), channel area (400 m^2), dispatch area (600 m^2).

Relationship diagram

According to Richard & Lee (2015), the relationship chart has become a cross-section form where the relationship between each activity (or function or area) and all other activities can be recorded. The relationship chart indicates the relationship connection of others and makes a criterion that displays their relationship closeness and rate with coded backup reasons.

The chart itself is self-explanatory. The crossing boxes show the relationship between the areas, the top half of the box shows the importance of the relationship, and the low half shows the reasons for its importance. Richard & Lee (2015) also rated the importance of relative closeness required between each pair of activities which are marked by a vowel-letter value scale:” ‘A’ means necessary; ‘E’ means especially important; ‘I’ means important; ‘O’ means ordinary closeness OK; ‘U’ means unimportant; ‘X’ stands for a negative degree of closeness- not desirable” (p. 55).

Based on the principles, the whole relationship chart can be described below.

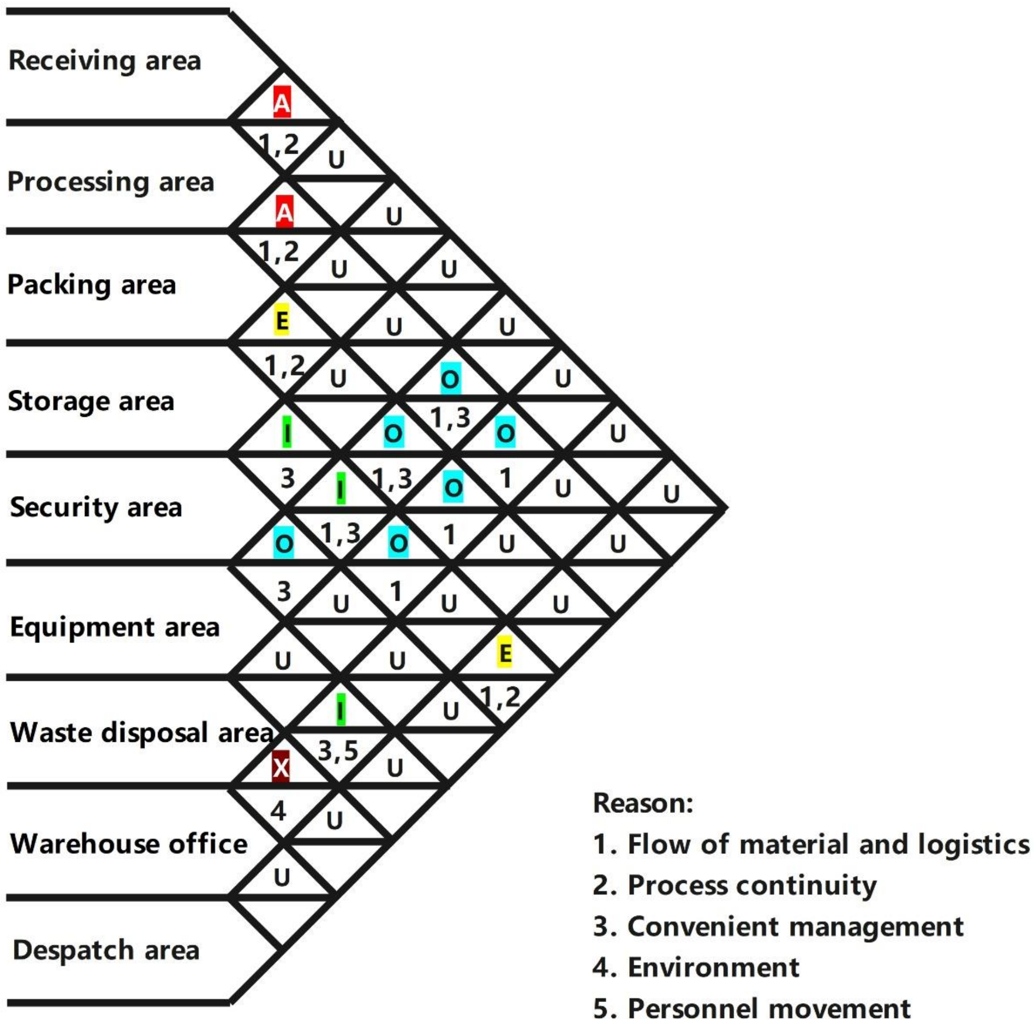


Figure 16: Relationship chart

4.1.4 Final layout

Conventions for Diagramming

The diagramming below indicates different areas and their connection strength directly, the closeness and interrelationship of each area have been described in this diagram. This step is the design structure with a clear vision and preparation for the result’s appearance.

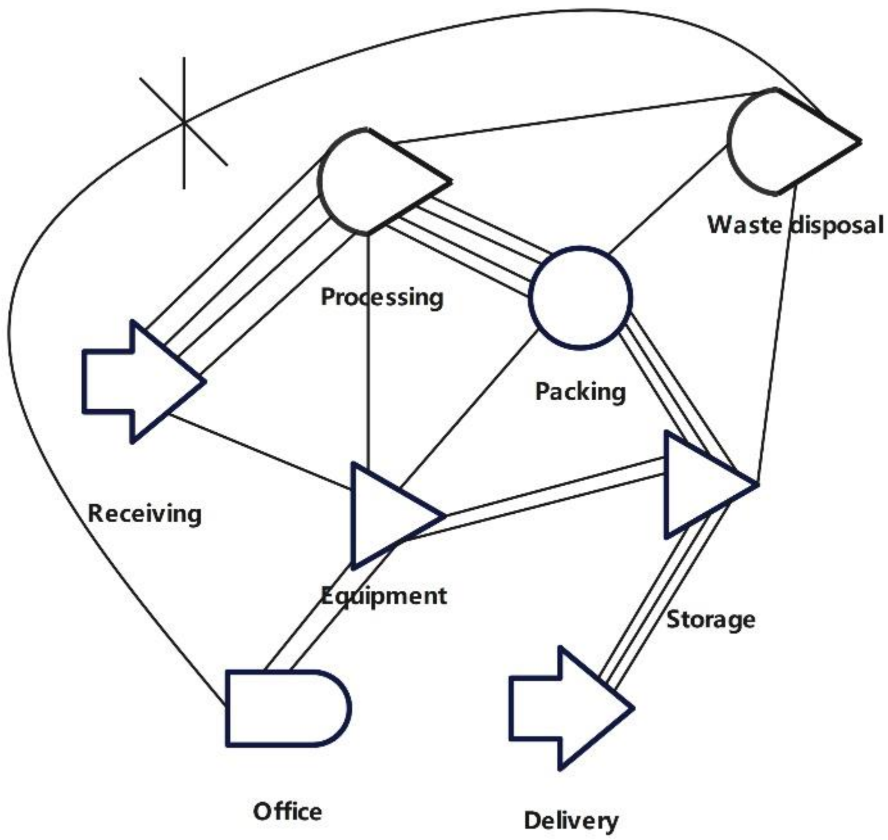


Figure 17: The relationship diagramming

Final sustainable warehouse layout

The final layout is based on the SLP method and is L-shaped. The basic structure is L-shaped which could stack large quantities of goods in the warehouse. The logistics flow inside is also in L shape and the operation process is continuous and consistent. The equipment area is near every area and is convenient for transportation. Waste disposal is far away from the living area and the pallet area is also considered for pallet stacking.

