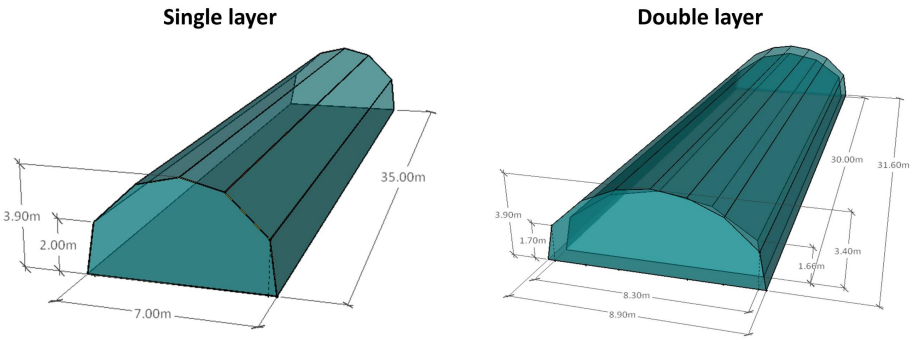

Figure S1. Schematic diagrams of the single-layered and double-layered greenhouses with their dimensions.

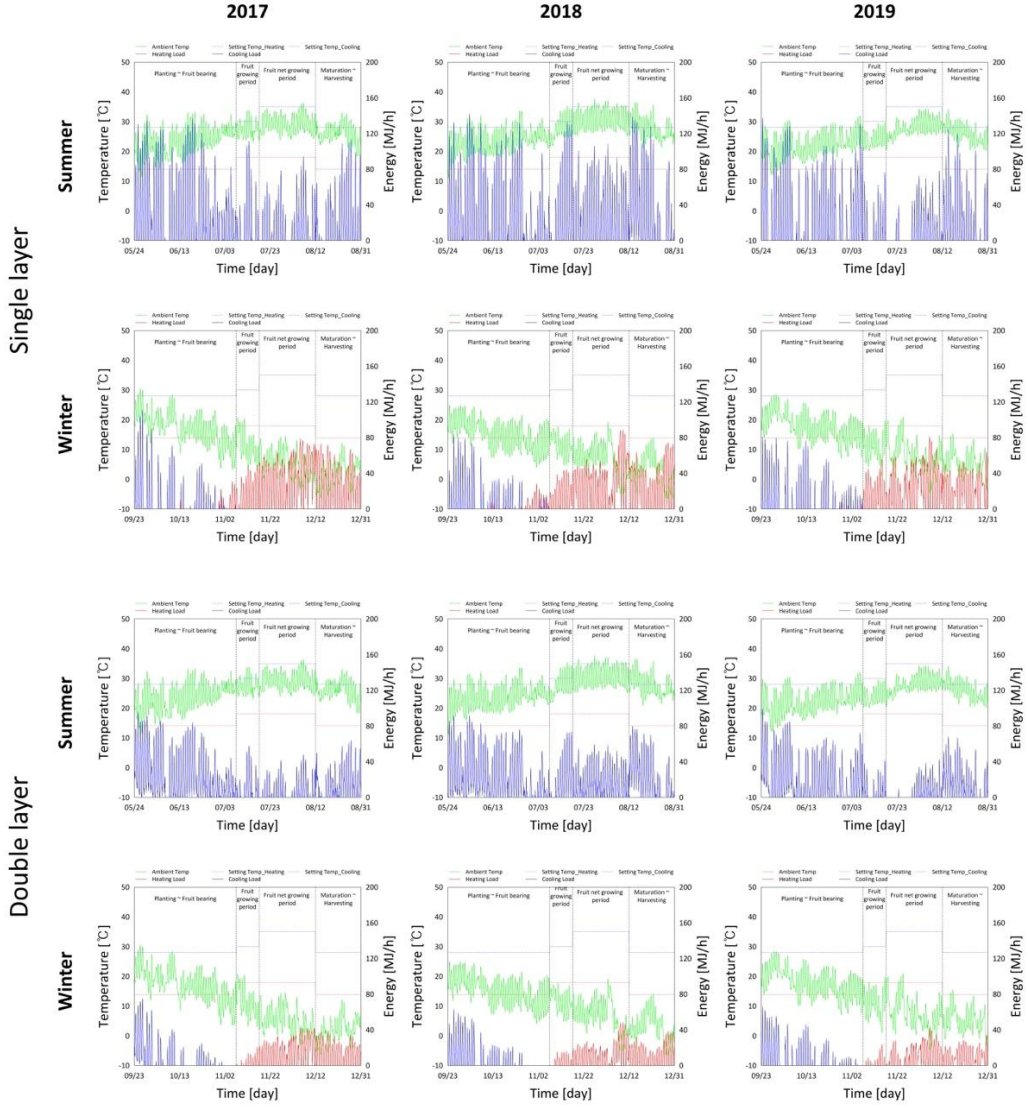

Figure S2. Cooling and heating loads of the greenhouse according to the setting temperature