Effects of the Partial Cooling on Tomato (*Solanum lycopersicum*) with the Method of the Undersurface Heat Exchange

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Breakdown of CO_2 Emissions by Fuel Combustion on Japanese Agriculture

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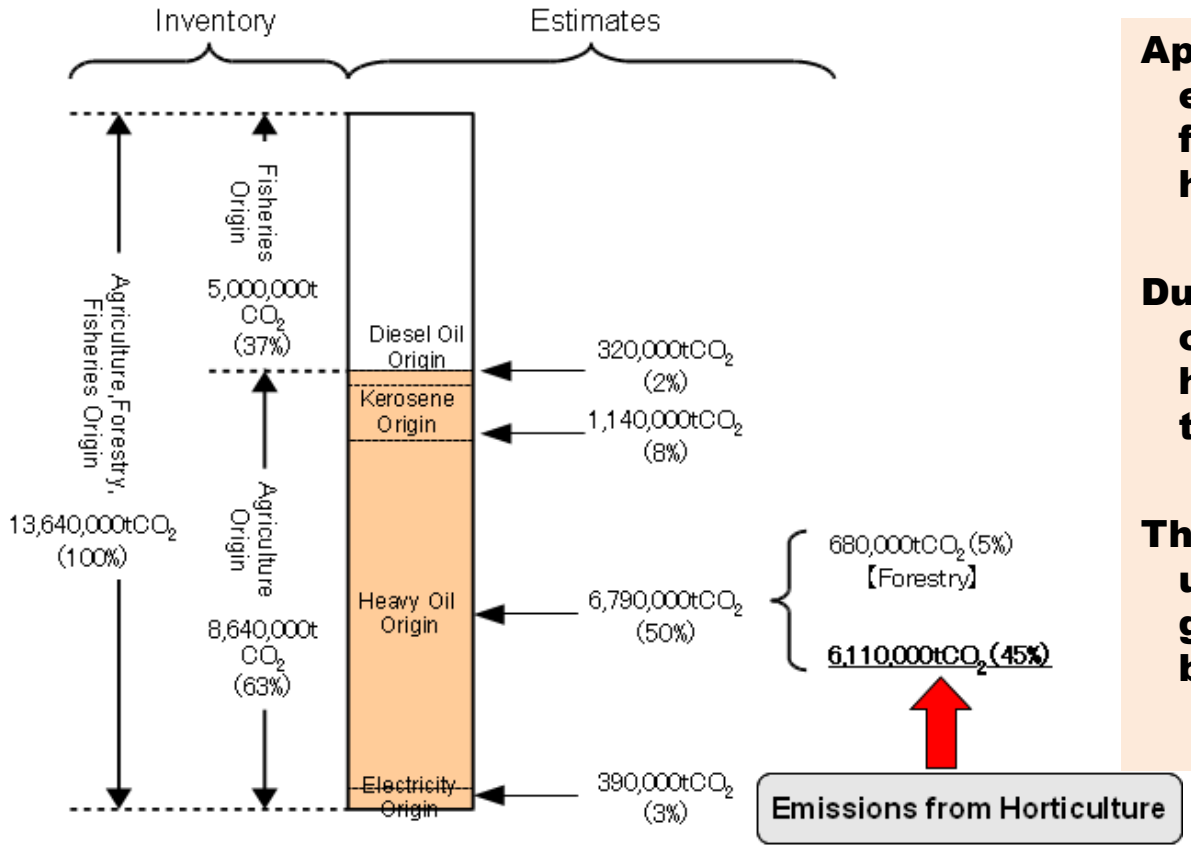

Breakdown of CO2 Emissions on Japanese Agriculture, Forestry, Fisheries (Oikawa, 2007)

Approximately 45% of CO_2 emissions from fuel combustion, for heating a greenhouse horticulture.

During1990 and 2005, consumption of heavy oil consumed by the horticulture has become more than doubled.

The development of a method is urgently needed alternative to greenhouse environmental control by fuel combustion.

High-temperature Injury of Tomato

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In recent years, the progress of global warming, which causes frequent injury of greenhouse tomatoes in summer.

<u>High-temperature Injury of tomato</u>

- **Death of the growing point**
- **Lost of pollen fertility**
- **Occurrence of fruit malformation**
- **Inhibition of fruit enlargement**
- **Occurrence of cleft fruit**

In summer a cooling technique of greenhouse is required that can be installed at low price.

Death of the Growing Point

Fruit Malformation

Cleft Fruit

Technical Targets and Solutions

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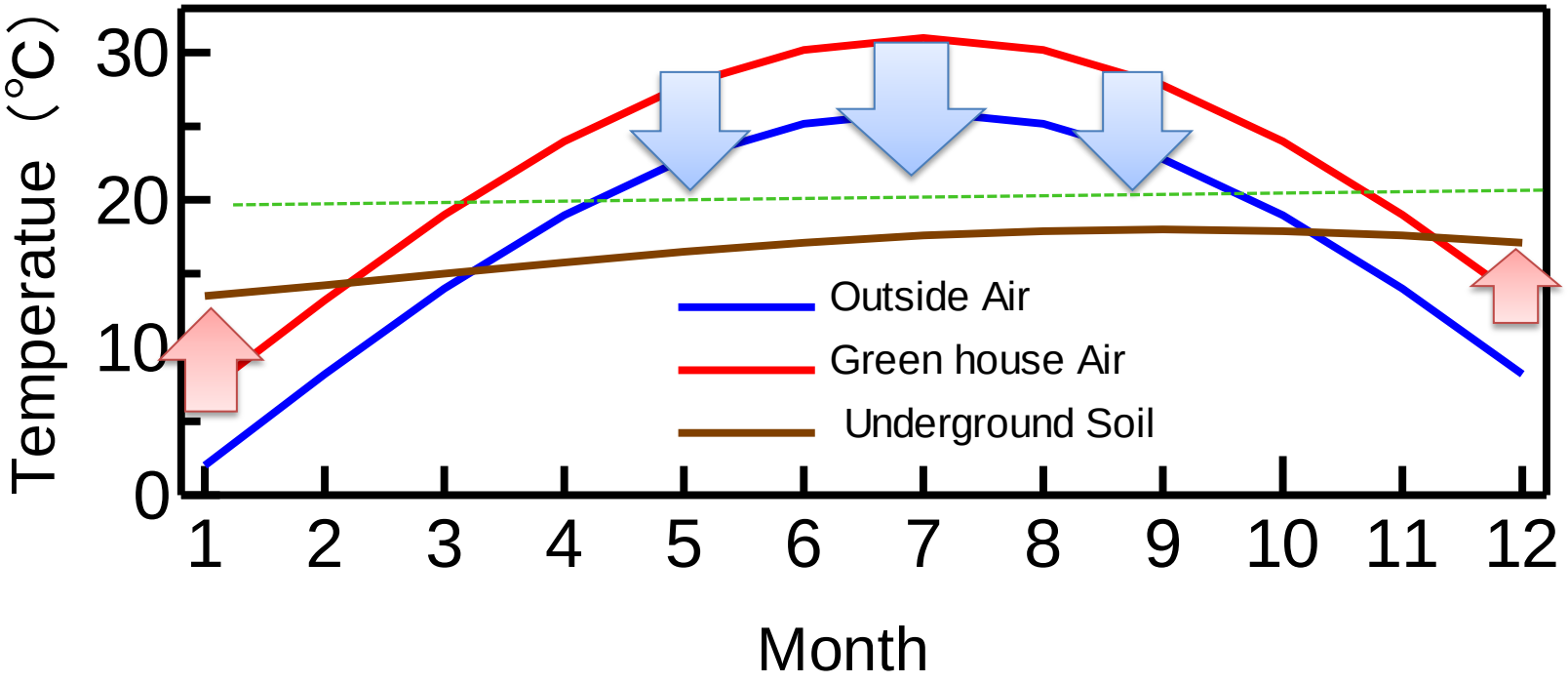
Targets

