International Sorption Heat Pump Conference

Thermal management of a greenhouse with adsorption energy storage

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SIMON FRASER UNIVERSITY
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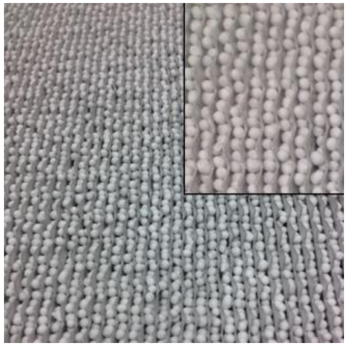
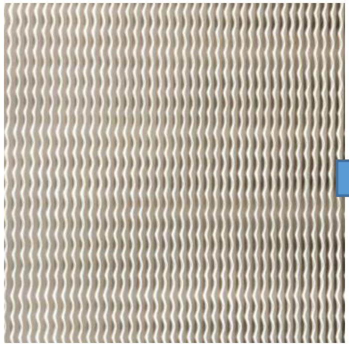
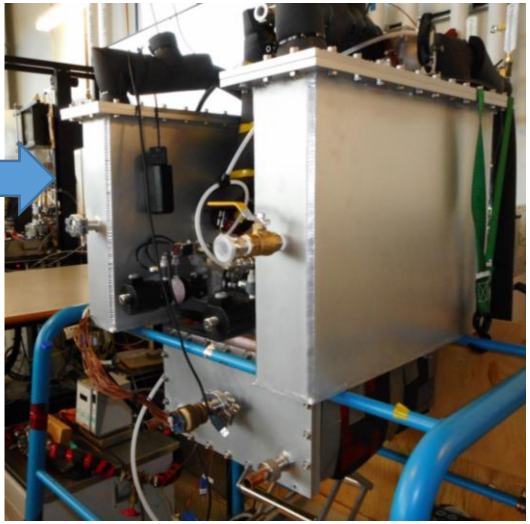
New composites



FAM-Z02 pellets



FAM-Z02 coating



Sorption cooling system
Cooling power = 500 W/kg sorbent

Research:

Lab-scale Sorption Chillers
Composite sorbents
Sorption thermal storage
Capillary-assisted low pressure evaporators

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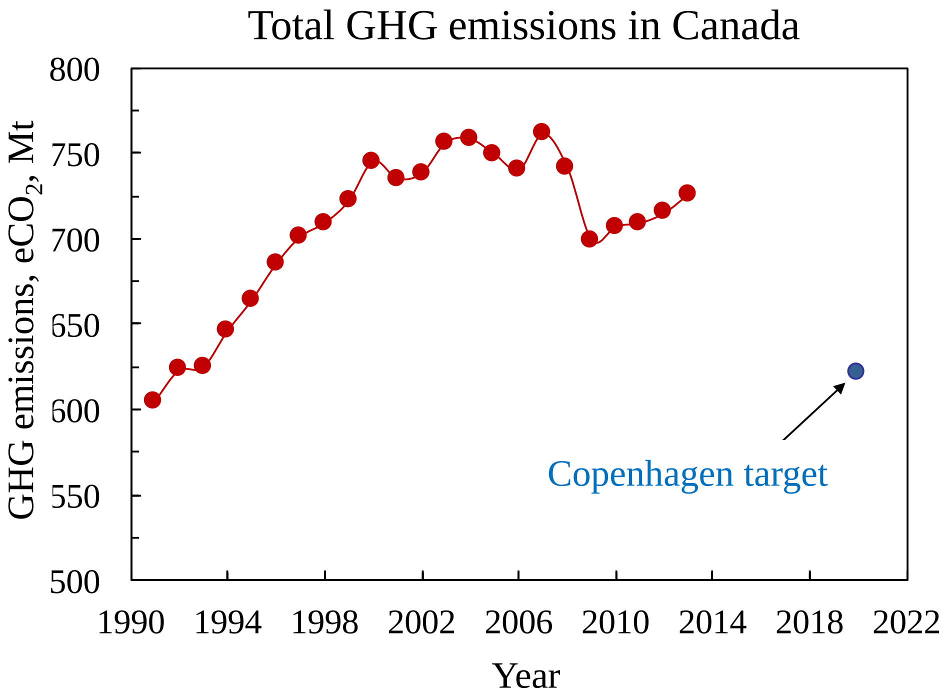
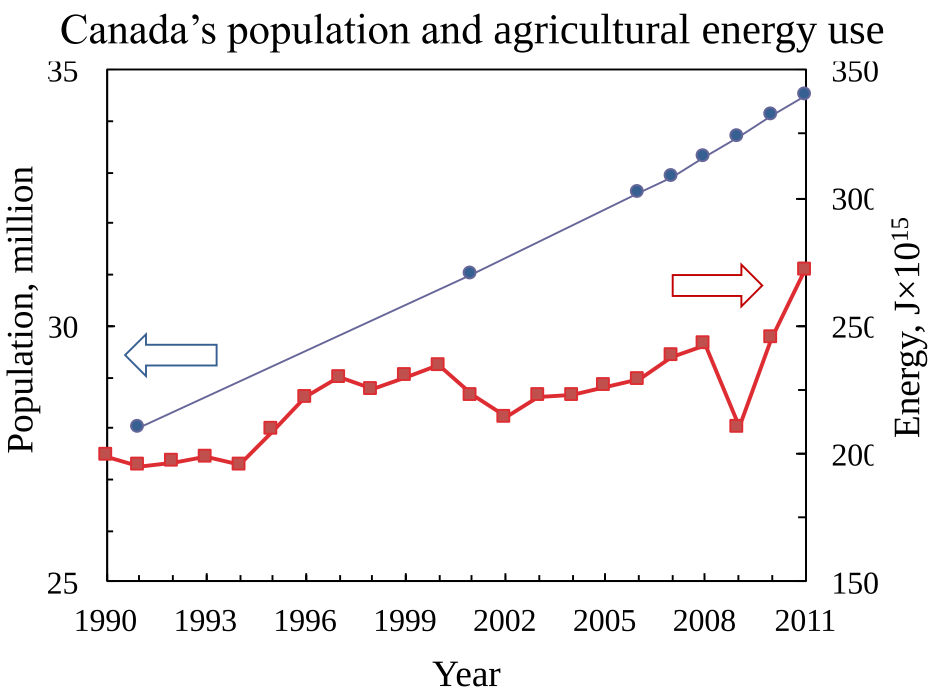
Energy demand and environmental impact

- **Greenhouses** are the most energy consuming agricultural sectors
- In cold climates, **65-85%** of total energy consumed by greenhouses is for heating [1].
- Fossil fuel consumption is a significant crop production cost and GHG source [2].

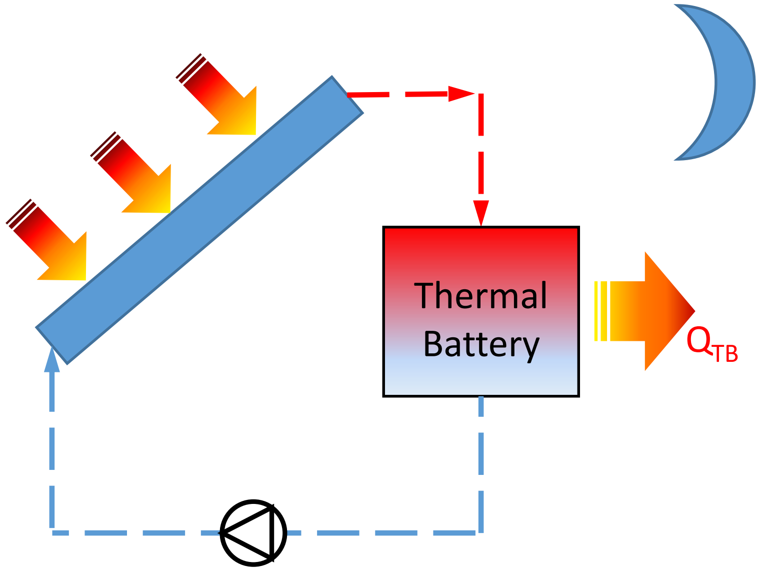




[1] Vadiee A., Martin V., Appl Energy 2014, 114, 880-888.
[2] Statistics Canada, Energy Supply and Demand in Canada, 2013.