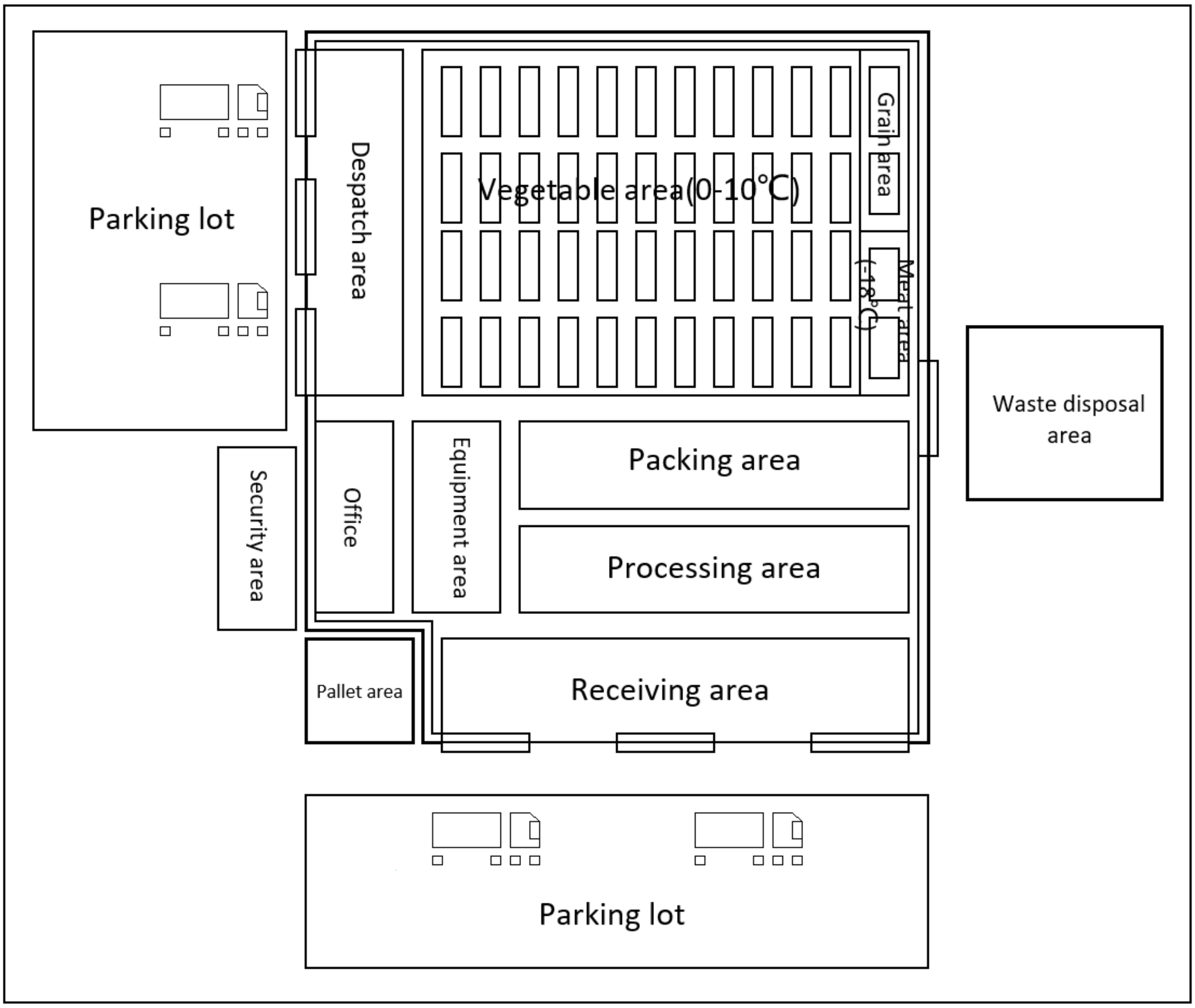


Figure 18: Final sustainable warehouse layout

4.2 Solution 2

4.2.1 Energy use analysis

When analyzing a solar panel system for a warehouse, to determine the size of the solar panel system in a warehouse, the constraints can be defined as the electricity extracted from the solar system and electricity use or Watts use in the warehouse system.

Determine the warehouse energy usage: the elements of warehouse energy consumption can be defined into energy consumption for cooling, energy consumption for ventilation, energy consumption for lighting, energy consumption for equipment area, energy consumption for office, and other energy consumption. Moreover, we need to consider these details: seasonal fluctuation factor because the energy consumption of heating and cooling system and ventilation will be increased or declined in summer and winter; and the photoelectric conversion rate for different solar panels. As this model is in estimation, the practical data is uneasy to access. This solution will be a rough estimate.