- Alternative method of greenhouse heating by fuel combustion.
- A cooling technique of greenhouse against global warming.
- Reasonable against the initial installation and running cost.
- Can be conducted anywhere in Japan.
- Can be attached to the greenhouse currently owns.

Solutions

- Use of renewable energy.
- Possible to achieve both heating and cooling with the same equipment.
- Optimized for size of greenhouse and the type of crops.
- Can be installed by the farmers themselves

Utilization of Soil Temperature



Soil temperature is almost constant throughout the year (deeper than a few meters) . By achieving equilibrium to the soil temperature, we can obtain cooler air in summer and warmer air in winter which is suitable temperature for the crop.

Zentsuji Test Site

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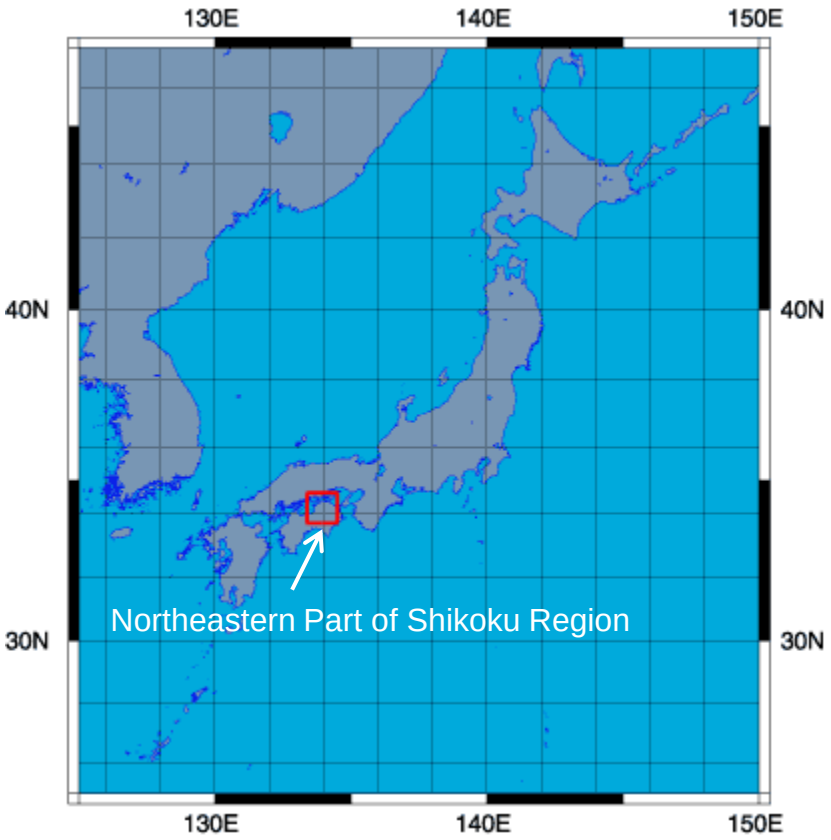

Latitude	34°12'26"N
Longitude	133°47'17"E
Elevation	106m
Average Air Temperature(2010)	16.2°C
Maximum Air Temperature	36.5°C
Minimum Air Temperature	-2.8°C

My Institute is located in Zentsuji-city in Kagawa Prefecture . Here is located in the northwestern part of Shikoku region.

Around here, because the elevation is low and the summer temperature is too high, it is not suitable for the greenhouse tomato production.

Also, in winter tomato production is impossible without any heating technique.

Application of Artificial Cave for Underground Heat Exchange

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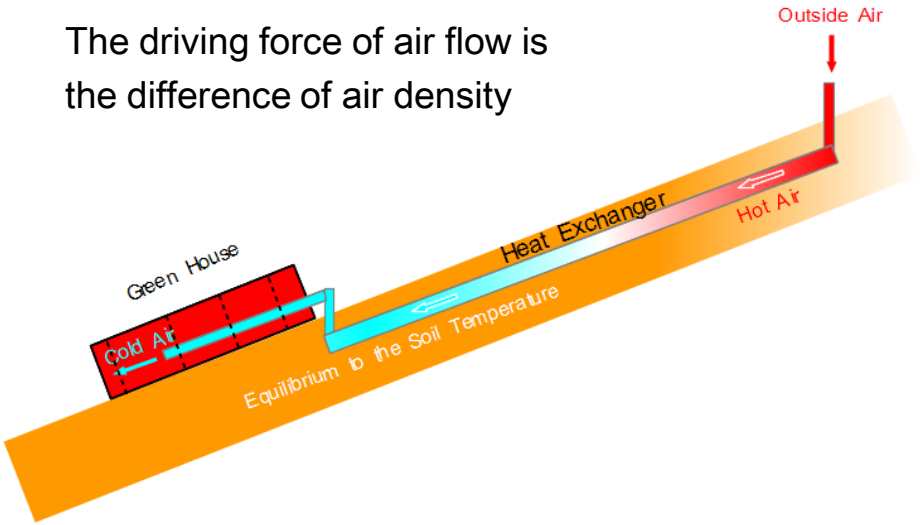
Landscape of slope where the tests were conducted. There builded two greenhouses for comparison.