and ambient temperature of the melon growth stage from 2017 to 2019.

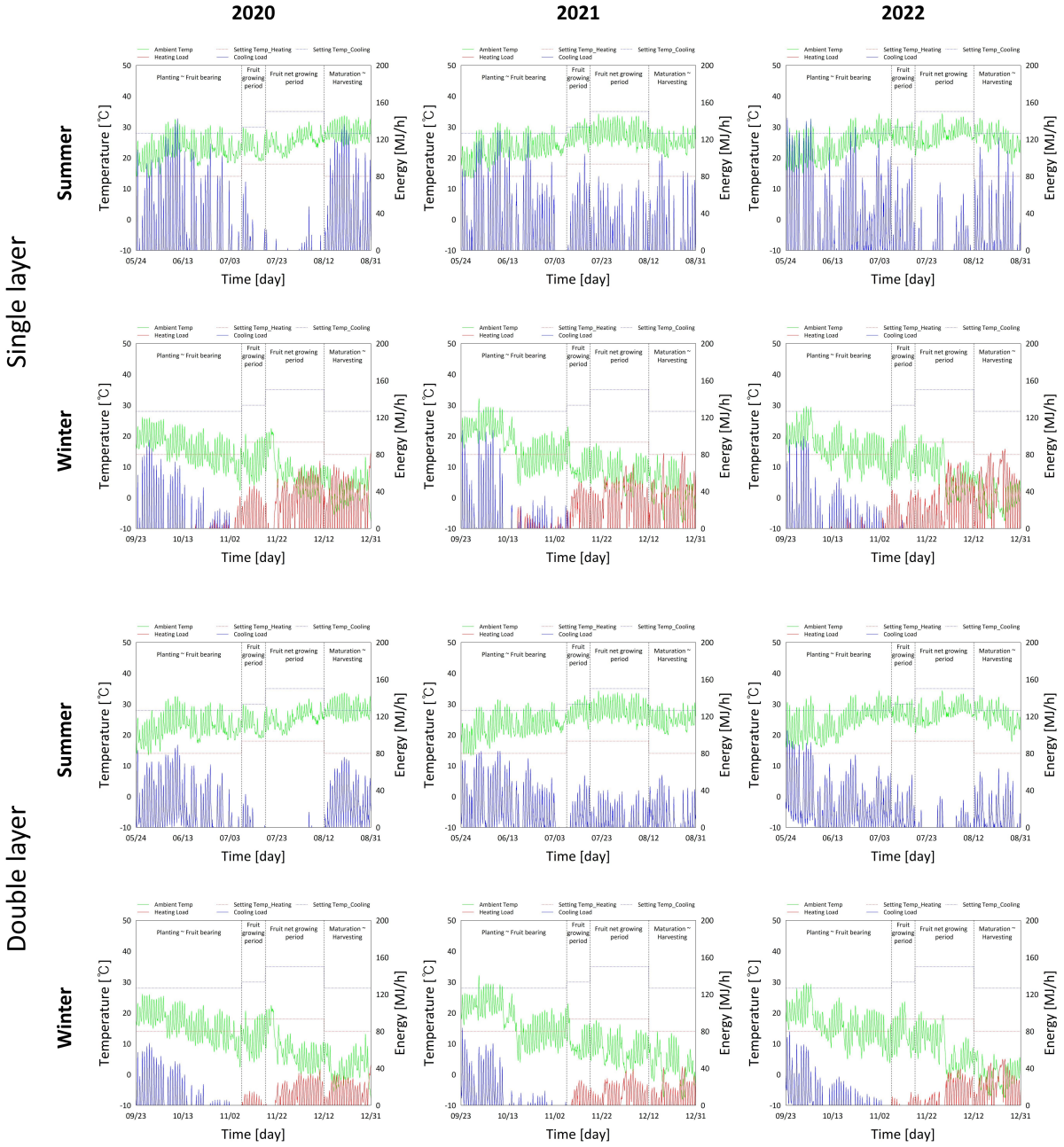

Figure S3. Cooling and heating loads of the greenhouse according to the setting temperature and ambient temperature of the melon growth stage from 2020 to 2022.