4.2.2 Solar panel tilt angle

One of the factors which affect the efficiency of solar panel conversion is solar panel tilt angle conversion. PVsyst is used to get a more accurate outcome.

Because refrigeration in our sustainable warehouse consumes the highest amount of electricity, the discrepancy in incidence angles of sunlight is very huge from summer to winter. As a result, this sustainable warehouse needs two adjustments each year.

Enter the coordinates of Yancheng, import the data from PVsyst, and get the annual solar path from PVsyst, the chart indicates the solar altitude from different times of year. The chart shows that the solar altitude is 76 degrees in the summertime and 30 degrees in the wintertime.

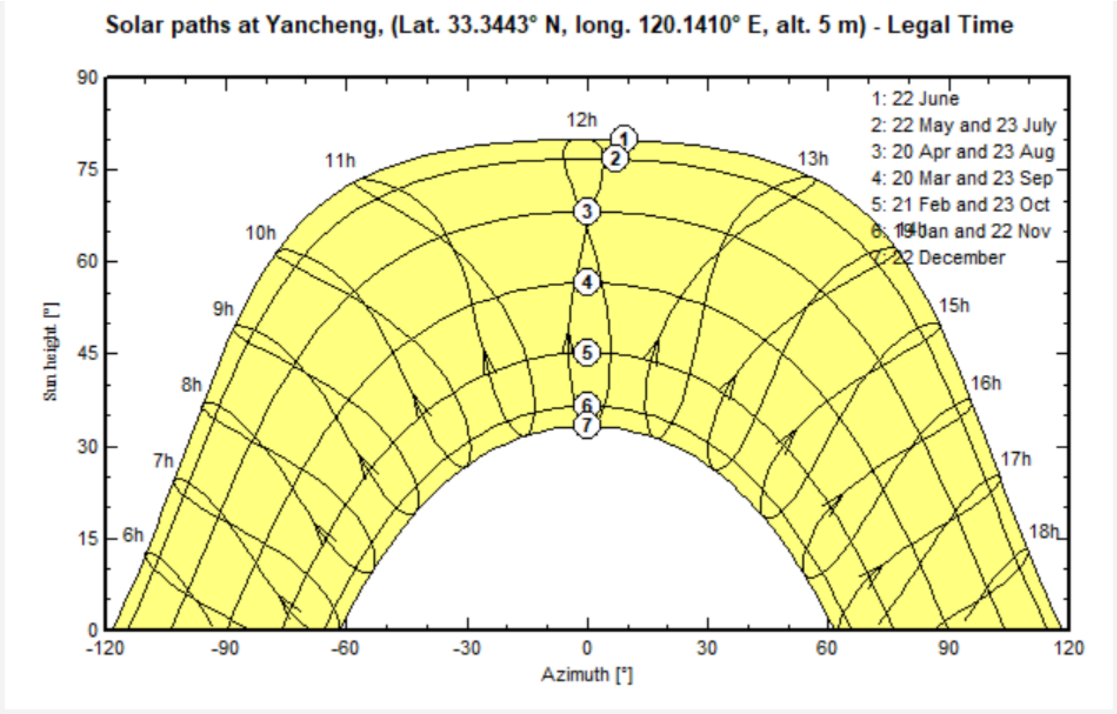


Figure 19: Yancheng city's solar path by PVsyst 7.3

Set the parameters and run the software, the result can be directly got from the optimal solution from PVsyst. For the summer season, the best plane tilt is 14 degrees. For the winter season, the best plane tilt is 43 degrees.

