Data Centre & Greenhouse Waste Heat Utilization

Summary Report:
Prepared for Microsoft by Orbital Farm

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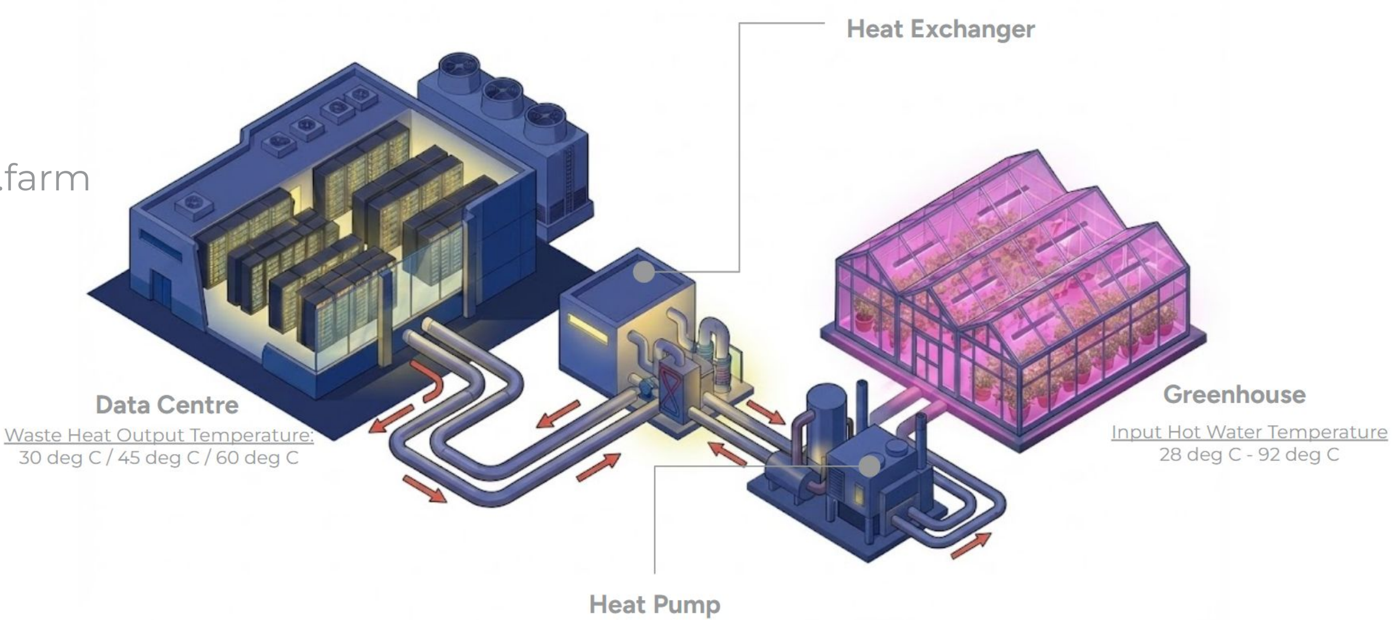

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Commercial Greenhouse

Technology	Climate Control Level	Estimated Investment (€/m²)
Low-Tech	Passive/Limited	< 30
Mid-Tech	Semiactive	30 to 60
High-Tech	Active/Fully Controlled	> 60 (up to 500)
Vertical Farm	Fully Control + Cooling	> 1000 to 1800 (up to 2000)

In General, high tech greenhouses produce 250 to 600 tonnes of tomatoes per hectare (Source).

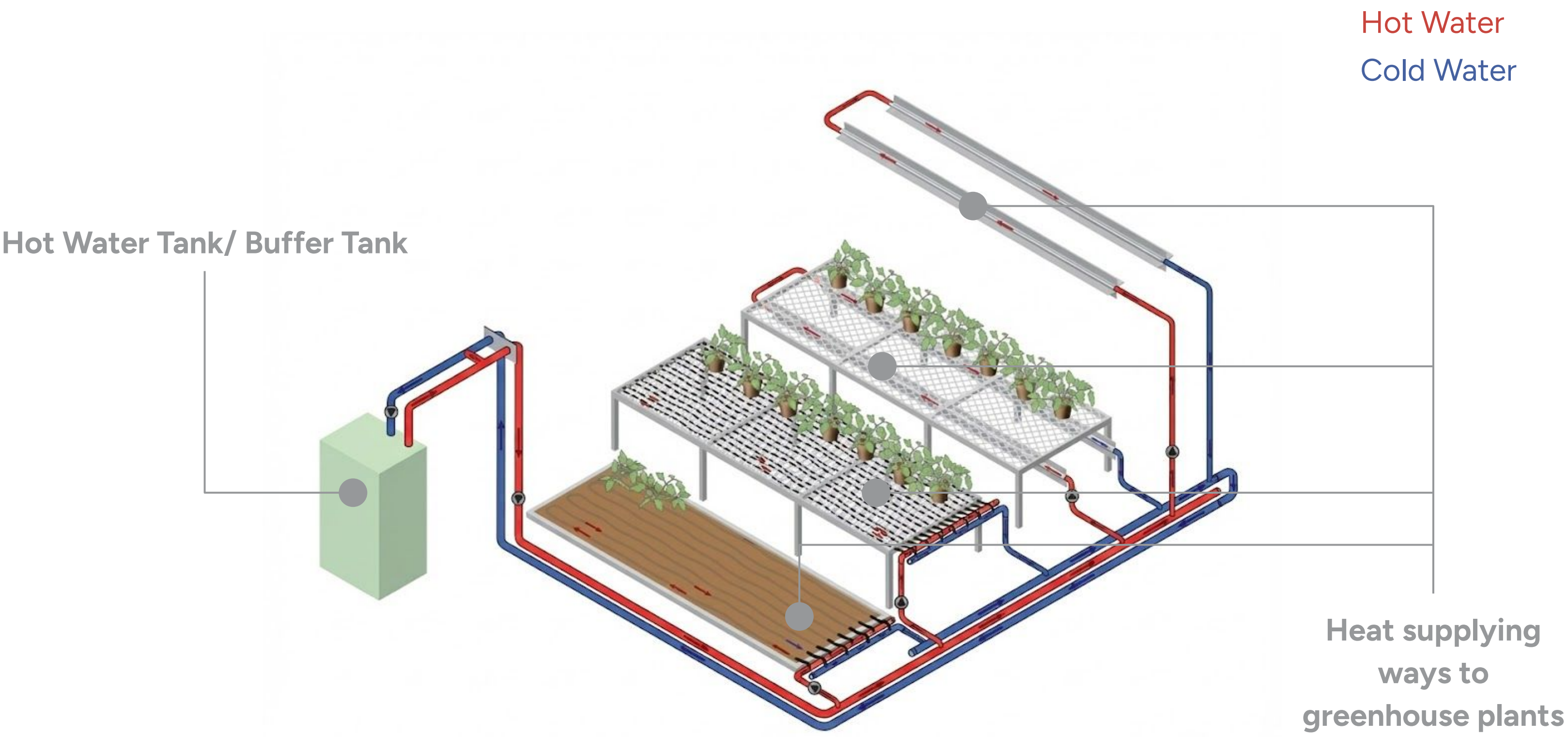
Typical growing temperatures greenhouse crops