Thermal Energy Storage System

- Buildings may satisfy their own heating/cooling demands if excess of thermal energy can be stored and accessed when needed
- Thermal energy storage (TES) **reduces energy consumption** and **GHG** by:
  1. Utilizing waste heat or renewables (Solar energy)
  2. Mitigate the mismatch between supply and demand of energy
  3. Time-shift use of renewable energy to the peak energy demand



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Why Sorption Storage?

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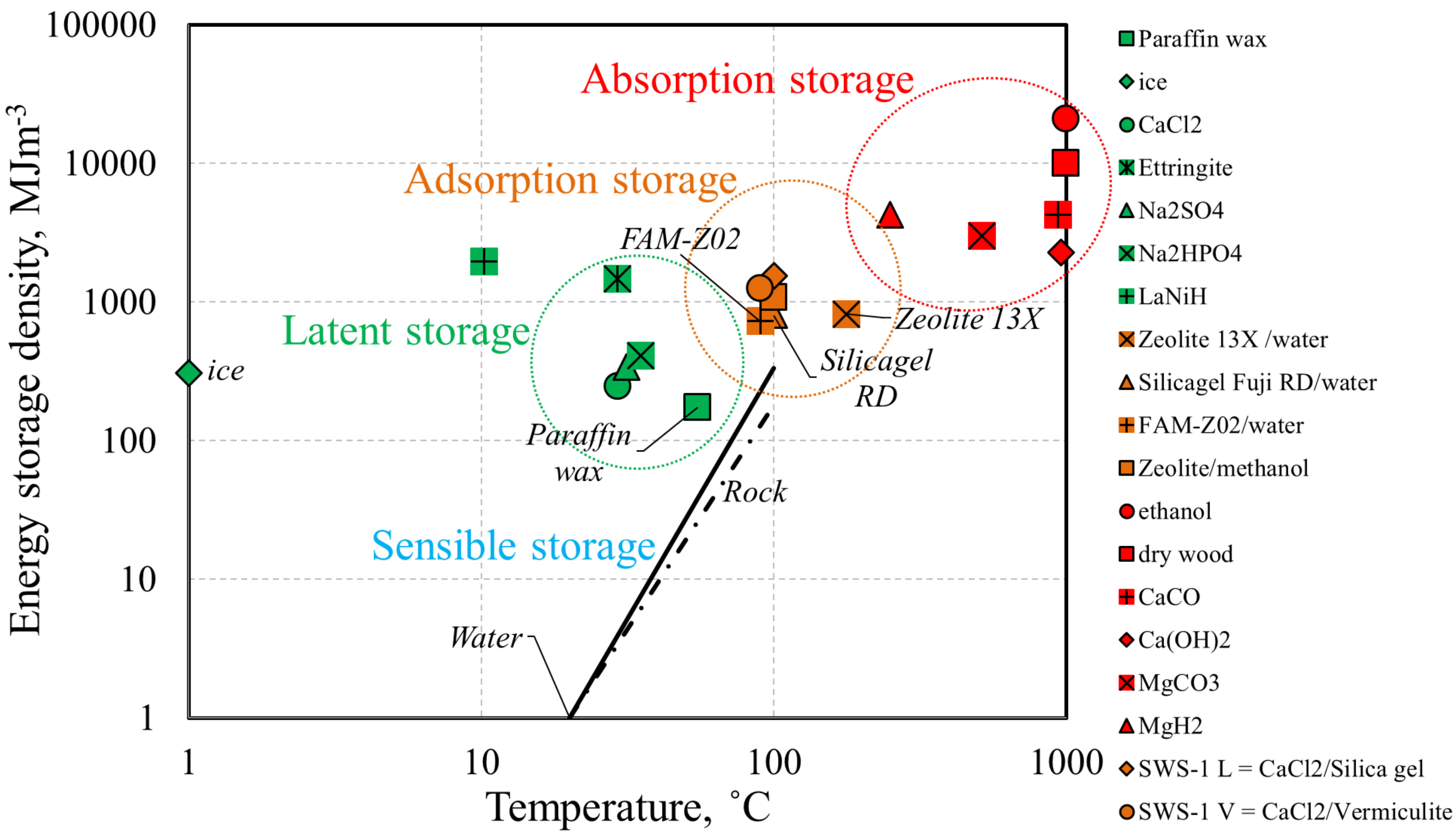

- High energy storage density (ESD=Q_{stored} /V, GJ·m^{-3})
- low heat loss

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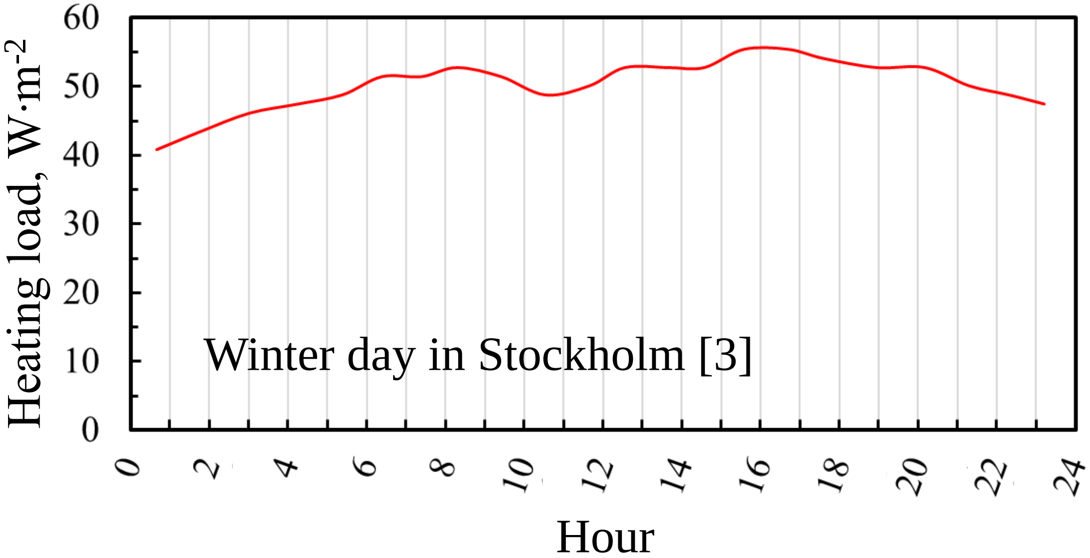
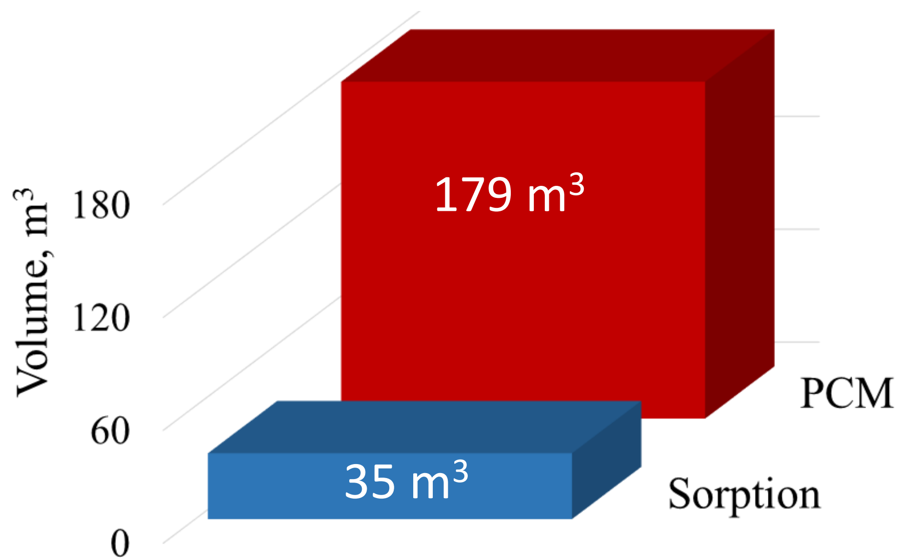
Short Term (Daily) Heat Storage