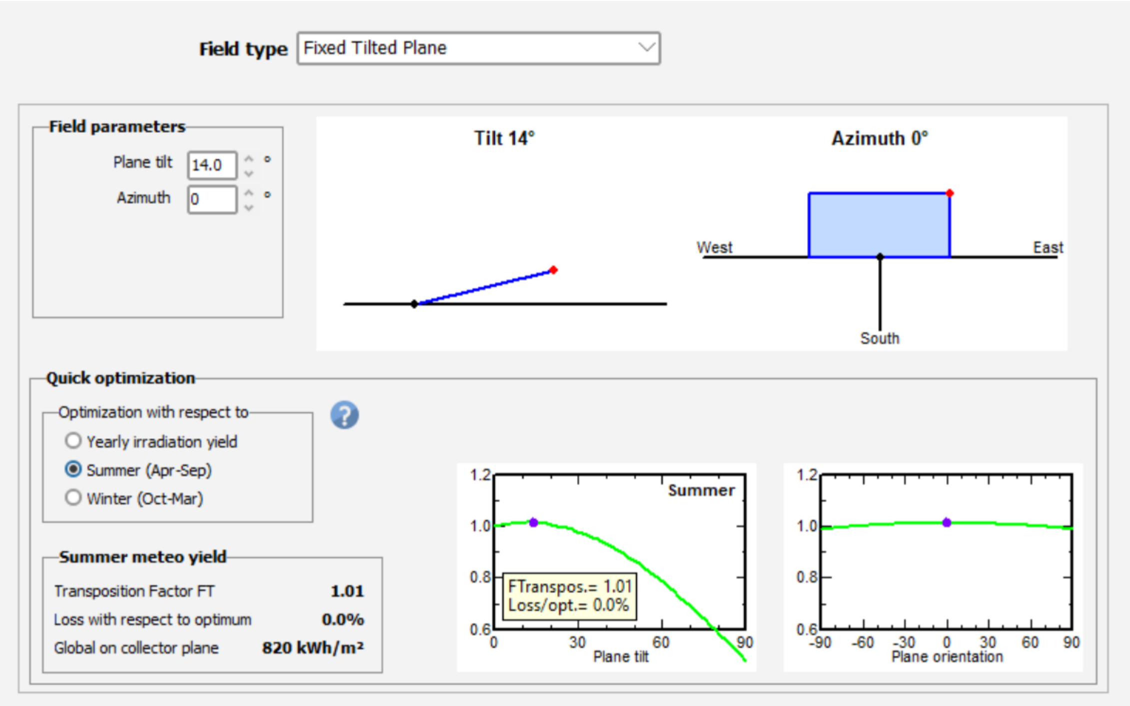


Figure 20: Optimal tilt degree in the summer season by PVsyst

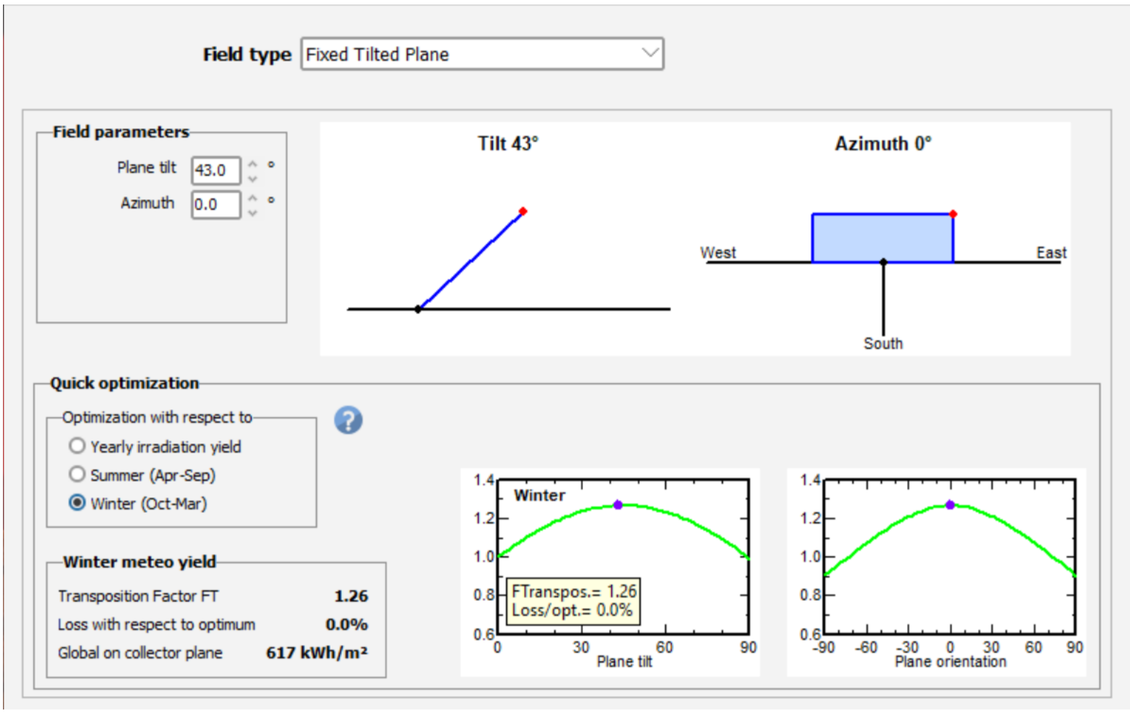


Figure 21: Optimal tilt degree in the winter season by PVsyst

4.2.3 The electricity output of PV solar panel system

The general formula of total electricity generated from the PV solar panel system can be estimated as:

$$E = A * \eta * H * PR$$

Where:

E: is the total energy generated per day(kWh).

A: is the total panel array(m^2).

η: is the efficiency of the yield of the solar panel (%).

H: is the annual average solar radiation on tilted panels.

PR: is the performance ratio, coefficient for solar system losses.

η is the yield solar panel efficiency ratio which equals electricity power (in kW) per solar panel divided by per panel area, the normal ratio should be given in units of W/(1kW) and should be tested in standard test conditions (STC): solar radiation=1000 W/m2, solar cell temperature=25 ℃, Wind speed=1 m/s, AM=1.5.

According to GIES (2018), PR means the solar system performance, the effective irradiance of a particular site is affected by the following factors: inevitable shading, the constrain caused by possible tilt angle, and the orientation of the solar array.

The photovoltaic-software.com gives examples of detailed losses that give the PV value:

- Inverter losses (4% to 10 %)

- Temperature losses (5% to 20%)

- DC cables losses (1 to 3 %)

- AC cables losses (1 to 3 %)

- Shadings 0 % to 80% (specific to each site)

- Losses at weak radiation (3% to 7%)

- Losses due to dust, snow... (2%)