Crops	Day Time Temperature (°C)	Night Time Temperature(°C)
Peppers	20 - 30	16 - 30
Tomatoes	21 - 25	17 - 20
Cucumber	25 - 28	21
Lettuce	25	20
Poinsettias	21 - 27	19 - 22
Carnations	25	10
Geraniums	21 - 27	18

Design Basis Comparison Table Between Ontario Canada and Netherlands

Parameter	Middenmeer, NL	Leamington, ON	Implication for 10 MW Design
Design Temp (T_{out})	-10°C	-23°C	Leamington requires ~45% more peak capacity per m^2
Design Temp (T_{in})	18°C	18°C	Standard tomato night setpoint.
Delta T (ΔT)	28°C	41°C	Driving force for conduction losses.
Wind Velocity Design	8 m/s	10 m/s	Higher infiltration risk in Leamington.
Snow Melt Load	Negligible	Critical	Leamington requires dedicated gutter heat capacity.

Heat Supply to Greenhouse



1. Rail Pipe
51mm Steel Pipe
ON: 80°C / 70°C
NL: 60°C / 53°C

2. Grow Pipe
Steering Loop
Max: 45°C - 50°C
Prevents burn

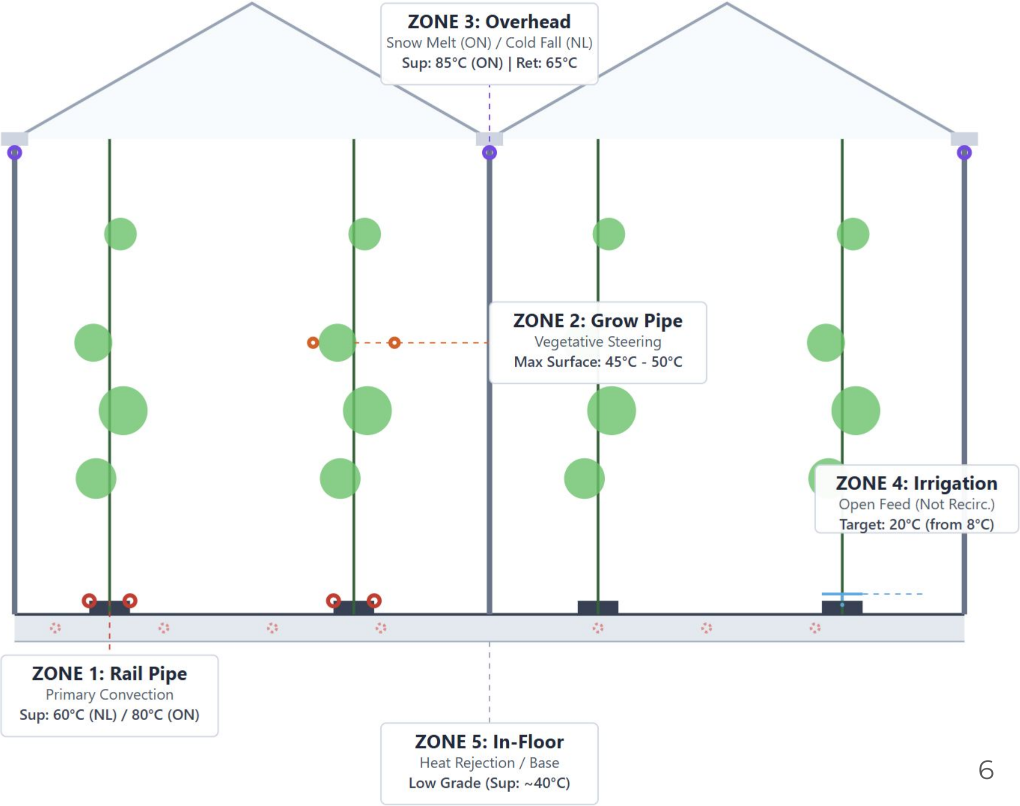
3. Overhead
Snow/Safety
ON: 85°C / 65°C
NL: Secondary

4. Root Zone
Irrigation Feed
Target: 20°C
Source: ~8°C

5. In-Floor
Radiant Slab
Type: Low Grade
Sup: ~40°C

Zonal Heating Locations & Temperatures

Cross-section showing the five thermal zones for greenhouses



Greenhouse Heating Demand

Zone	Latitude	Heating Requirement
Lower	40° to 50°	250 to 430 kWh/m2/y
Higher	50° to 60°	430 to 650 kWh/m2/y

(Source)

Note: Actual heat consumption is significantly affected by **crop variety, greenhouse infrastructure, and local climate patterns.**

Seasonal Heating Needs: Netherlands

Month	Net Heat Demand (kWh/m2)	Total Energy (MWh)	Zone 5 (Floor) Supply/Return	Zone 1 (Rail) Supply/Return	% Load to Zone 5	% of Total
Jan	135	5,400	45 / 35	80 / 65	22%	19.7%
Feb	115	4,600	45 / 35	75 / 60	26%	16.8%
Mar	85	3,400	42 / 32	65 / 50	35%	12.4%
Apr	45	1,800	40 / 30	50 / 40	50%	6.6%
May	15	600	35 / 25	Off	100%	2.2%
Jun	5	200	Off	Off	0%	0.7%
Jul	2	80	Off	Off	0%	0.3%
Aug	3	120	Off	Off	0%	0.4%
Sep	15	600	35 / 25	Off	100%	2.2%
Oct	50	2,000	40 / 30	55 / 45	50%	7.3%
Nov	90	3,600	42 / 32	70 / 55	33%	13.1%
Dec	125	5,000	45 / 35	80 / 65	24%	18.2%
Total	**~685**	**27,400**			**~30% Avg**	**100.0%**

Zone-by-Zone Hydronic Analysis @ 10MW
Leamington Ont. Canada High Load with Floor Heat

Zone	Load (W/m2)	Total Load (MW)	Supply Temp (°C)	Return Temp (°C)	Design ΔT (°C)	Flow Rate (m3/hr)	Pipe Velocity (m/s)
Zone 1: Rail Pipe	113	4.52	85	70	15	260	0.8 - 1.2
Zone 2: Grow Pipe	45	1.8	50	40	10	155	0.5 - 0.8
Zone 3: Overhead	35	1.4	85	65	20	60	0.4 - 0.6
Zone 4: Irrigation	Negligible *	0.1	40	20	20	4	N/A
Zone 5: In-Floor	30	1.2	45	35	10	103	0.5 - 0.8
Peripheral	15	0.6	85	65	20	26	0.5
Total	**238**	**9.62**				**608**	