The driving force of air flow is the difference of air density

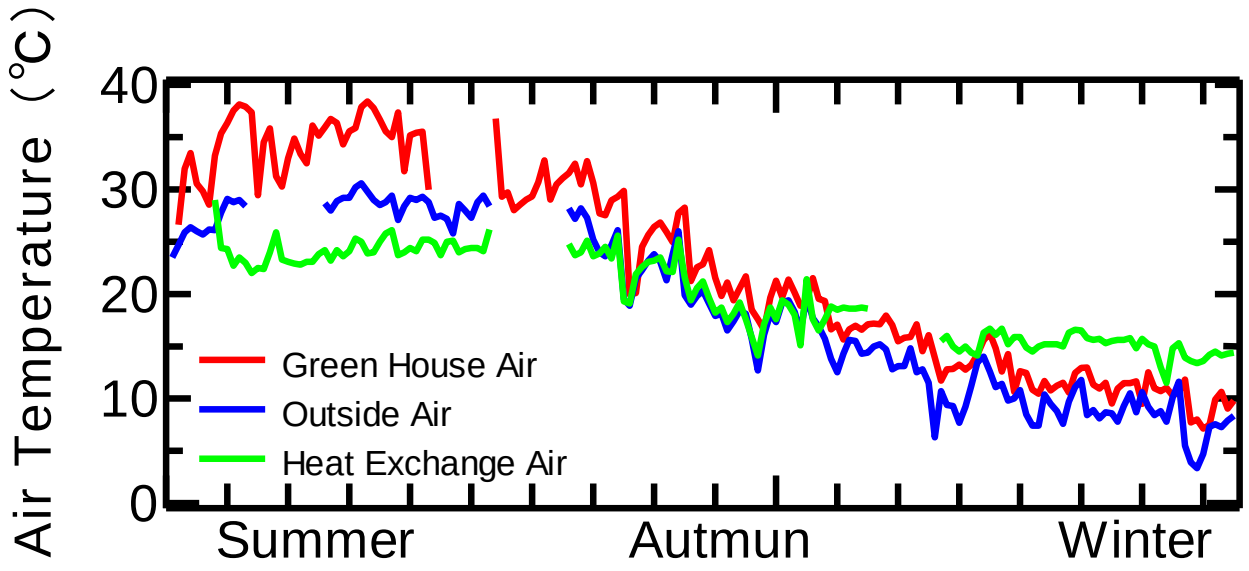


Schematic diagram of the underground heat exchanger

This figure represents the status of active transport of cold air to the greenhouse in summer.

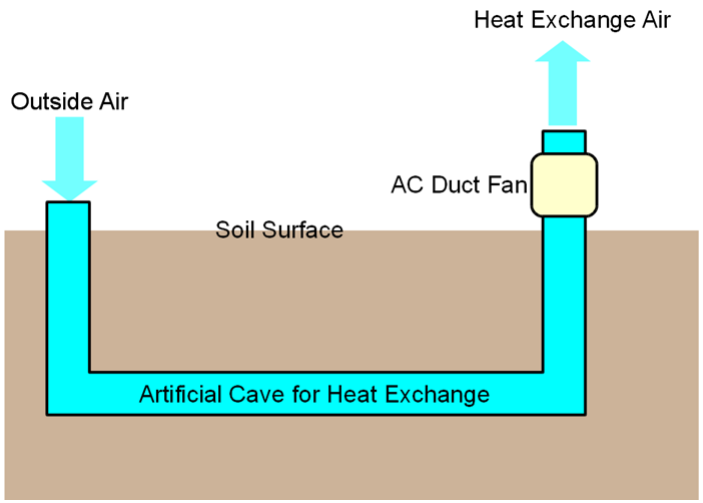
The heat exchanger, 0.6m diameter, 70m long pipe made of polypropylene, which works like an artificial cave.

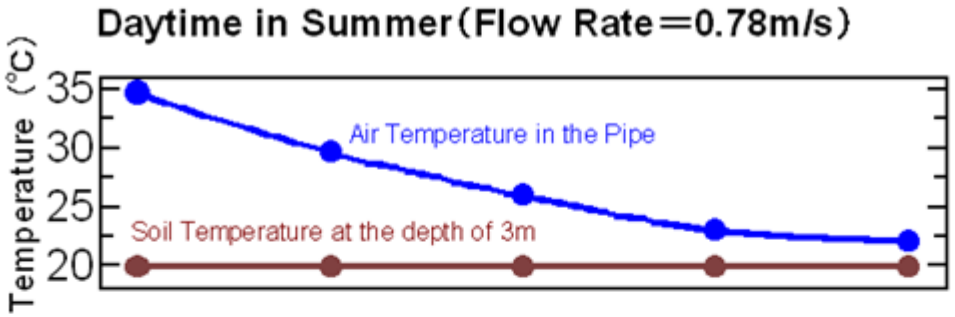
Performance of Artificial Cave

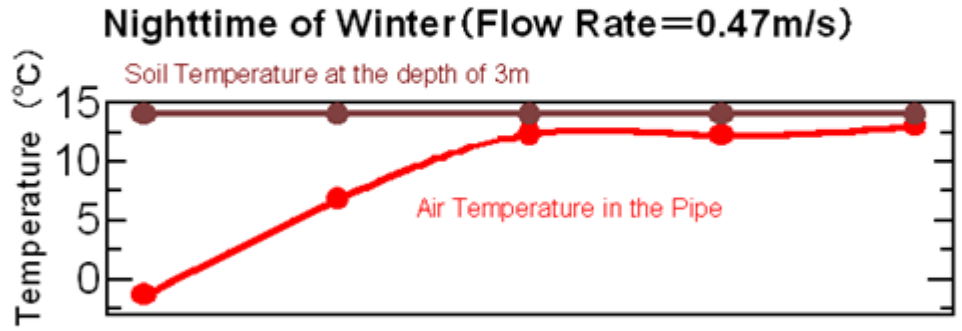


Undergronud heat exchange air showed the expected temperature. However, since its amount is too small to control the temperature of the entire greenhouse. Also because of the effect of wind, the flow rate was unstable.