Average heating load	50 $W \cdot m^{-2}$
Daily heating demand per square meter	4.35 $MJ \cdot m^{-2}$
Greenhouse area	10000 m^2
Daily heating demand	43.5 GJ

Stand-alone heat storage for daily heating of 43.5 GJ

PCM	S19 (salt hydrate)	179 m^3
Sorption	SWS-1 V (Vermiculite $CaCl_2$) [4]	35 m^3



[3] A. Vadiee and V. Martin, Appl. Energy, vol. 109, pp. 337–343, 2013.
[4] Y. I. Aristov, *Futur. Cities Environ.*, vol. 1, no. 1, p. 10, 2015.

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- Preliminary study and feasibility analysis of a sorption TES in greenhouse

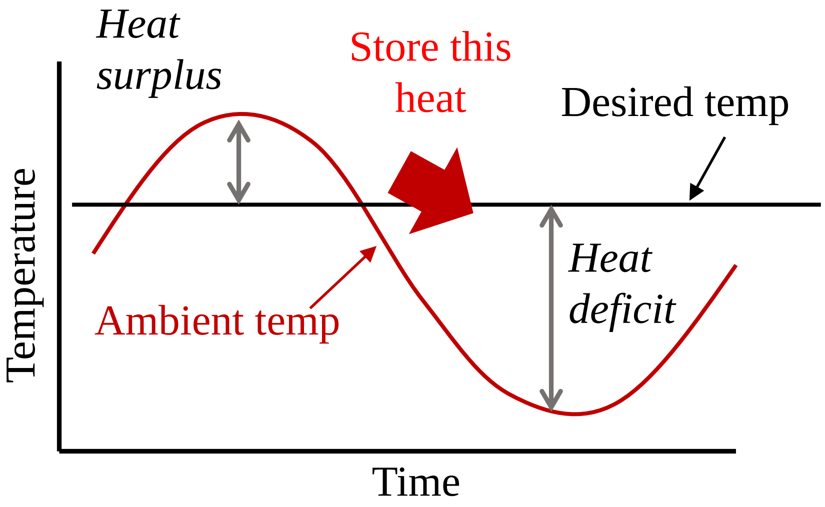
Climate zones: **Oceanic, temperate**

Discharge duration: **Daily**

Heat sources: **Solar energy, waste heat**

Greenhouse type: **Closed greenhouse**

- Improved control of system [1]
- Improved total efficiency of system
- Decreased usage of pesticides
- Increased use of renewable energy



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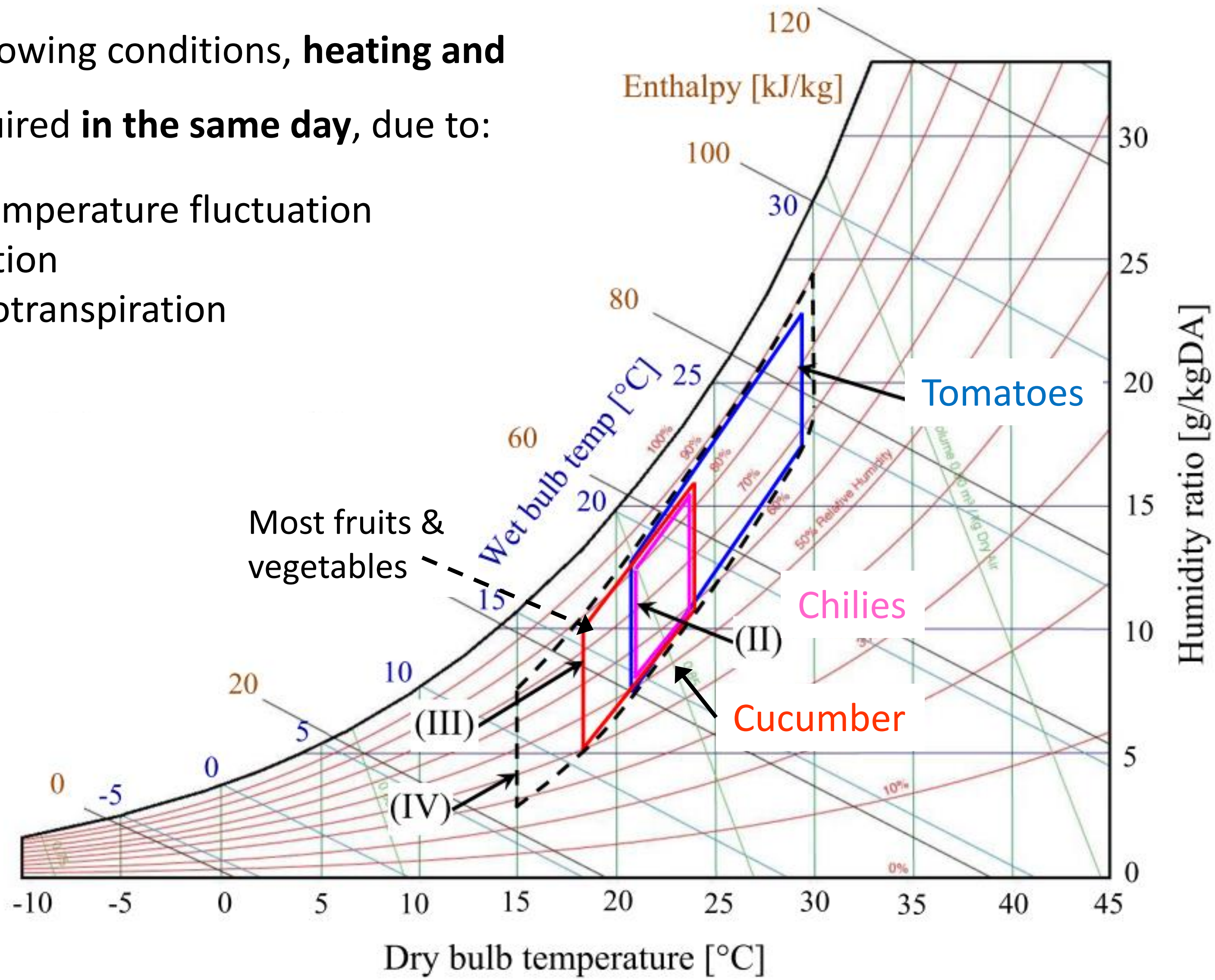
Climate Control in Greenhouses

To maintain good growing conditions, **heating and cooling** may be required **in the same day**, due to:

- Ambient temperature fluctuation
- Solar radiation
- Plant evapotranspiration



[4] M. Sultan, Thesis, Kyushu University, 2015.