Zone-by-Zone Hydronic Analysis @ 10MW

Target Zone 2, 4, & 5 = 32.2% of Heat Demand

Zone	Load (W/m2)	Total Load (MW)	Supply Temp (°C)	Return Temp (°C)	Design ΔT (°C)	Flow Rate (m3/hr)	Pipe Velocity (m/s)
Zone 1: Rail Pipe	113	4.52	85	70	15	260	0.8 - 1.2
Zone 2: Grow Pipe	**45**	**1.8**	**50**	**40**	**10**	155	0.5 - 0.8
Zone 3: Overhead	35	1.4	85	65	20	60	0.4 - 0.6
Zone 4: Irrigation	**Negligible***	**0.1**	**40**	**20**	**20**	4	N/A
Zone 5: In-Floor	**30**	**1.2**	**45**	**35**	**10**	103	0.5 - 0.8
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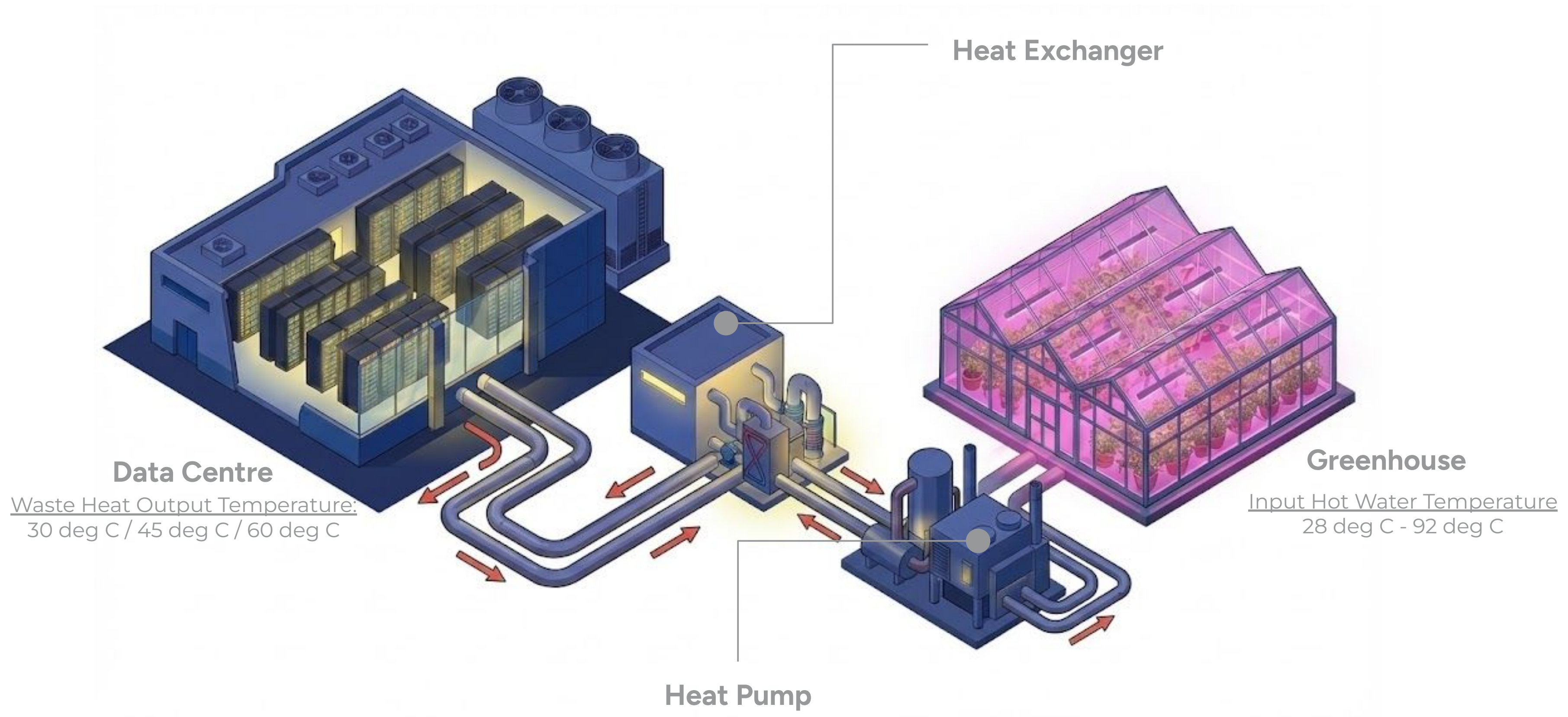
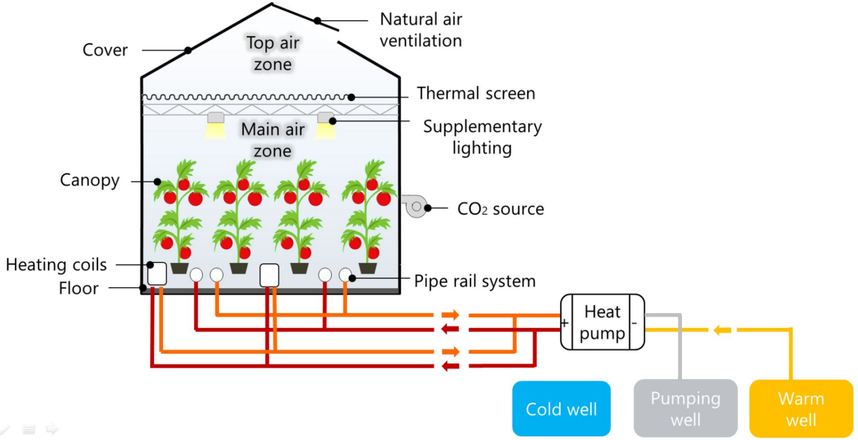
Waste Heat Recovery System