Performance in the case of forced air transportation



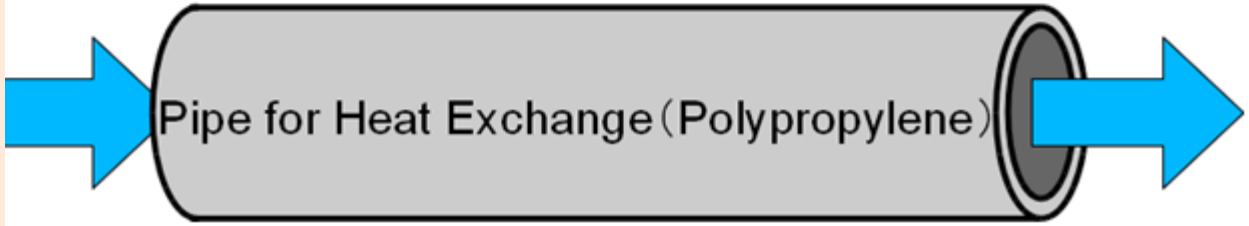




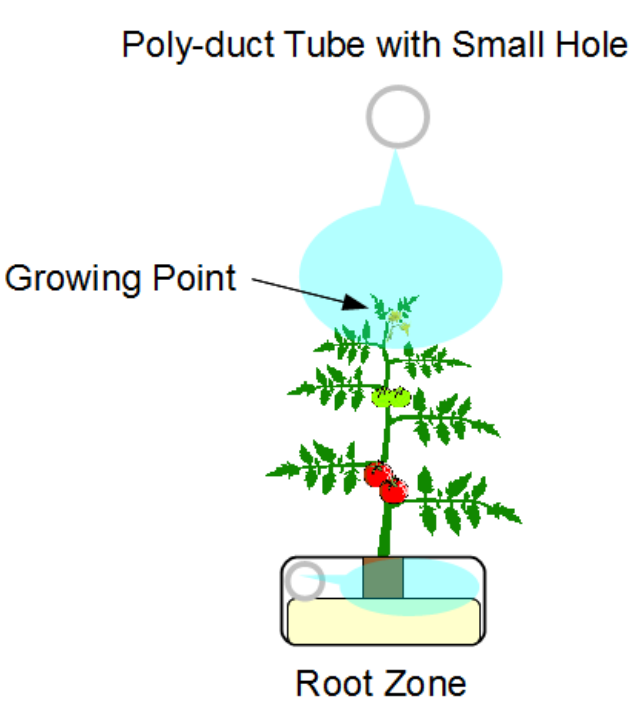
To obtain heat exchange air stably a AC duct fan was installed.

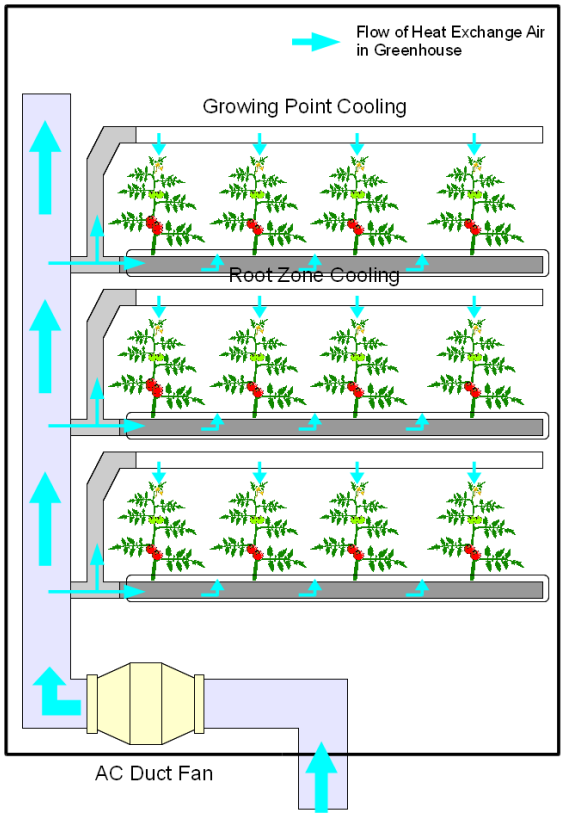
In the daytime of summer the 35 degree-C outside air could be controlled to 22 degree-C.

In the nighttime of winter -2 degree-C outside air could be controlled to 13 degree-C.



Partial Environmental Control





Schematic Diagram of Entire Greenhouse

Situation of Tomato Cultivation In 2011

In order to control the temperature of the whole greenhouse, the heat exchanger is required unrealistically large.

Partial environmental control was conducted focusing on the important part for plant physiology.

Heat exchange air was transported onto the top of plant (growing point) and supplied in the film wrapped the rock wool mat.

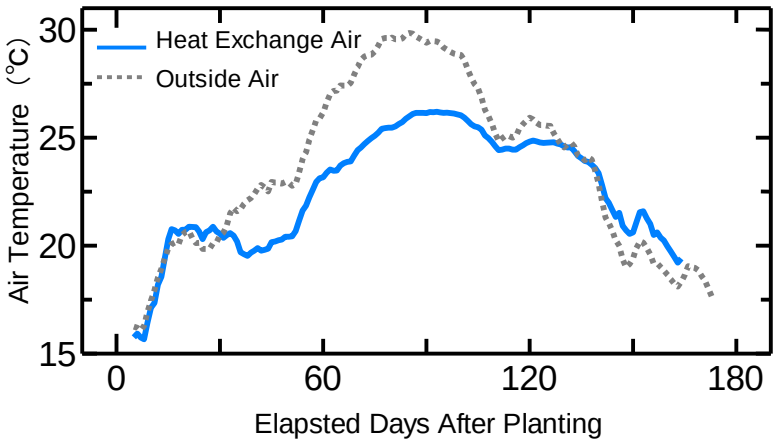
Method

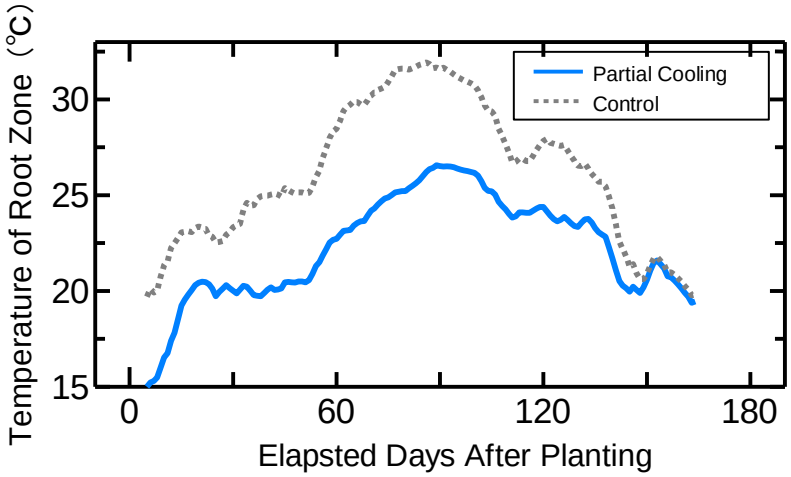
Warming Condition (+1.5degree-C)
Cultivar: Tomato (Momotaro eight)
Cultivation: Nutriculture
Period: 2008 June – Dec.