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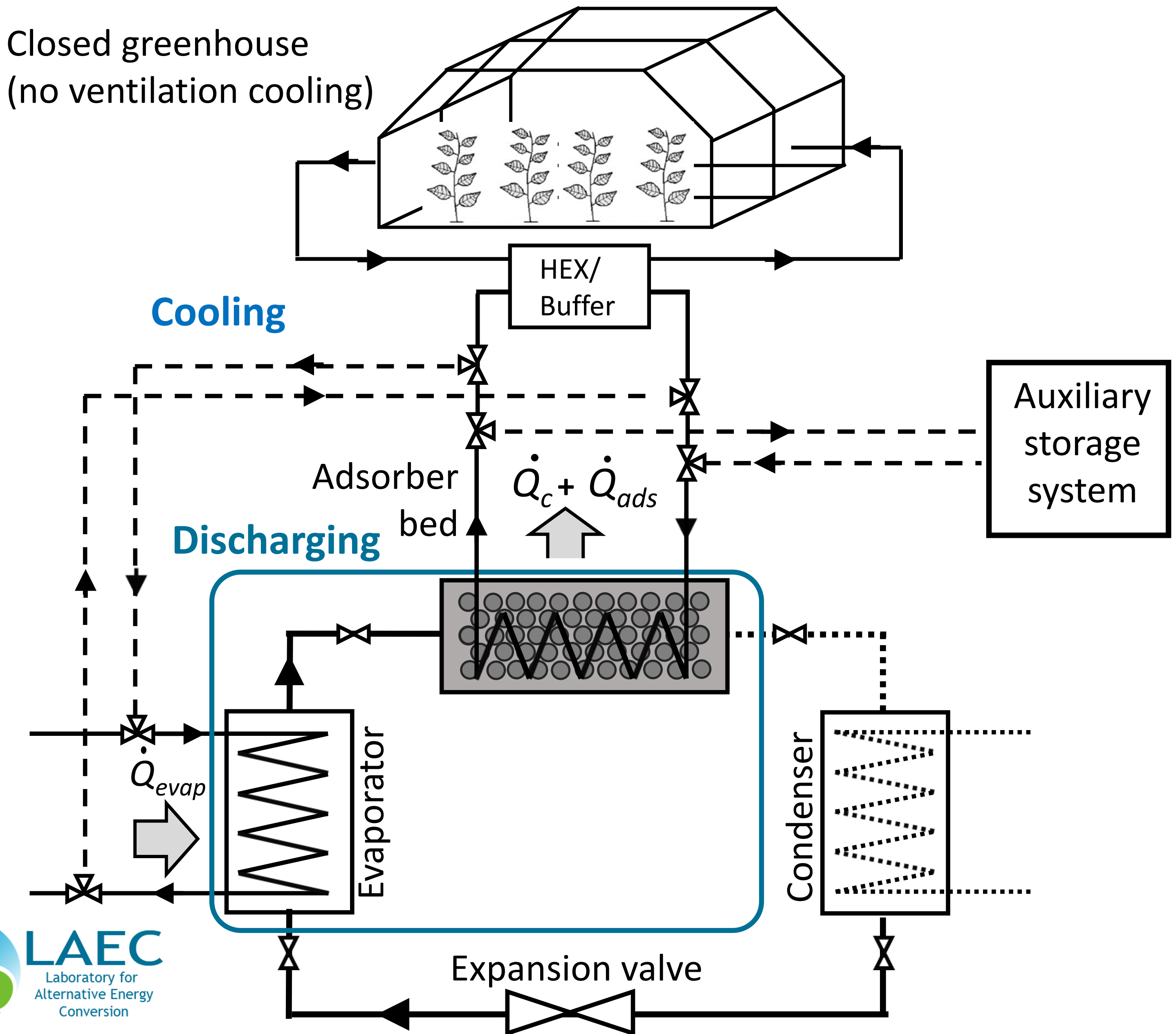
Proposed Sorption TES for GH



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Thermal Management System Modeling Modules

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GH module:
(Heating/cooling load calculation)

- T_{target}, crop properties
- T_{amb}, I_{rad}, V_{air}
- GH parameters

↓

- Load calculation

$$\sum heat\ loss - \sum heat\ gain$$
$$= Q_{rad} + Q_{lamp} - Q_{wall} - Q_{trans} - Q_{vent}$$

↓

GH heating/cooling demand

→

Sorption TES module:

- Heating/cooling load
- Operating conditions (including Q_{des}, T_{des})

↓

- Selecting adsorbent
- Sizing of the sorption TES (all components), based on the heating/cooling demand
- Sorption fully-dynamic thermodynamic cycle modeling

↓

Adsorption/evaporation power

↕

Control module:
- Check if T_{GH} is close enough to T_{target}. Change design parameters if necessary.

↕

Optimization

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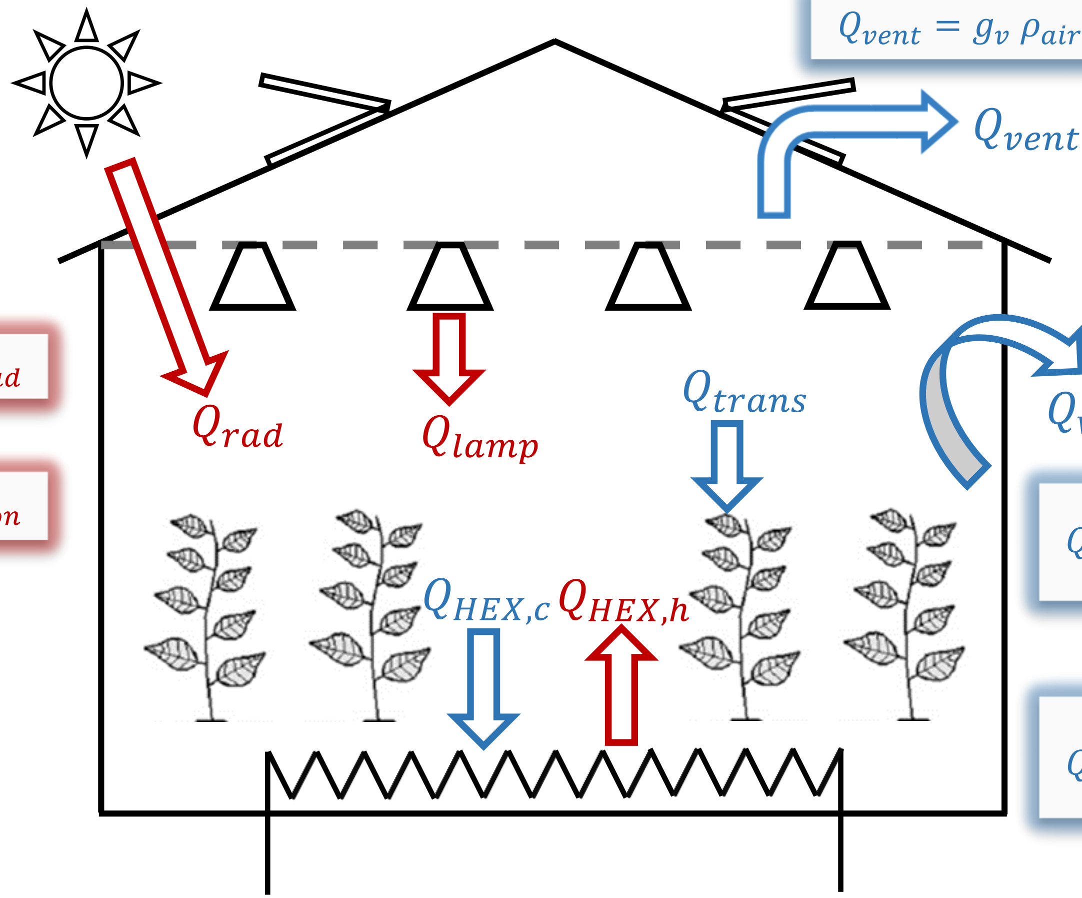
GH Module: Thermal Load Calculation of the GH

$$Q_{vent} = g_v\, \rho_{air}\, c_{p,air}(T_{air} - T_{amb})$$

$$Q_{rad} = \tau\, I_{rad}$$

$$Q_{lamp} = \eta\, P_E\, f_{on}$$



$$Q_{wall} = U \frac{A_{wall}}{A_{floor}}(T_{GH} - T_{amb})$$

$$Q_{trans} = \frac{2LAI(x_{crop} - x_{air})L}{(1+\epsilon)R_b + R_s}$$

$$Heat\ load = \sum heat\ loss - \sum heat\ gain$$

$$\underbrace{\frac{dT_{GH}}{dt}}_{\approx 0} = \frac{1}{C_{GH}}(Q_{rad} + Q_{lamp} - Q_{wall} - Q_{trans} - Q_{vent} - Q_{HEX,c} + Q_{HEX,h})$$