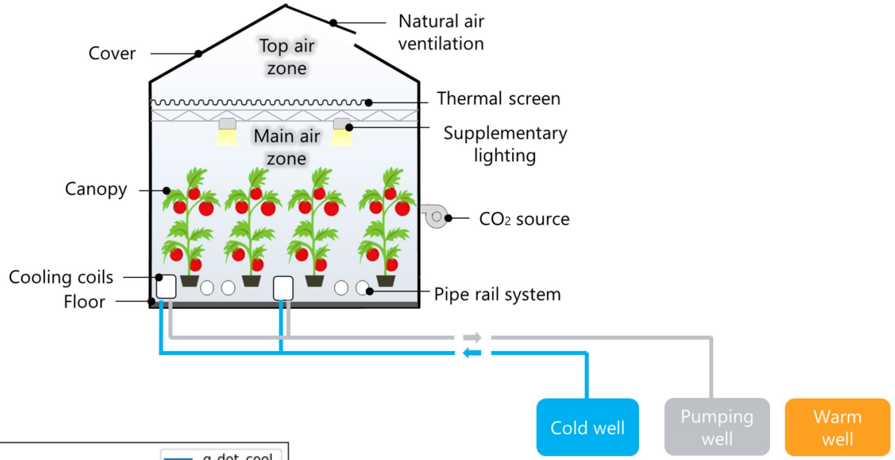


Thermal Storage & Recovery System

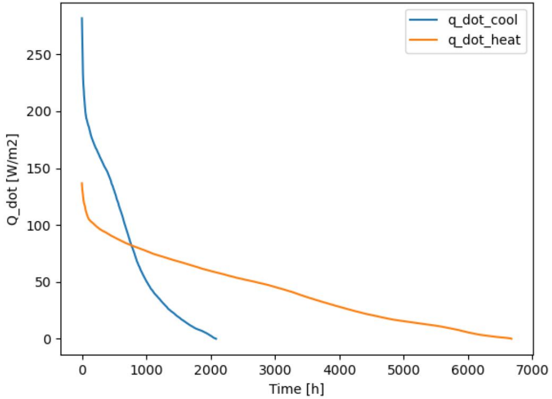
Heating Needs



Cooling Needs

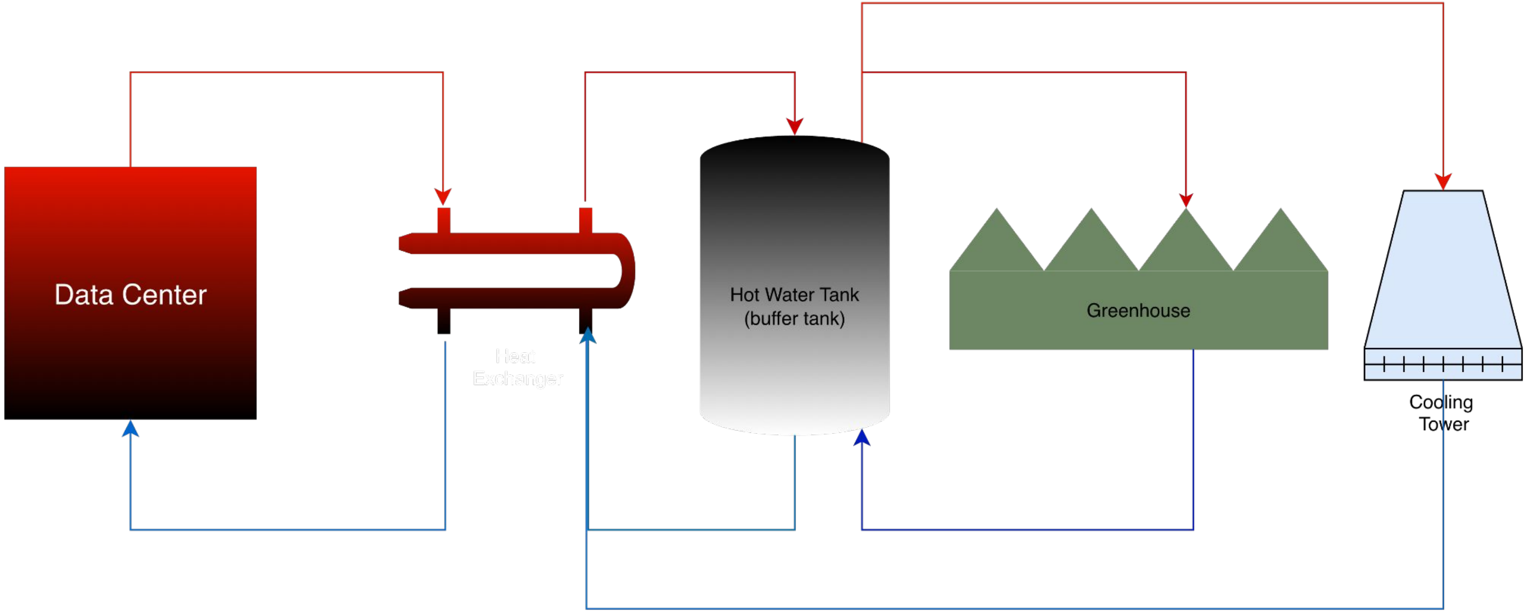


Yearly load duration curves of cooling and heating



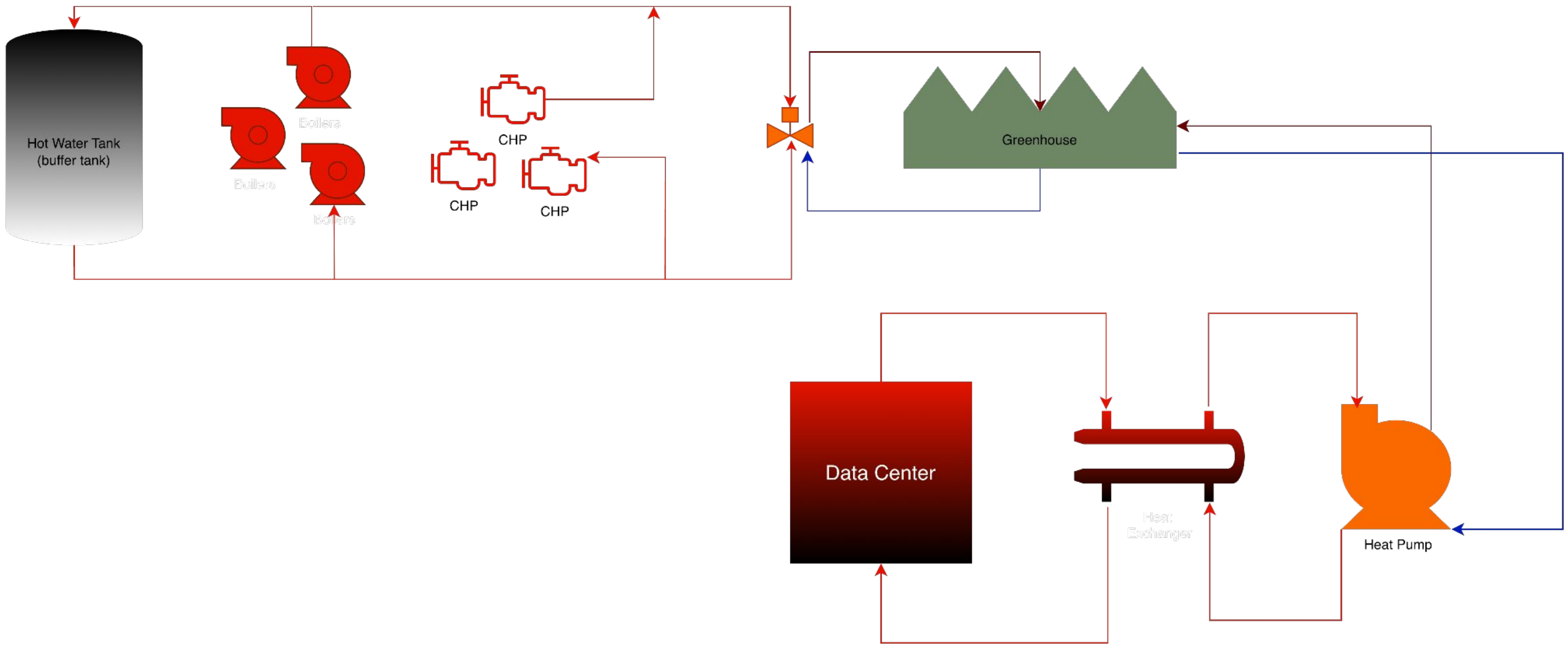
Study 1 - Direct Use With Thermal Storage