Table S1. Dimensions of the greenhouse model.

Characteristics	Specifications		
	Single-layer	Double-layer	
		in	out
Floor area (m^2)	245	249	281.24
Length (m)	35	30	31.6
Width (m)	7	8.3	8.9
Ridge height (m)	3.9	3.4	3.9
Eaves height (m)	2	1.66	1.7
Volume (m^3)	744.97	657.25	193.28(850.53)
Cladding material (mm)	PE film 0.1	PE film 0.1	PE film 0.1

Table S2. Melon growth data during cropping season.

Characteristics	Specifications	
	0~962 (h)	963~2400 (h)
Leaf length (cm)	6.4~23.4	23.4
Leaf area (cm^2)	30~400	400
Leaf number	3~28	28
LAI	0.02~2.8	2.8

Table S3. TRNSYS components used in the energy model of greenhouse.

Component	Images	Specification
Data reader		It is used to read meteorological and crop data.
Equation		It is used to calculate crop energy by receiving meteorological and crop data, as well as greenhouse internal environment data.
Solar radiation processor		Estimate solar radiation on multiple surfaces in fixed or variable orientations.
Psychrometrics		It is used to calculate humidity and temperature.
Effective sky temperature		It is used to determine the effective sky temperature.
Multi-zone building		It is used to model the thermal processes inside the greenhouse, including heating, cooling, ventilation, infiltration, and other related processes.
Online plotter		It outputs the simulation results.
Solar collector		As a flat plate solar collector, users can determine the thermal performance of the collector by providing standard test results.
Thermal storage tank		As a cylindrical storage tank, it is possible to control the stratification and heat interaction within the tank using an isothermal model divided into temperature nodes.
Pump		As a variable speed pump, the flow rate changes according to the control signal settings, and the power consumption is modeled as a polynomial function.
Controller		It can control the equipment by providing ON/OFF signals based on the upper and lower temperature limits.
Load		It is used to calculate the fluid conditions that arise from applying the user-specified load to the flow stream.
Exchanger		A zero-capacitance sensible heat exchanger is modeled in various configurations. In this instance, a counter flow heat exchanger is modeled.

Table S4. Parameter values of components used in the STES model.

Components (type)	Object	Parameters	
Solar collector (1b)	Solar collector; quadratic efficiency, 2nd order incidence angle modifiers	Collector area	10-130 m²
		Fluid specific heat	4.19 kJ/kg·K
		Tested flow rate	40 kg/h·m²
		Intercept efficiency	0.8
		Efficiency slope	13 kJ/h·m²·K
		Efficiency curvature	0.05 kJ/h·m²·K²
		Incidence angle	45°
		Collector slope	South
Thermal storage tank (158)	Cylindrical storage tank	Tank volume	50-400 m³
		Tank height	7 m
		Loss coefficient	0 / 0.3 / 0.5 / 1 / 1.5 / 2 kJ/h·m²·K
		Fluid specific heat	4.182 kJ/kg·K
		Fluid density	992 kg/m³
		Fluid thermal conductivity	2.224 kJ/h·m·K
Pump (110)	Variable speed pump	Rated flow rate (Solar collector)	3,000 kg/h
		Rated flow rate (Load)	30,000 kg/h
		Rated flow rate (Pump1,2,3)	500~5000 kg/h
		Fluid specific heat	4.19 kJ/kg·K
Controller (165)	ON/OFF differential controller	High limit cut-out	80°C
		Upper input temperature Th	Solar collector outlet temperature
		Lower input temperature Tl	Tank nodal temperature-10
		Monitoring temperature Tin	Average tank temperature
		Upper dead band dT	10, 0°C
		Lower dead band dT	2, -2°C
Exchanger (5b)	ON/OFF differential controller	Specific of source side fluid	4.19 kJ/kg·K
		Specific of load side fluid	1.012 kJ/kg·K
		Overall heat transfer coefficient of exchanger	4,400 kJ/h·K