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S-TES Module: Sorption Fully-dynamic Thermodynamic Model

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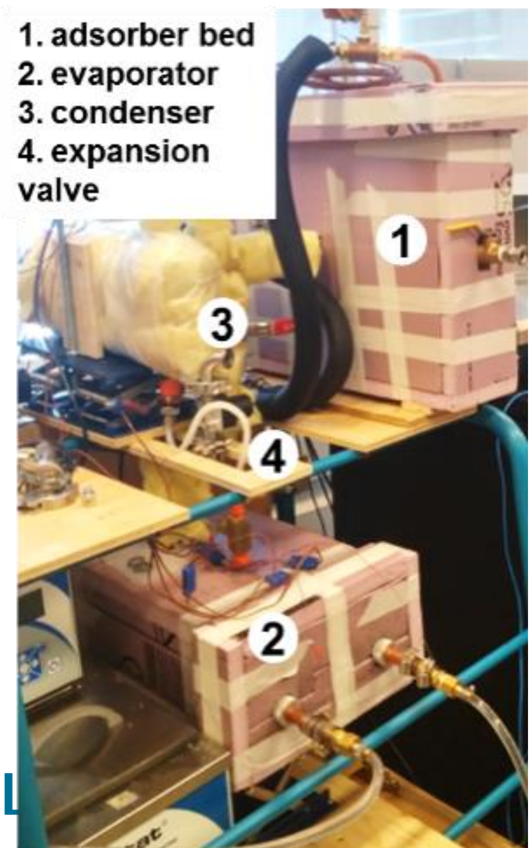
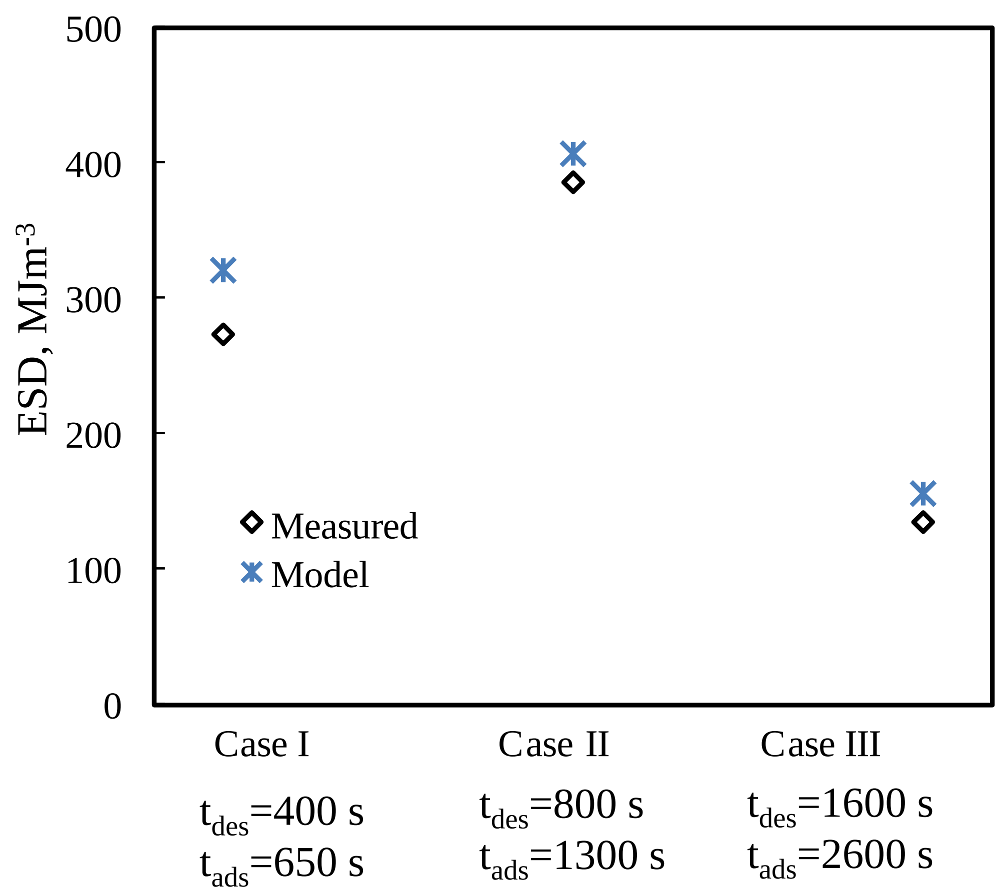
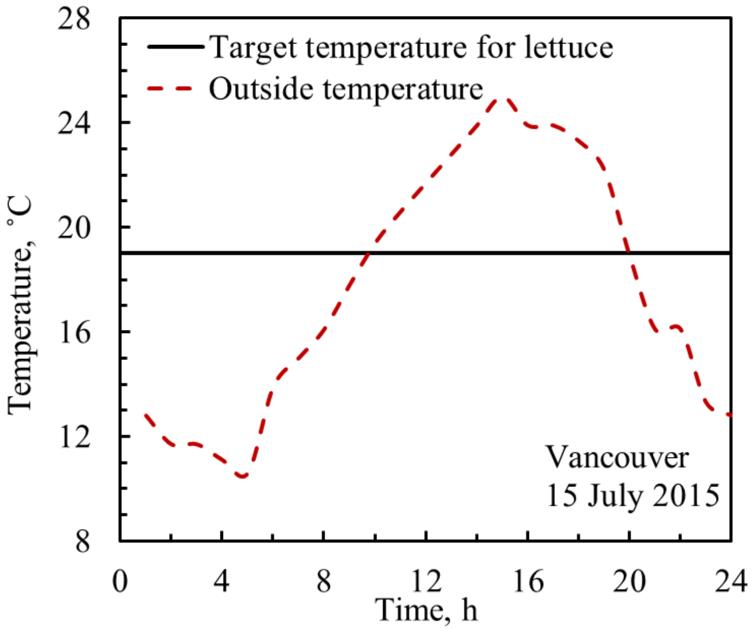
- Lumped-body thermodynamic model
- Fully-dynamic
- Equilibrium condition between adsorbate and adsorbent
- Linear driving forced model for non-equilibrium uptake rate, $\frac{d\omega}{dt} = \frac{15 D_{s0} \exp\left(-\frac{E_a}{RT}\right)}{r_s^2} (\omega_{eq} - \omega)$