Direct utilization of data center waste heat to supply thermal energy for greenhouse vegetable cultivation.



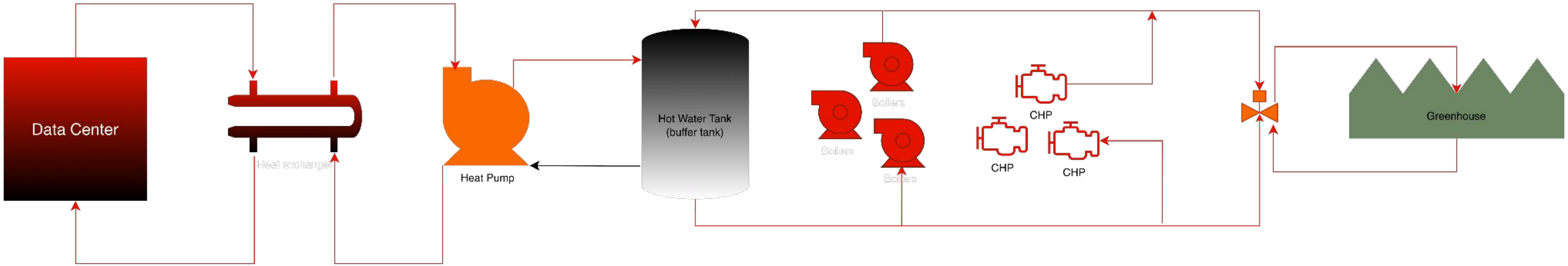
Study 2 - Baseload GH heat Direct: Leamington

Supplying heat to the greenhouse continuous to maintain root zone temperature.



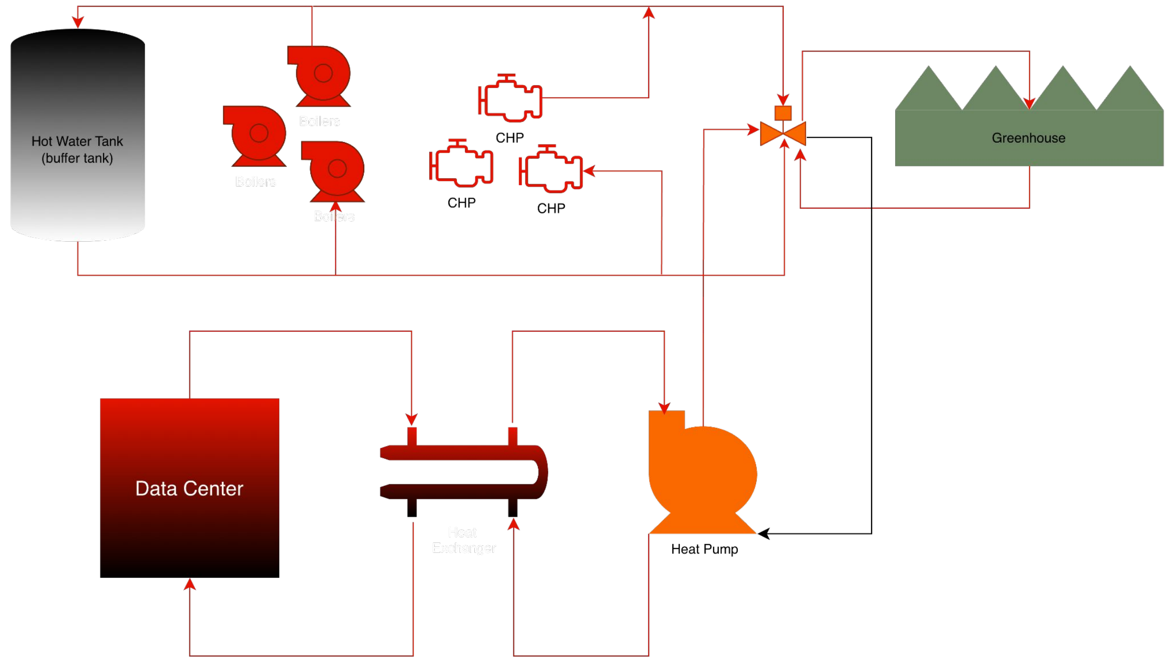
Study 3 - Upgrade and Inject to water tank

Integrating data center heat into the greenhouse’s existing energy loop (hot water storage tank)



Study 4 - Baseload @ Mixing Valve: Netherlands

Integrating data center heat into the greenhouse’s feed water mixing valve.