Forcing Test
Cultivar: Tomato (Home Momotaro)
Cultivation: Nutriculture
Period: 2010 Sept. – 2011 Mar.

Extension of Cropping Period
Cultivar: Tomato (Momotaro eight)
Cultivation: Nutriculture
Period: 2011 May – 2012 Mar.

Results of Warming Condition





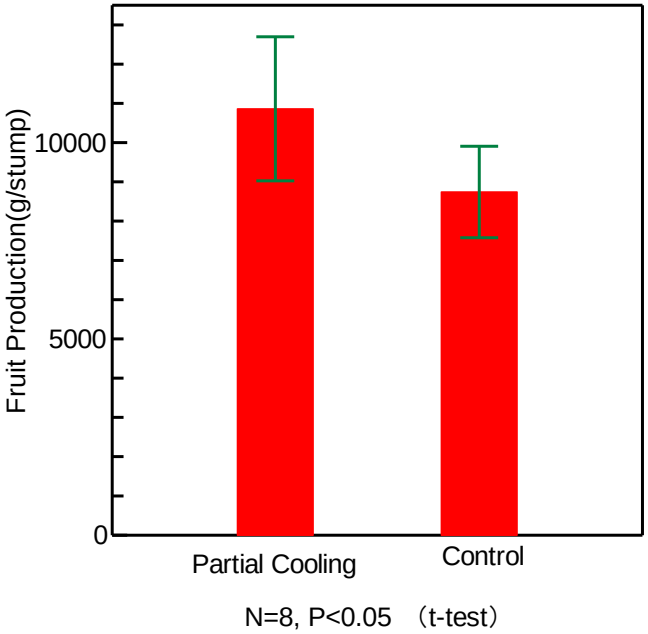
In the summer of 2008 we settled the warming condition by reducing the open of side window. Average daily air temperature exceeded 30 degree-C. Sometimes air temperature exceeded 50 degree-C in the daytime.

Despite such a severe condition, the heat exchange air less than 26 degree-C was supplied. And that the temperature of root zone dose not exceed 27 degree-C.

Effects on Tomato Fruit Production When the Warming Condition

Leaf color is good.

Leaf color is yellow.
Owing to the injury of root,
fertilizer was not fully absorbed



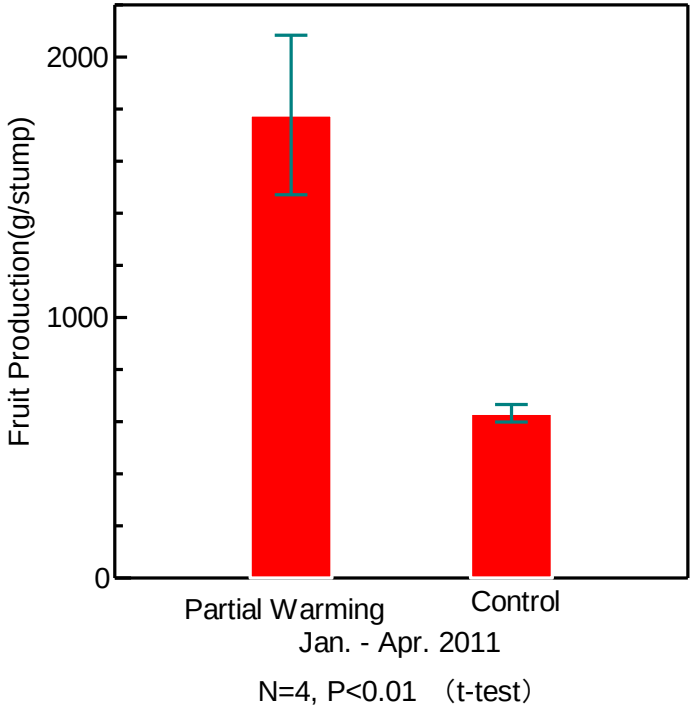
N=8, P<0.05 （t-test）

The leaf color and plant vigor was much better and the fruit yield was 20% higher than control by partial cooling.

Tomato Fruit Production in Forcing Test

Growing point is vigor.

Growing point is dead with the advent of cold weather in January.



With the advent of cold weather, tomatoes of control are dead.

As a result, the yield of partial heating treatment is much more yeild than control.

However, the yield is low comparing with generic forcing.