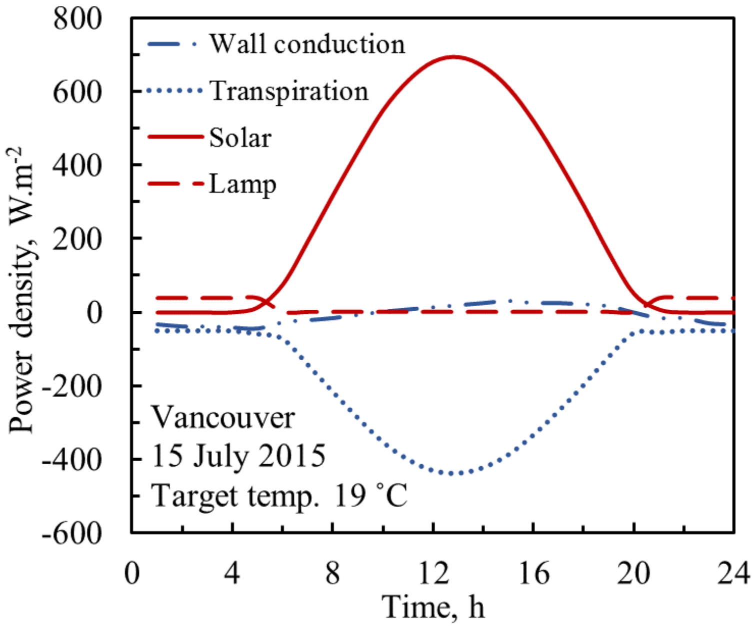




Conversion

Results: Thermal Load of a GH in Vancouver

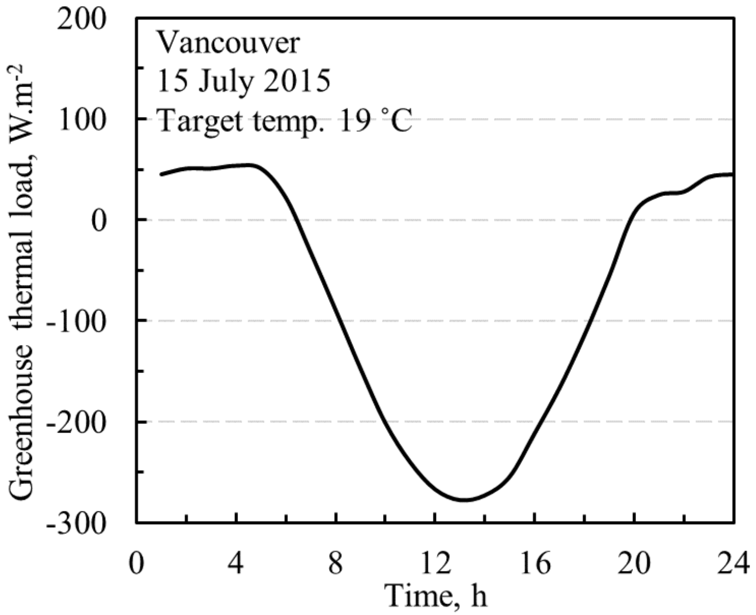




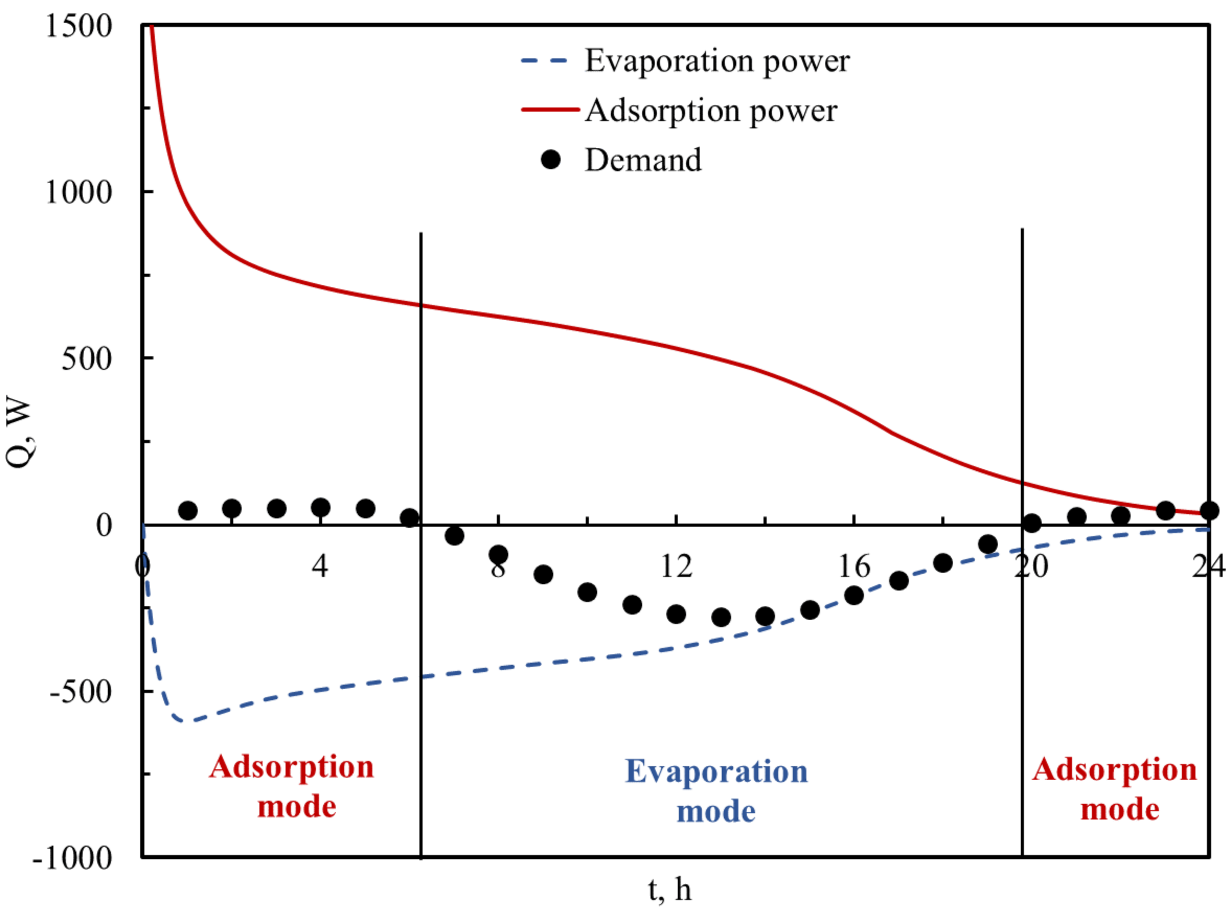
Mid-July, Vancouver

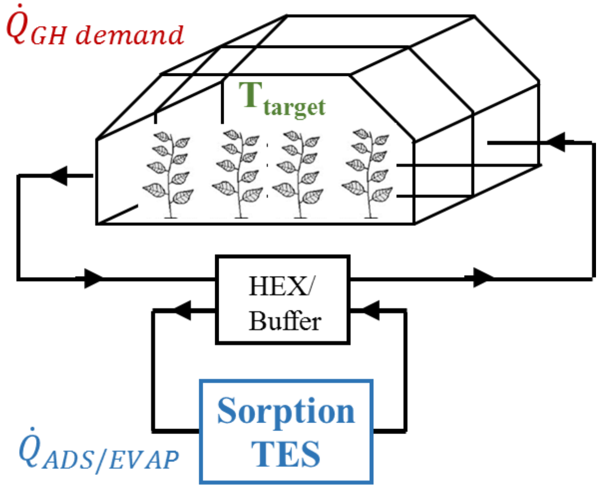
Target temperature: 19˚C (lettuce)