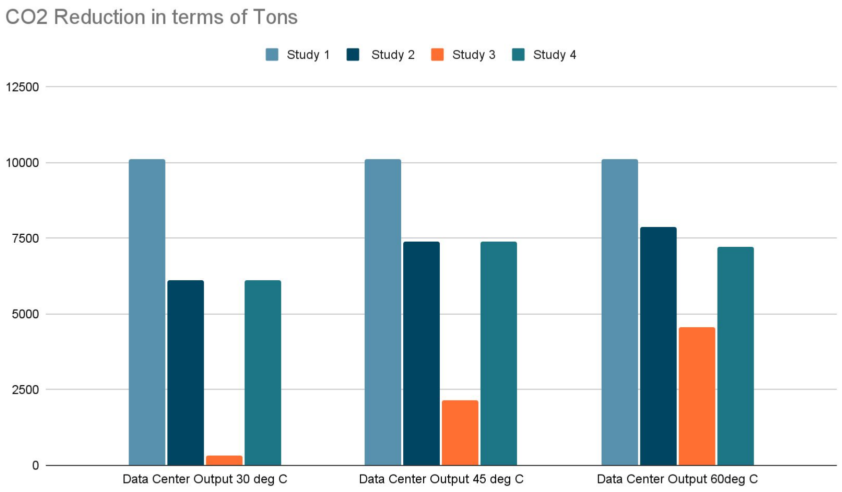
Assumptions

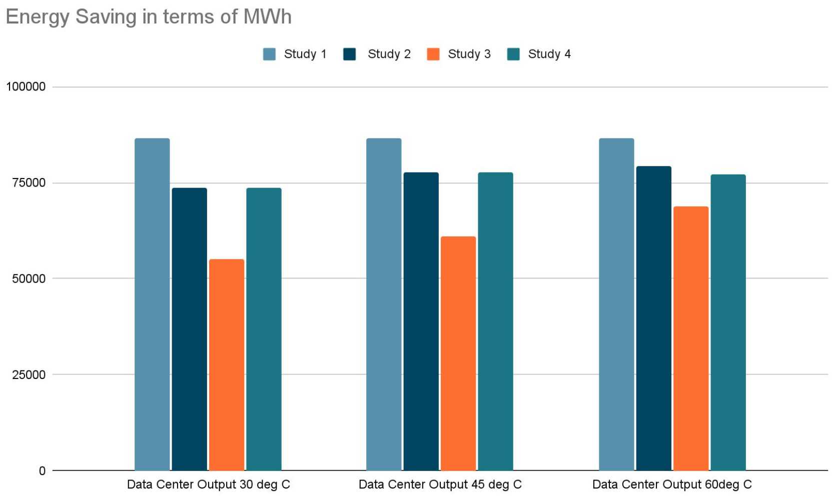
	Data Centre (10 MW)		**Greenhouse** (10 MW)	
Study	Output Temperature	Input Temperature	Output Temperature	Input Temperature
1	30°C	18°C	16°C *	28°C
	45°C	33°C	31°C	43°C
	60°C	48°C	46°C	58°C
2	30°C	18°C	35°C	45°C
	45°C	33°C	35°C	45°C
	60°C	48°C	40°C	50°C
3	30°C	18°C	32°C	91°C
	45°C	33°C	32°C	91°C
	60°C	48°C	32°C	91°C
4	30°C	18°C	35°C	45°C
	45°C	33°C	35°C	45°C
	60°C	48°C	50°C	65°C

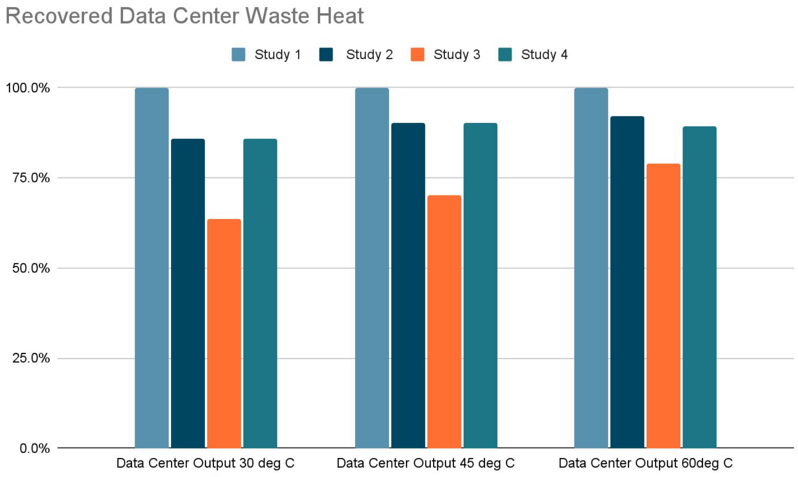
A simple numerical method is used, which doesn't take into account transient behaviour. Pump power calculations are based on affinity laws and typical efficiencies on pumps & motors. Heat pump performance is based on empirical knowledge from applications with medium density refrigerants and using centrifugal compressors and shell & tube evaporators. Where separation heat exchangers are used, we have assumed a 2K approach temperature. CO2 emission factor for gas, oil and electric energy is based on 2021 EIA data. For gas and oil boilers we have assumed a total efficiency of 90% based on hi [kJ/kg without condensation]. Heat-loss in distribution lines are not included in calculation. Service cost estimated as a fixed percentage of CAPEX. **CAPEX estimated to be within +/- 20%**

User of excess heat is:	**External use**
Type of heat recovery:	HEX (separation) and HP (boost)
Heat source:	Data center cooling (fluid)
Excess heat available capacity:	10 MW
Excess temp. supply side:	30˚, 45˚, 60˚C
Excess temp. return side:	18˚, 33˚, 48˚C
Heat demanded by user:	10 MW
Supply temp. from HP:	28, 43, 45, 50, 58, 65, 91 ˚C
Return temp. from consumer:	31, 32, 35, 40, 46, 50 ˚C
Current type of heating:	Gas Boiler
Cost of current type of heating:	0.08 €/kWh
Cost of electricity:	0.08 €/kWh
Agreed heat sales price:	0.01 €/kWh

Energy Saving CO2 Reduction & Recovered Heat







Economic Analysis

	Data Centre		CAPEX (k€)		Annual OPEX (k€)		Simple Payback Period (Years)	
Study	Output Temperature	Input Temperature	Data Centre (Supplier)	Greenhouse (Consumer)	Data Centre (Supplier)	Greenhouse (Consumer)	Data Centre (Supplier)	Greenhouse (Consumer)
1	30°C	18°C	3076.72	1025.57	837.08	6968.05	3.7	0.1
	45°C	33°C	3076.72	1025.57	837.08	6968.05	3.7	0.1
	60°C	48°C	3076.72	1025.57	837.08	6968.05	3.7	0.1
2	30°C	18°C	4559.44	10017.3	714.87	4874.31	6.4	2.1
	45°C	33°C	4804.11	10017.3	754.27	5518.41	6.4	1.8
	60°C	48°C	4900.8	10017.3	769.83	5772.86	6.4	1.7
3	30°C	18°C	3376.38	10017.3	524.4	1819.83	6.4	5.5
	45°C	33°C	3729.72	10017.3	581.28	2749.86	6.4	3.6
	60°C	48°C	4204.52	10017.3	657.72	3999.7	6.4	2.5
4	30°C	18°C	4559.44	10017.3	714.87	4874.31	6.4	2.1
	45°C	33°C	4804.11	10017.3	754.27	5518.41	6.4	1.8
	60°C	48°C	4752.41	10017.3	745.93	5406.21	6.4	1.9