Effects on Tomato Fruit Production When the Normal Summer Condition

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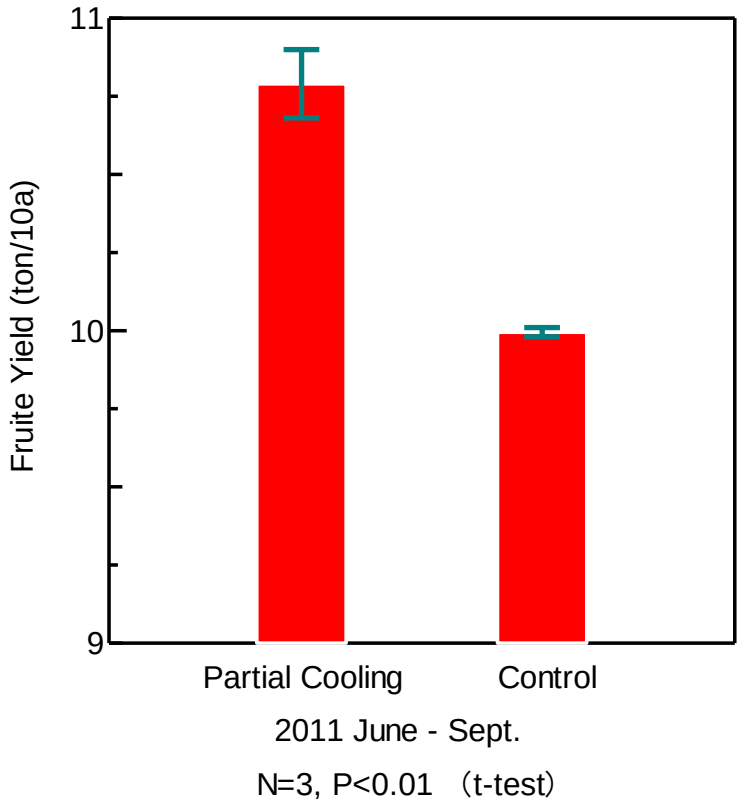
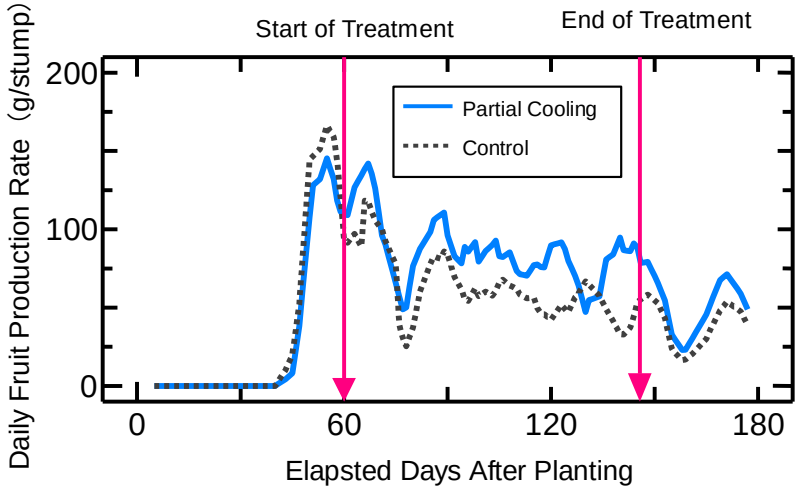


The fruit yield was about 10% higher than control by partial cooling even in the normal summer condition.

Cultivation will continue until next March.

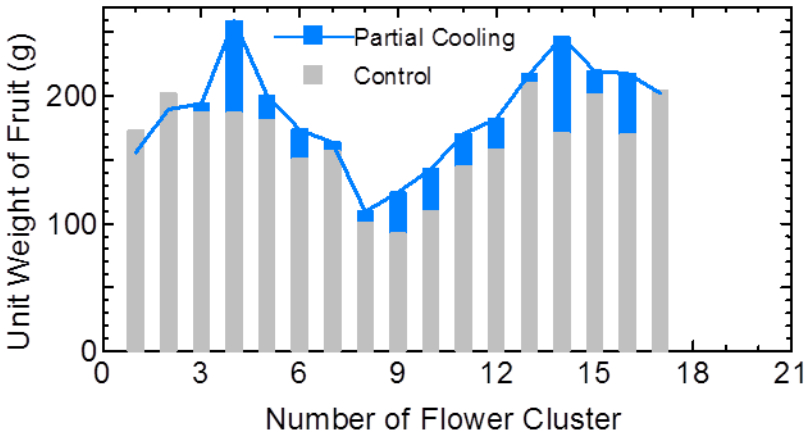
How far is the fruit yield increased ? How much is the estimate of CO_2 reduction per unit fruit yield with this undersurface heat exchange method? I'm looking forward to its conclusion.

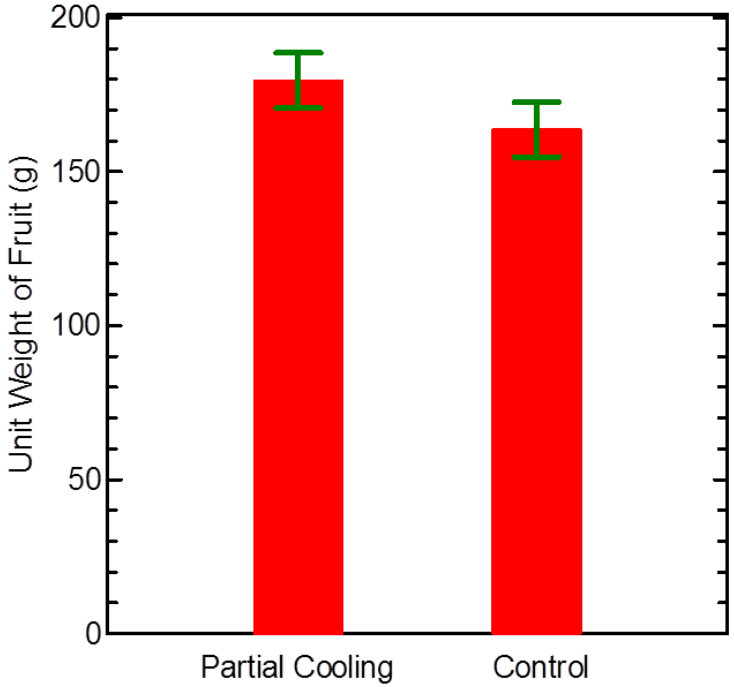
Reason of Higher Production



The partial cooling treatment raise the daily fruit production rate continuously. The rate of photosynthesis was increased.