GH dimensions: 8×50×3 m^3



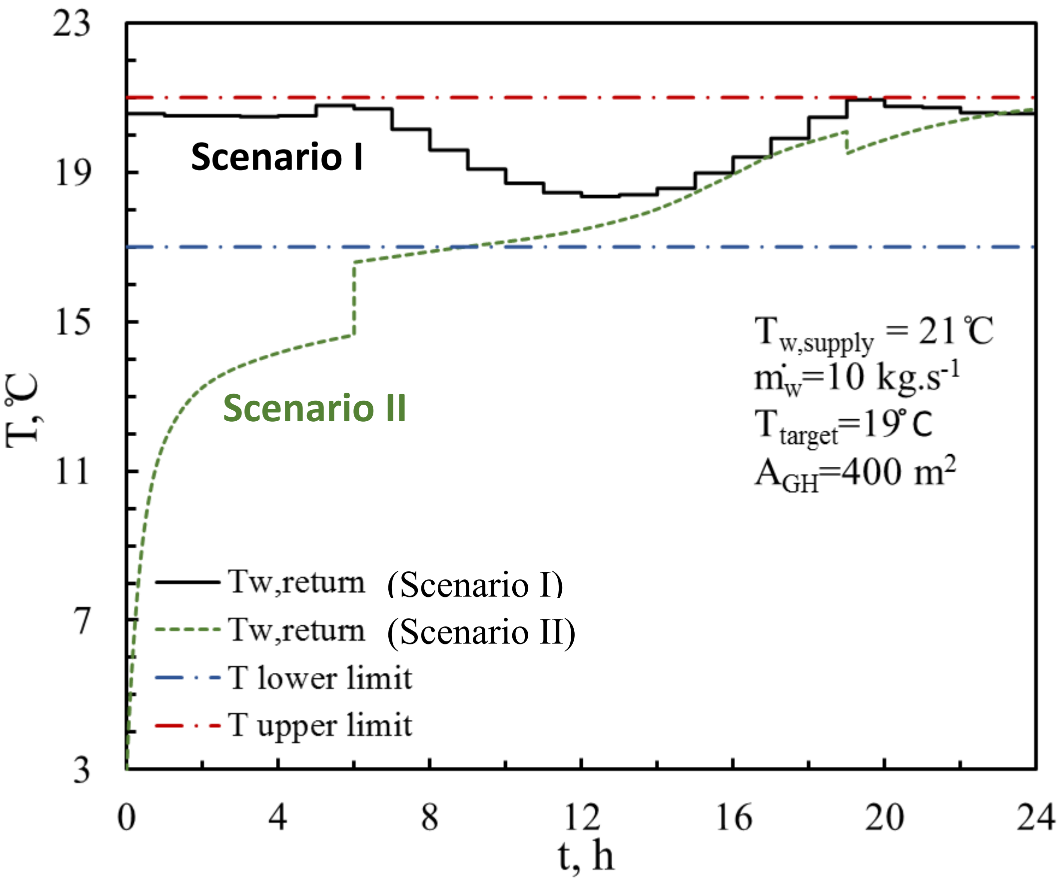
Results: Adsorption/evaporation Power to Meet the GH Thermal Demand

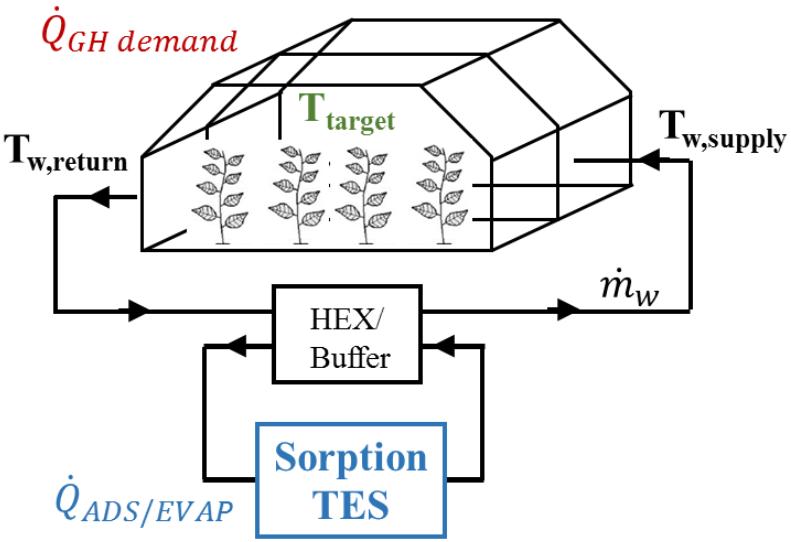




Adsorbent: FAM-Z02

Results: Return Water Temperature Variations





- Scenario I) Controlled delivered heat:
  Discharge power to GH = $\dot{Q}_{GH\ demand}$
- Scenario II) Uncontrolled delivered heat:
  Discharge power to GH = $\dot{Q}_{ADS/EVAP}$

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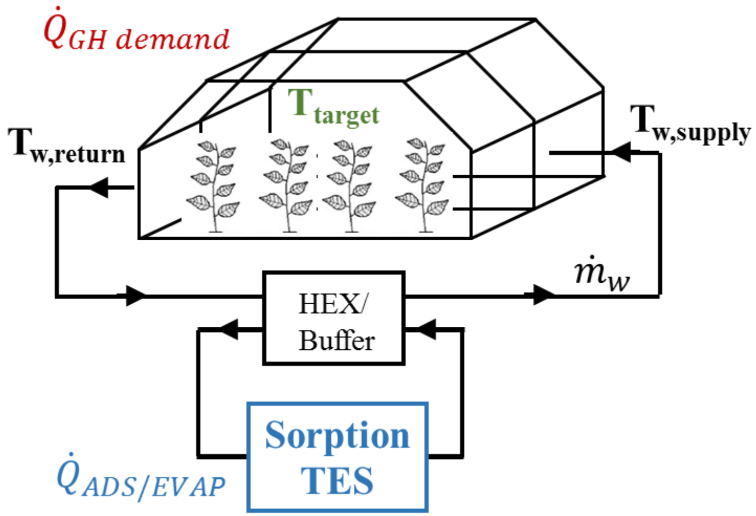
Challenges for Two Heating/Cooling Energy Delivery Scenarios

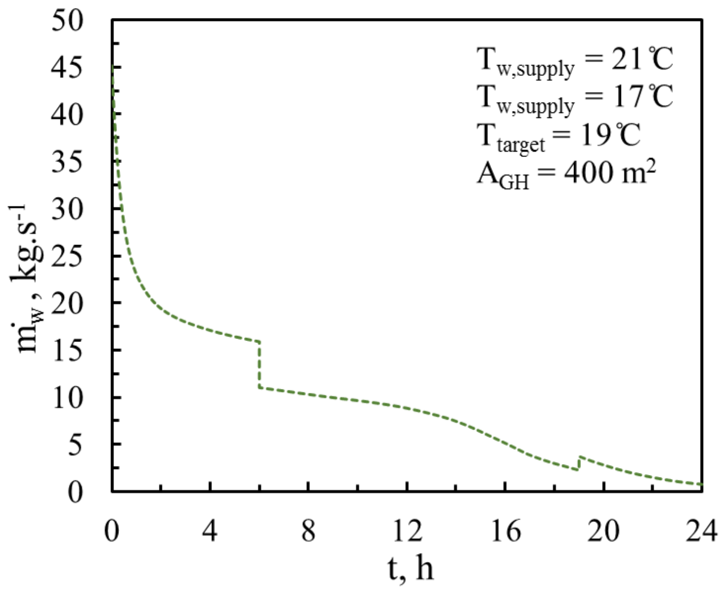
Scenario I) Discharge power to GH = $\dot{Q}_{GH\ demand}$

- Thermal load control in the HEX/Buffer before the greenhouse (Buffering the temperature)



Scenario II) Discharge power to GH = $\dot{Q}_{ADS/EVAP}$

- Variable flowrate pump



Summary and Future Work

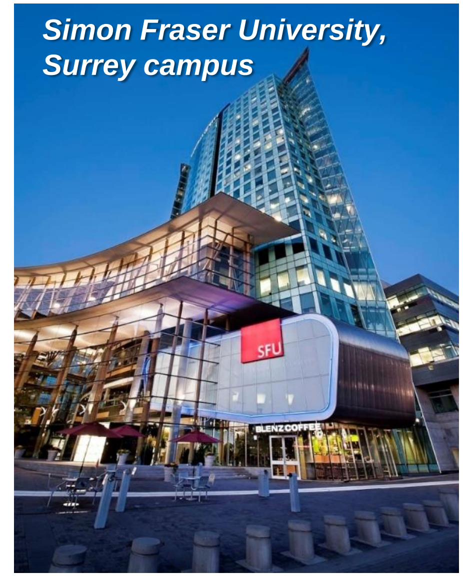
Summary:

- A sorption TES is proposed for temperature control of GH (preliminary study).
- A model developed which contains the heat load calculation module, fully-dynamic sorption modeling module and control module.

Future work:

- Economical feasibility assessment of the sorption TES system with different control strategies.
- Optimization of the sorption TES system.

Thank you for your attention!