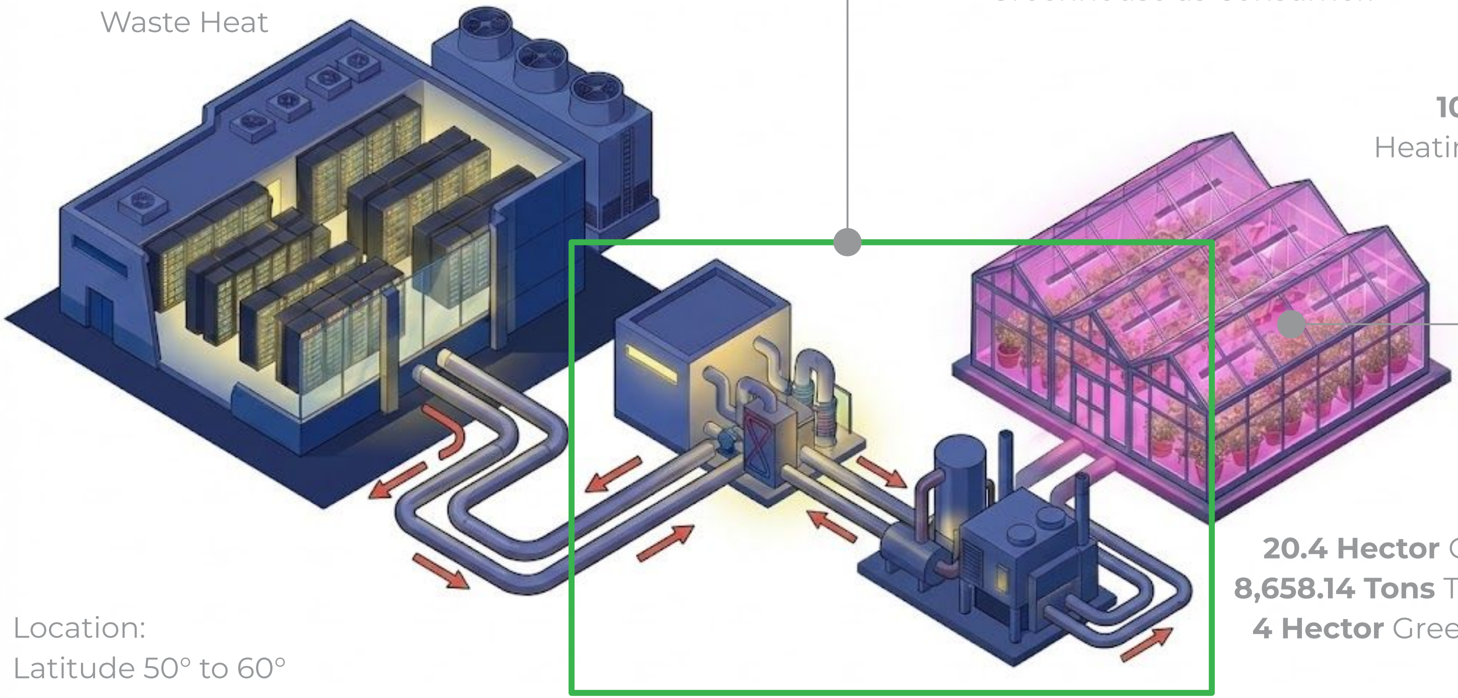
Summary

Heat Recovery Unit

A Heat Exchanger is part of the Data Centre as Supplier.

A Heat Pump is included in the Greenhouse as Consumer.

10 MW/y
Waste Heat



10 MW/y
Heating Demand

20.4 Hector Greenhouse (Max)
8,658.14 Tons Tomatoes (Avg. Max)
4 Hector Greenhouse (Avg. Size)

Location:
Latitude 50° to 60°

Complexity of Greenhouse Sizing

Greenhouse energy needs are complex. Location plays a major factor in the total annual energy but also peak capacity of the energy needs and the temperatures required to offset the rate of loss during the cold and windy days. Furthermore snowfall and melt requirements add further complexity to maximum temperatures necessary to maintain the structural integrity, crop health and quality.

Optimization of greenhouse size to datacenter rejected waste heat can be approached from a variety of angles.

CO2 Emissions: offsetting natural gas boilers from use providing heat, but also taking into account heat upgrading and temperature needs and load on the heat pump and the local power grid's CO2 emissions which can change seasonally and by country.

Economics: Cost of heating can be 30% of the operating cost of a greenhouse. These costs can be near eliminated with only minor costs to cool the facility.

Waste Heat Utilization Rate optimized: Minimizing data center rejected heat is another factor to being able consider and could be optimized for.

Complexity of Greenhouse Sizing

Taking the worst case scenario: Study 3.1 - 30°C rejected heat, 18C returning to the datacenter.
A heat pump upgrades this heat to 91°C and puts it into the Thermal storage tank. Heat use is ~6,000-6,500 hrs per year.

Feasible Area Calculation (10 MW Basis):

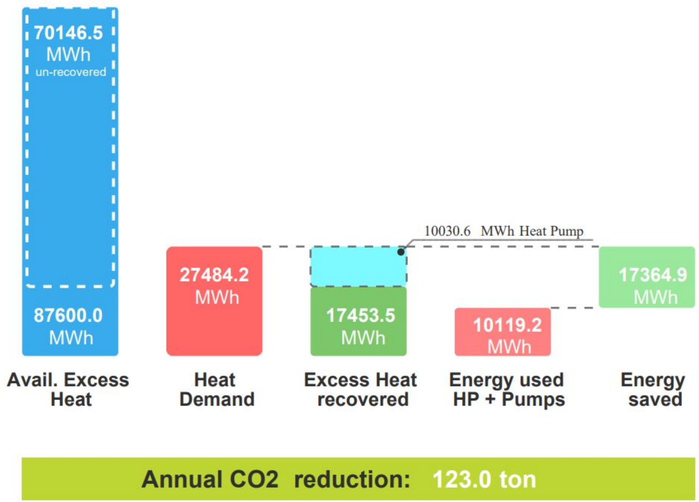
The 10 MW source capacity defines the maximum grow area.

- **Middenmeer**: 10,000,000 W / 161 W/m2 = ~62,111 sq. m (**6.2 Hectares**).
- **Leamington**: 10,000,000 W / 238 W/m2 = ~42,016 sq. m (**4.2 Hectares**).