- Other Losses

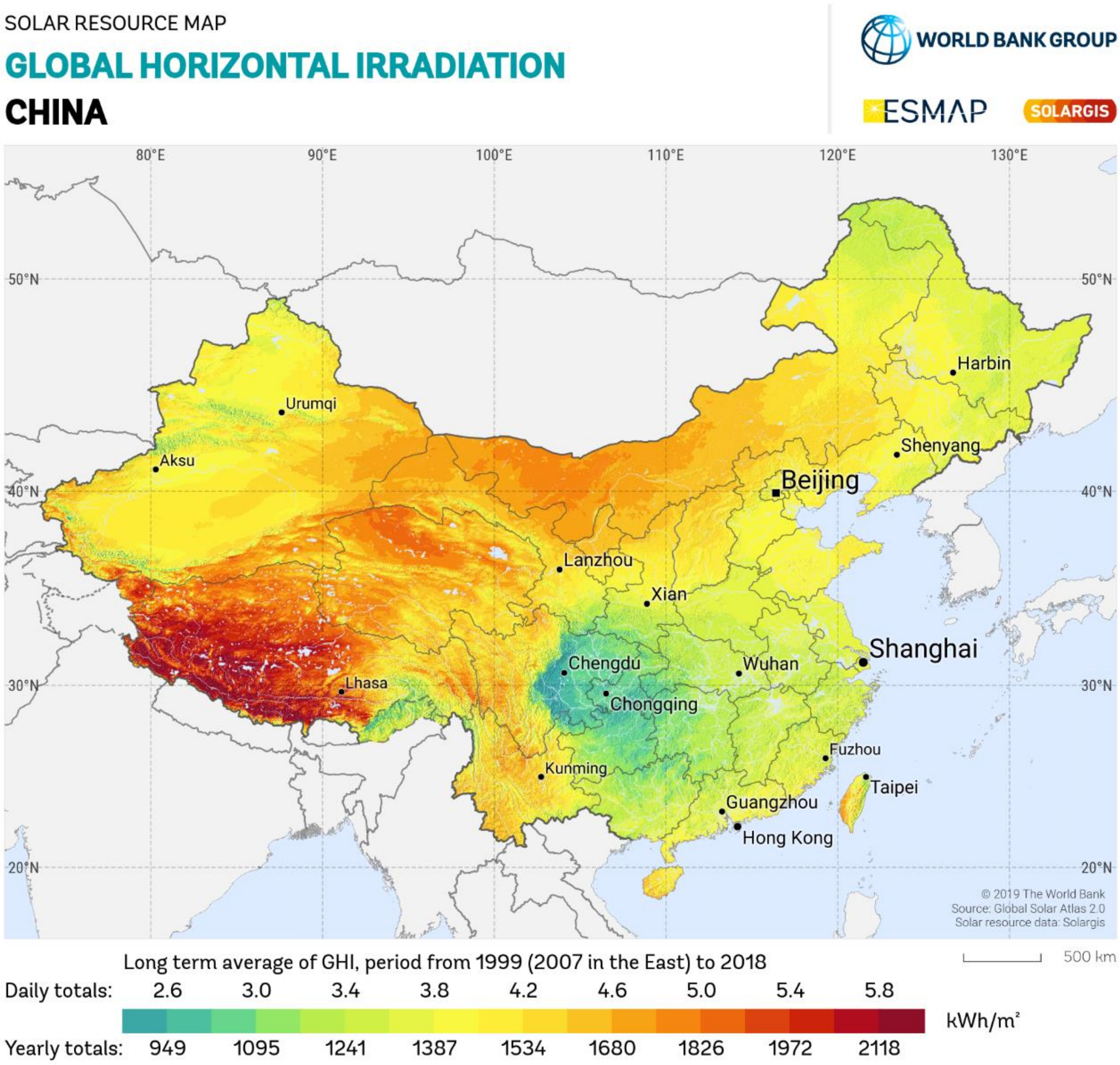


Figure 22: Photovoltaic power potential, world bank, 2019

From this picture, the annual average solar radiation on tilted panels in Yancheng city is around 1400 kWh/m^2 .

The efficiency of the yield of the solar panel can be estimated as:

$$\eta = \frac{PM}{a * PIN}$$

Where:

η: is the efficiency of the solar panel (%).

PM: the peak power refers to the maximum output power of solar cells under normal working or test conditions, that is, the product of peak current and peak voltage (W).

a: is the area of the solar panel (m^2).

PIN: is incident light power per unit area (1 kw/m^2).

In this case, we choose the Chinese brand Trinasolar as our solar panels, the table below indicates their products' parameters.

Specification	W	mm
AK100W-18M	100	1000*540*30
AK120W-18M	120	1200*540*30

Solar panel reference table

The efficiency of solar panel η is 21.45% according to the formula.

4.2.4 The electricity used in the warehouse

The electricity calculation can be estimated as different categories: electricity consumption for refrigerating systems, electricity consumption for ventilation, electricity consumption for illumination, electricity consumption for IT networks and offices, and electricity consumption for forklifts.

$$E_T = E_1 + E_2 + E_3 + E_4 + E_5$$

Where:

E_T: is the total electricity consumption from the warehouse (W).

E_1: is electricity consumption for refrigerating system (W).

E_2: is electricity consumption for ventilation (W).