Reason of Higher Production



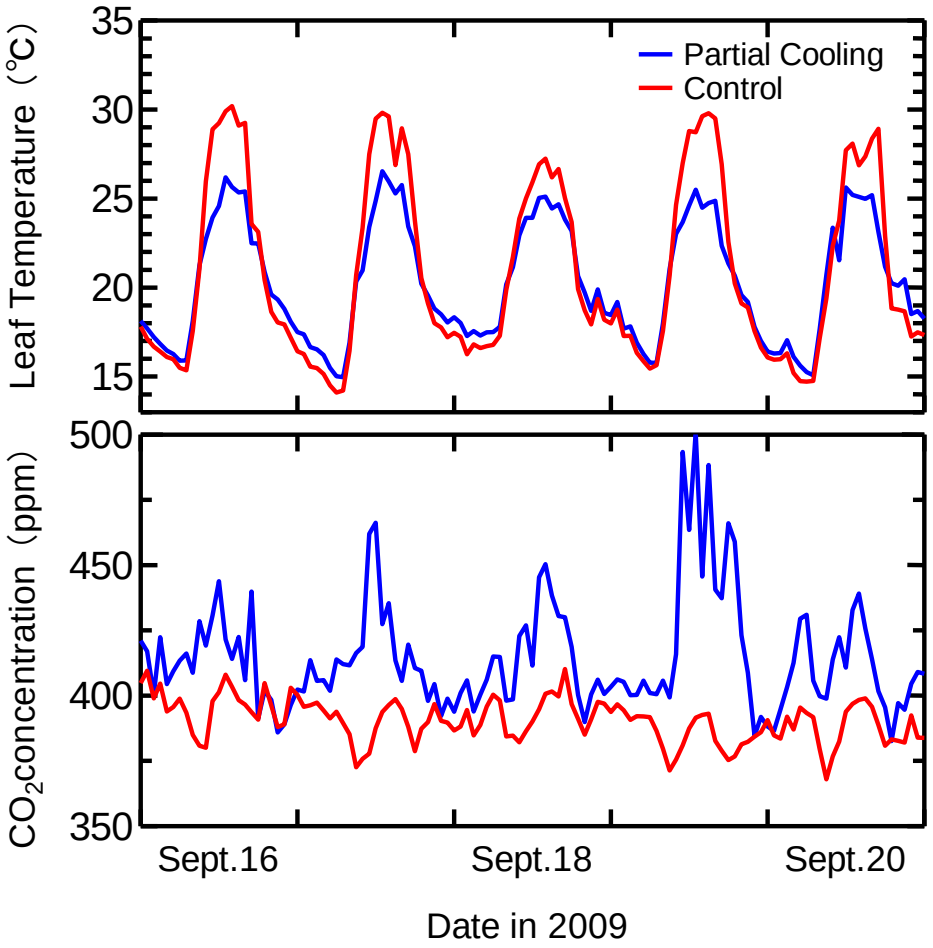


N=8, P<0.05 (t-test)

Number of fruits is not so much different. In other words, partial cooling treatment does not lead to the fruiting efficiency.

Since a significant difference between average weight per fruit, increased yield was brought by increased weight of unit fruit.

Air Quality Control



Observations revealed that relatively high concentrations of CO_2 are sent during the day by partial cooling.

Moreover, since the temperature drops below the dew point at the underground, the humidity has dropped.

Not only the temperature but also the modification of these air quality increased the rate of photosynthesis.

Demonstration at Ato Test Site

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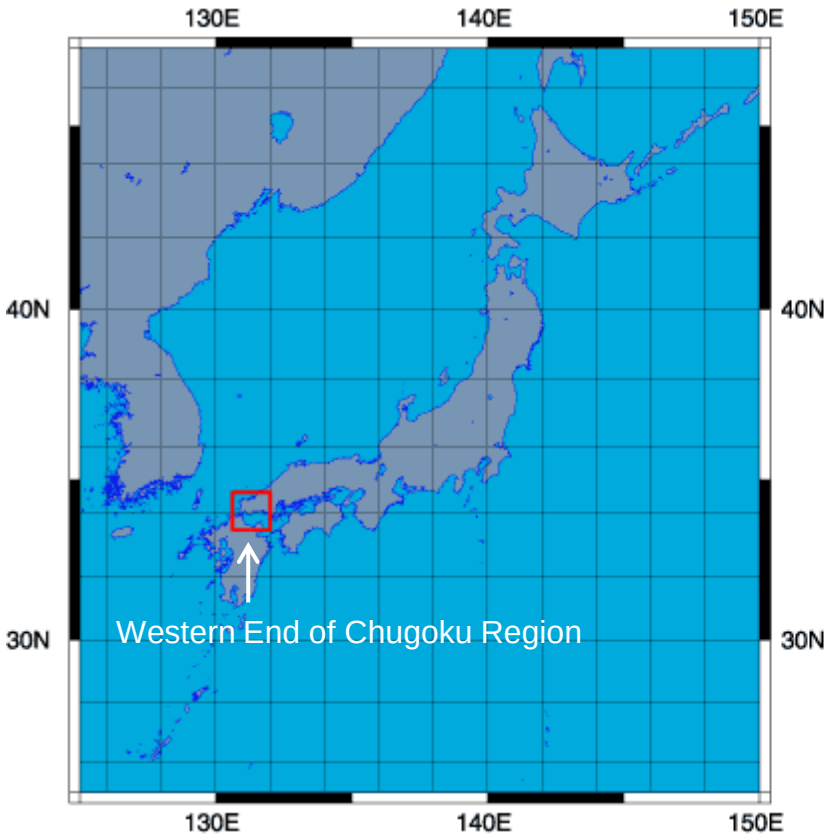
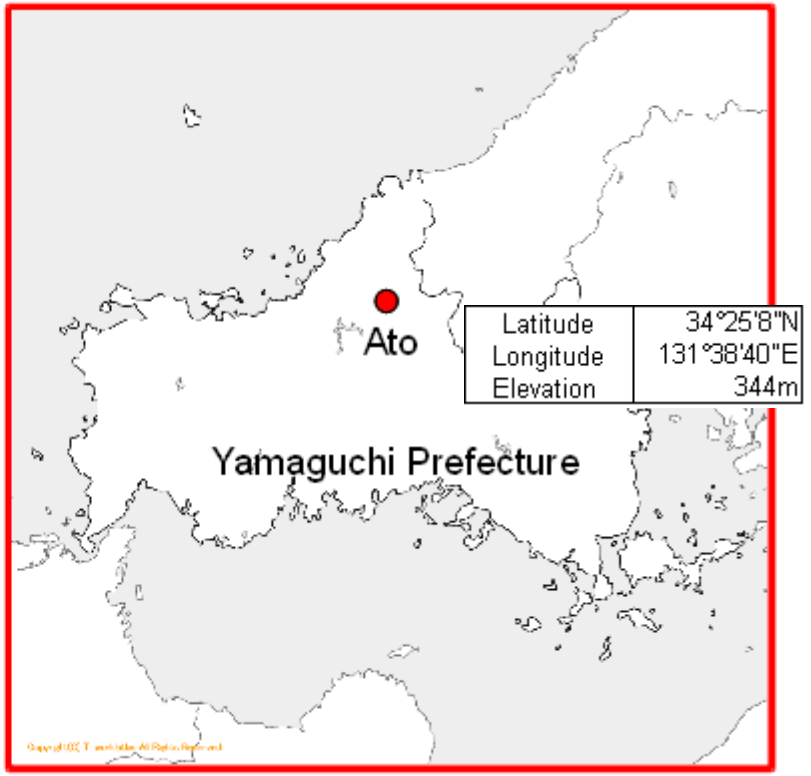
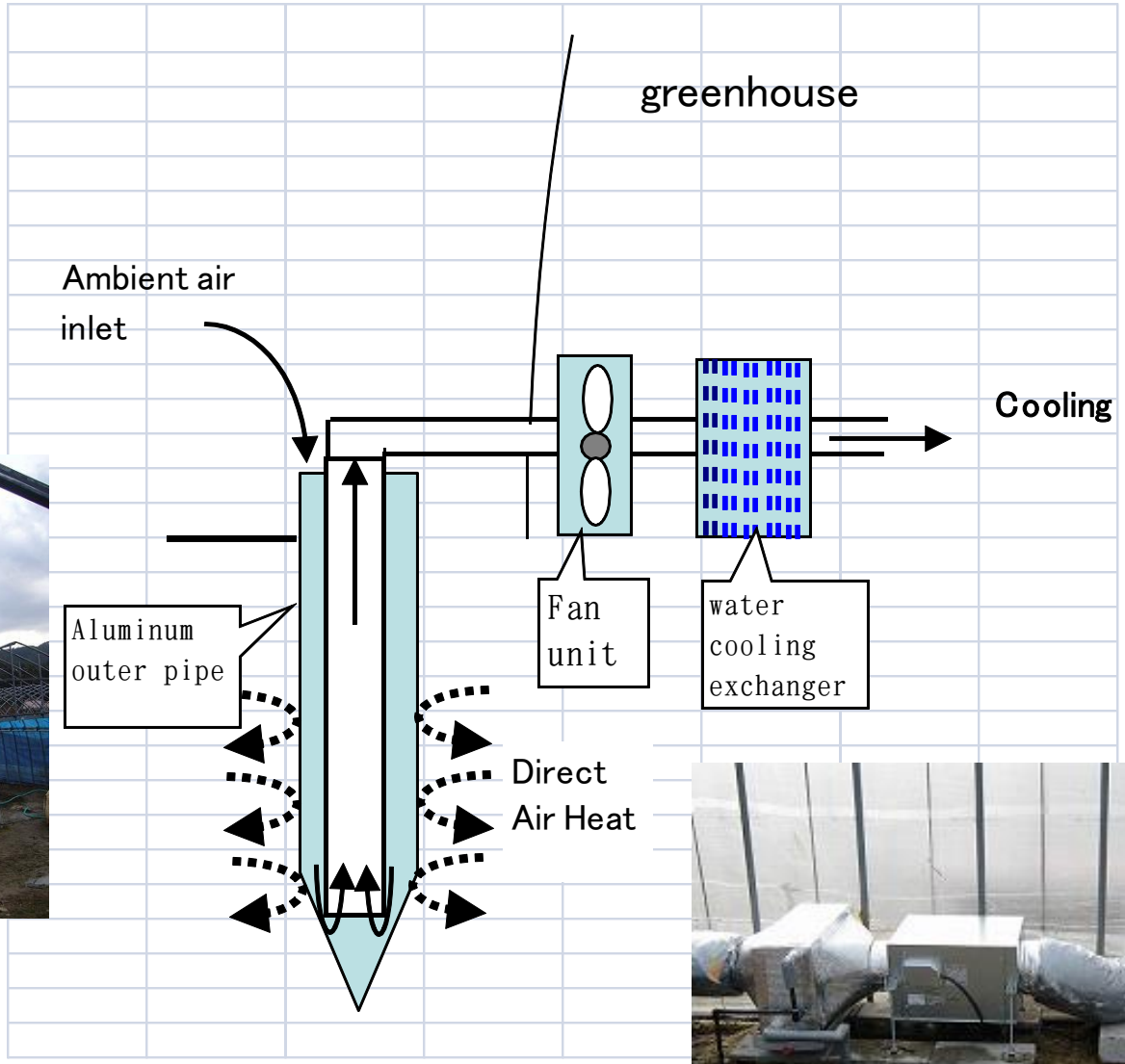