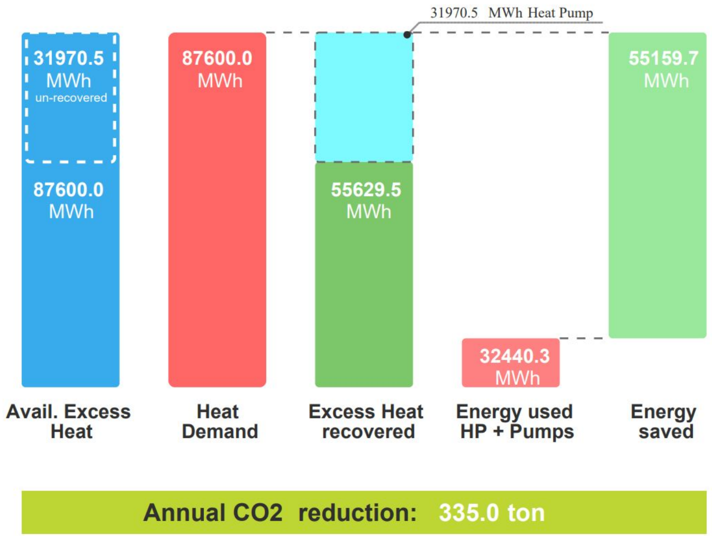
Design Decision: To facilitate a direct zone-by-zone comparison, we will base the detailed hydronic analysis on a standardized 4.0 Hectare (40,000 m2) facility.

- In **Leamington**, this **utilizes ~95%** of the 10 MW capacity at peak (Critical constraints).
- In **Middenmeer**, this **utilizes ~64%** of the 10 MW capacity at peak (High redundancy).

Meet Greenhouse Peak Heating demand
~10MW = 4-6 Hectares



Meet Greenhouse Annual MWh Heating demand @ 10MW DC with Seasonal Storage = ~20 Hectares



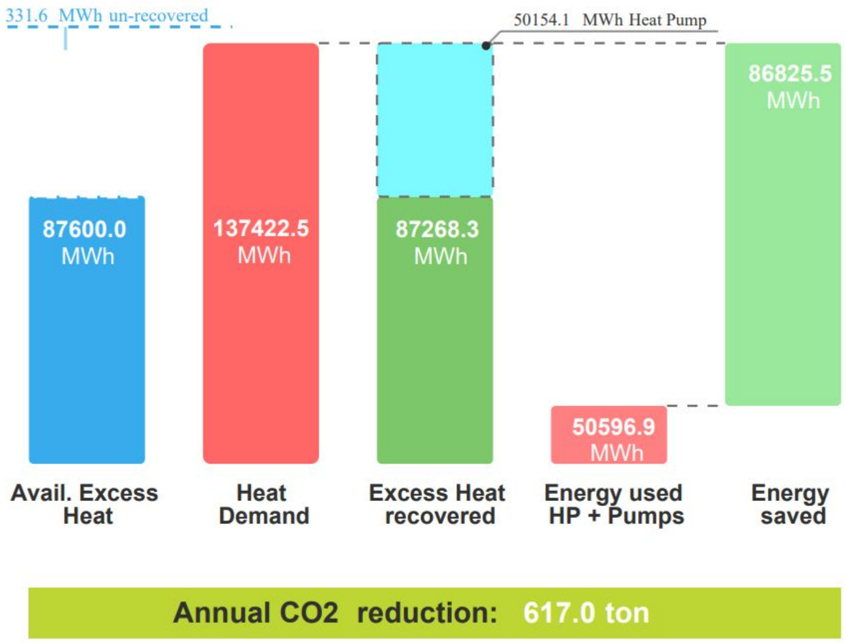
40–45°N (e.g., Southern Ontario/Northern US): Greenhouses here typically average around **3,000–3,500 MWh/ha/y.**

50–55°N (e.g., Netherlands/Central Germany): Intensive Dutch greenhouses often fall into the **4,500–5,000 MWh/ha/y** range to maintain high yields in winter.

60°N+ (e.g., Finland/Northern Canada): Energy needs can exceed **7,000 MWh/ha/y** if producing high-light crops like cucumbers throughout the winter.

Maximize Data Center Heat reuse

@ 10 MW of rejected heat ~32 Hectares



Ontario Sizing Example

Strategy	Greenhouse Size	% of Waste Heat Utilized	% of Greenhouse Demand Covered	Backup Boiler Needed?
Peak Match (Small)	4 – 8 ha	~18%	100%	No (HP covers peak)
Base Load (Optimal)	25 – 35 ha	~60 – 65%	70 – 80%	Yes (for extreme cold)
Annual Match (Large)	>50 ha	~70 – 80%	<50%	Massive boiler plant

Greenhouse Sizing Formula:
The "DC-to-Food" Formula (for Peak Need)

H (Hectares) = (P_{DC} x N_{rec}) / Peak Heat Demand (MW/ha)

Y (Annual Yield in Tonnes) = H x Y_{crop}

PDC = Data Center IT Load (MW)
N_{rec} = Recovery Efficiency (Typically 0.70 or 70% of IT load is recoverable as usable heat)
Peak Heat Demand = Maximum MW required per hectare based on location
Y_{crop} = Typical annual yield per hectare for your chosen crop (e.g., ~600 tonnes/ha for tomatoes)

Practical Example: 10 MW Data Center in Ontario

If you have a 10MW datacenter in Ontario (45N) and want to grow tomatoes:

1. **Recoverable Heat:** 10MW x 0.70 = 7MW available.
2. **Sizing Greenhouse:** 7MW / 2.8MW/ha (avg peak) = 2.5 Hectares.
3. **Crop Yield:** 2.5ha x 600 tonnes/ha = 1,500 Tonnes of tomatoes per year.

Recommendations

At the end, **each site needs to be reviewed and evaluated individually** to establish the ideal heat reuse, greenhouse sizing and production facility needs.

It is clear that focusing on utilizing higher temperatures from datacenters rejected heat will have a measurable impact on the **reduction of natural gas use from greenhouses.** However what has a larger impact is the placement of that heat vs simply injecting that heat into the thermal storage tank from the boilers. Lower temperature thermal storage tanks should be utilized to maximize the rejected heat use. This storage has a much more meaningful impact on the heat utilization rate vs the increase in temperature of the rejected heat.

The sizing of greenhouses to data centers **should be maximized to utilize all the rejected heat, but not to replace all the heating needs of a greenhouse.** This will ensure commercial viability but ensure that assets are far too oversized for the peak needs, but operate to provide baseload heating needs and support ~80% of the required heat.

Feasible Area Calculation (10 MW Basis):

Sizing Strategy	MWh/yr	Datacenter Heat Utilization	Greenhouse demand (MWh)	Unrecovered Heat (MWh)	Greenhouse Size (ha)	Tomato Production (tons)	Population: Tomato Food Secure (5.5kg/person)	Jobs
Peak Match	87,600	**19.9%**	27,484	70,146	6.4	2,716	493,902	40
Base Load	87,600	**63.5%**	87,600	31,971	20.4	8,658	1,574,207	126
Max Use	87,600	**99.6%**	137,423	332	32	13,582	2,469,538	198

Next Steps

Next research needs should focus around:

- Real time, real world data collections from data centre & greenhouse.
- Site specific feasibility and sizing.
- Thermal storage solutions.
- Heat Recovery System risk & reliability analysis.

END SLIDE