E_3: is electricity consumption for illumination (W).

E_4: is electricity consumption for IT networks and offices.

E_5: is electricity consumption for forklifts.

The chart below shows the product parameters which include product name, product model, and type specification. The number refers to the number of the product. Power is the energy converted per unit of time (W/H). The hour is the production time required per day (h). The area represents the area required for each product (m^2). We assume the office and other electricity utilization accounts for 5 percent of total electricity utilization.

Parameters	Quantity	Power	Hour	Area
Refrigeration system 1 DD-28.0/140 (-18℃)	1	550	18	140
Refrigeration system 2 SEDL-160(0-10℃)	12	250	18	160
Forklift	2	5500	8	None

XUDA_A_Type_1.0T				
LED 1 YAMING_LED_150W	60	150	8	65
LED 2 Philips_BN005C	24	30	10	15

Refrigeration system 1 is typically used in the meat area, the refrigeration system 2 is used in the vegetable area, we also need two electric forklifts for porterage. For the illumination system, LED 1 is accounted for warehouse large site illumination, and LED 2 is accounted for office illumination.

Therefore, the energy consumption can be estimated as E_T=231.1 kWh per day, the annual electricity consumption is 88791 kWh. The table below shows the calculation of the solar panel area. For the loss details, we estimate the inverter loss is 8%; temperature loss is 8%; DC cables loss is 2%; AC cables loss is 2%; shading is 3%; loss due to dust is 2%; loss due to weak irradiation 3%.

Calculation of the solar PV energy ouput of a photovoltaic system

Global formula : **E = A * r * H * PR**

E = Energy (kWh)	88791	kWh/an
A = Total solar panel Area (m²)	394.47	m²
r = solar panel yield (%)	21%	
H = Annual average irradiation on tilted panels (shadings not included)*	1400	kWh/m².an
PR = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)	0.75	
Total power of the system	84.6	kWp

Losses details (depend of site, technology, and sizing of the system)

- Inverter losses (6% to 15 %)	8%
- Température losses (5% to 15%)	8%
- DC cables losses (1 to 3 %)	2%
- AC cables losses (1 to 3 %)	2%
- Shadings 0 % to 40% (depends of site)	3%
- Losses weak irradiation 3% yo 7%	3%
- Losses due to dust, snow... (2%)	2%
- Other Losses	0%

Figure 23: Final calculation of the solar panel

The total solar panel area is 394.47m^2 , which requires 731 solar panels (AK100W-18M), or 609 solar panels (AK120W-18M) in this sustainable warehouse.

5 Conclusion

To conclude, this project aims to propose a specific warehouse layout with specific constraints. This thesis delves into two questions about warehouse layout and solar panel applications based on the prediction data. The thesis also gives a structure about what is a sustainable agriculture warehouse like in conception.

Question one: What is a suitable layout for a sustainable agricultural warehouse?

The solution combines the SLP method and an L-shaped layout. SLP is a systematical method of layout design, the limitation of this method is the relationship chart may lead to different solutions, and it is difficult to compare the best option. The innovation of this solution is advanced planning based on forecast data; it may cut down construction costs and optimize warehouse internal logistics. For further study, combining the SLP with the designed algorithm through Python will contribute to solving defective restrictions in the best solution.

Question two: How to apply renewable energy to the warehouse system?

The solution is to determine the PV system, analysis the maximum solar energy from the panel tilt angle, the solar panel parameter's comparison and the conditions of energy loss should be considered in solar panel calculation. The basis of the method is the output of electricity is equal to the input from the solar system which is an easy model. When it applies to real calculation, the actual electricity measurement is the basis of solar panel application, and the monthly electricity could be fluctuant, it can apply time series or other estimating methods and build its mathematical model through this to get an accurate result.

Sustainability is the lubricant in circular material flow, the concept of sustainability is accepted by more companies and recognized as enterprise culture. In agriculture, a sustainable warehouse will cut down the waste management of traditional agriculture and create a sustainable economy for farmers consistently.

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