Application of the Heat Exchanger Marketed by Geo-Power System Co. Ltd



Demonstration at the Farm

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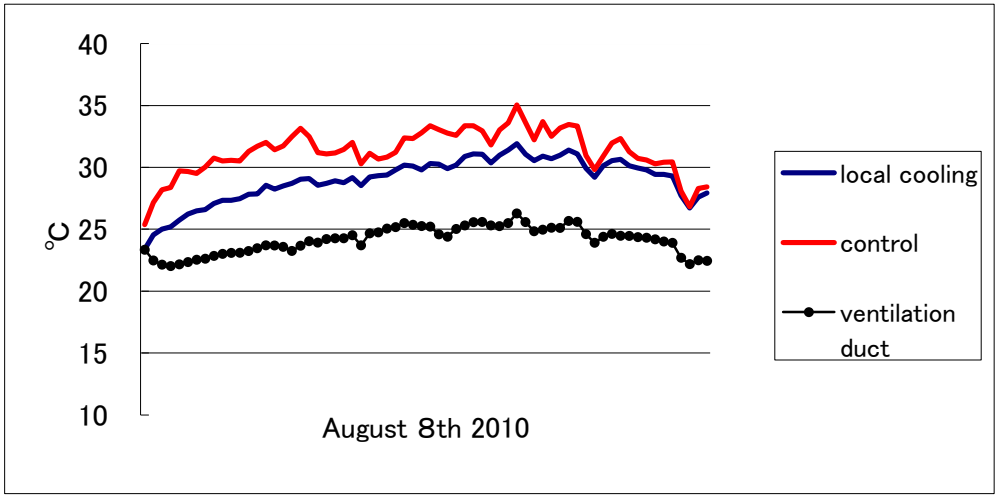

Table Effct of local cooling method with underground heat exchange system on fruit quality of tomato

treatment	no. of fruit	average weight of fruit	fruit quality			
			shipped fruit	malformed fruit	high temperature injury	others
		(g)	(%)	(%)	(%)	(%)
local cooling	157	160.4	92.1	3.4	2.2	2.3
control	160	156.9	86.2	6.5	4.6	2.7

Sampling : Septmber 5th,15th,25th 2010 No. of sampling:71plants

Then the ratio of damaged tomato fruit by high temperature was reduced and increased high-quality fruit in summer

Optimizing the Size of Heat Exchanger

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Two pipes are buried for the test of optimizing the size of heat exchanger.

(0.3m diameter, 25m long, each buried in the depth of 1.5m and 3m)

We will obtain the basic data for the simulation of heat exchange air temperature and flow rate.

Summary

The tomato fruit yield from summer to autumn was higher than control by partial cooling with the method of undersurface heat exchange.

- 20% higher in warming condition
- 10% higher in normal summer

Increased yield was brought by increased weight of unit fruit.
Not by the number of fruit.

Not only the temperature but also the modification of air quality (CO_2 concentration and humidity) seems to raise the rate of photosynthesis.

In winter, the productivity of tomato was maintained by partial heating.