Partners:

ARGUS CONTROLS

BC GREENHOUSE GROWERS' ASSOCIATION

Nexus BIOFUEL

Research Greenhouse
Institute for Sustainable Horticulture,
Kwantlen Polytechnic University

BACK-UP SLIDES

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Open Greenhouse versus Closed Greenhouse

Open greenhouse [1]:

- Economic limitations associated with energy consumption,
- Restriction on crop delivery date due to the seasonal climate conditions.
- Need for a better pesticides control and CO_2 enrichment system

Closed greenhouse [1]:

- **Improved energy efficiency.**
- **Improved water conservation.**
- **Improved production rate.**
- **Improved control of system.**
- **Improved total efficiency of system.**
- **Improved sustainable management.**
- **Decreased usage of pesticides.**
- **Reduced costs.**
- **Increased use of renewable energy which leads to reduced greenhouse gas emission from fossil fuels.**

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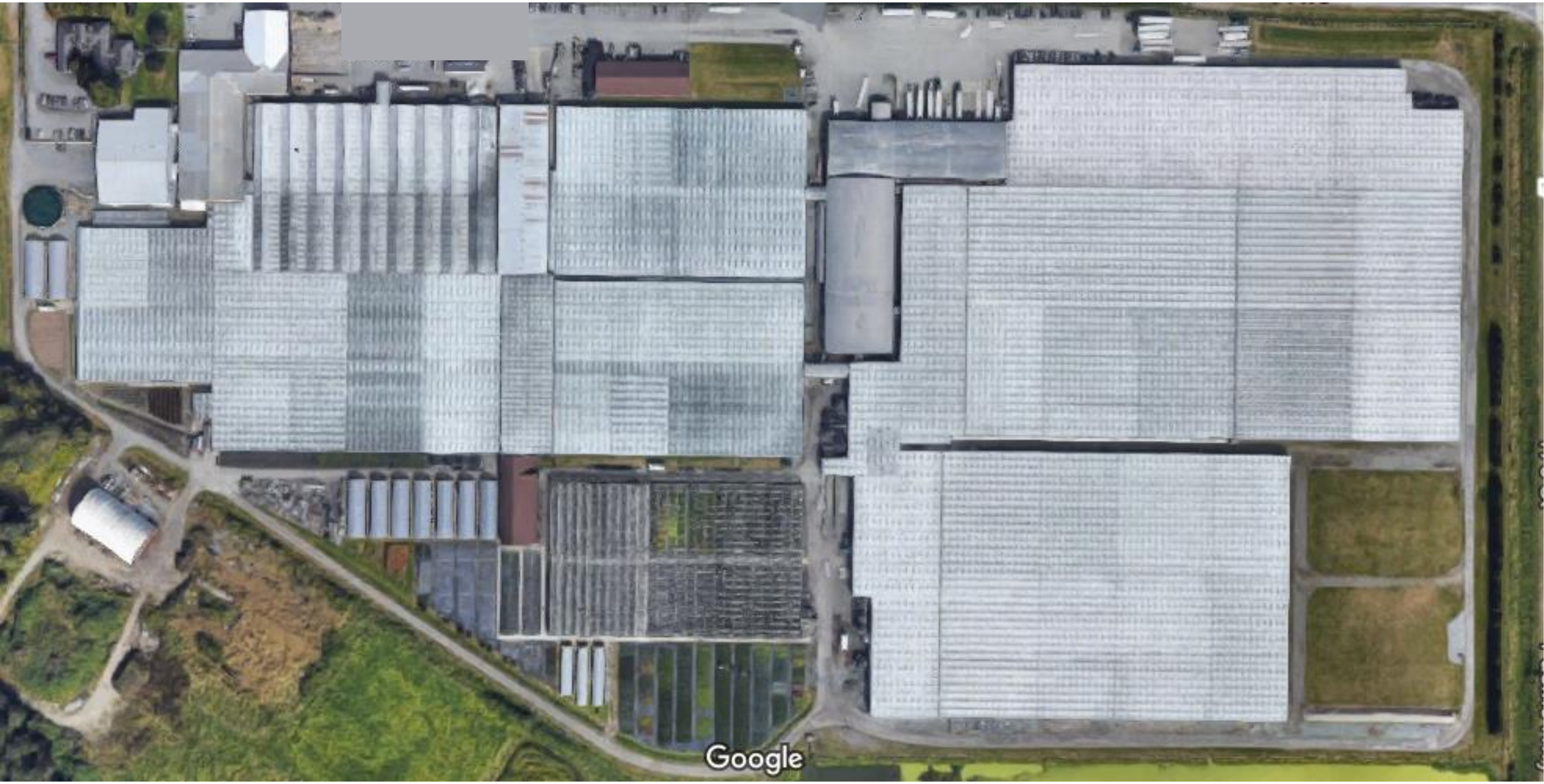
[1] A. Vadiee and V. Martin, *Renew. Sustain. Energy Rev.*, vol. 16, no. 7, pp. 5087–5100, 2012.

Large local greenhouse facilities



- 111 500 m^2 (35 acres, 1.2 million ft^2)
- Greenhouses split into 50 separate zones up to 30 crop types per zone
- 3 climatic control systems

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Greenhouse with natural gas boilers and heat storage is water tanks

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We are working with local greenhouses to learn:
- Crop growth requirements
- Current climate control methods
- Energy consumption

Greenhouse: 17,500 m^2 of peppers, tomatoes, cucumbers
Optimal temperature: 22°C day, 17°C night

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Greenhouse with natural gas boilers and heat storage is water tanks

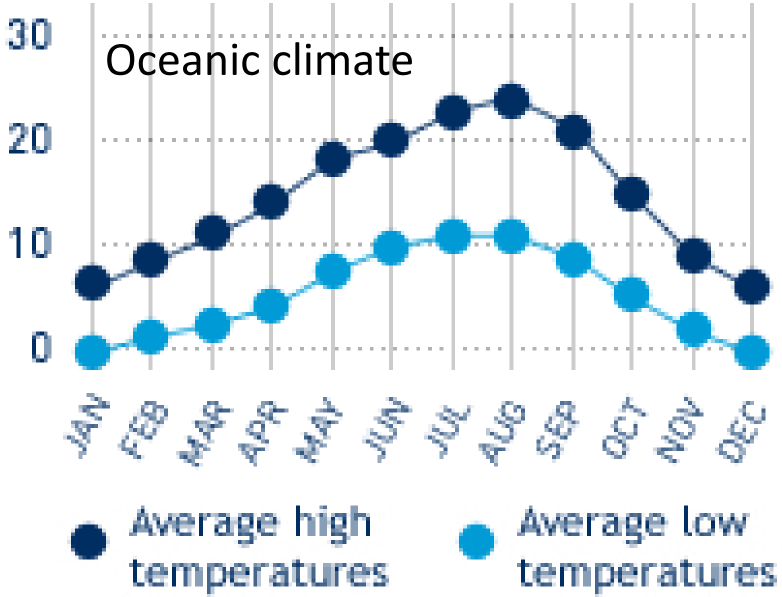
Greenhouse:

17,500 m^2, peppers, tomatoes, cucumbers

Cooling: Roof vents

Heating: Boiler and in water tank heat storage.

Optimal temperature: 22°C day, 17°C night



- The boiler is run during the day to elevate CO_2 (~1000 ppm) for optimal plant growth
- CO_2 generation is not required at night
- Water tanks store heat from the boiler during the day for use at night

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New sustainable greenhouse research program

- Assess energy consumption and climate control needs of local greenhouses
- Develop and test new heat-driven systems for climate control in a research greenhouse compartment
- Small-scale greenhouse germination and growth trials

→ Thermal energy storage
→ Sorption cooling systems
→ Desiccant heat and moisture recovery systems

Partners:

Research Greenhouse
Institute for Sustainable Horticulture,
Kwantlen Polytechnic University

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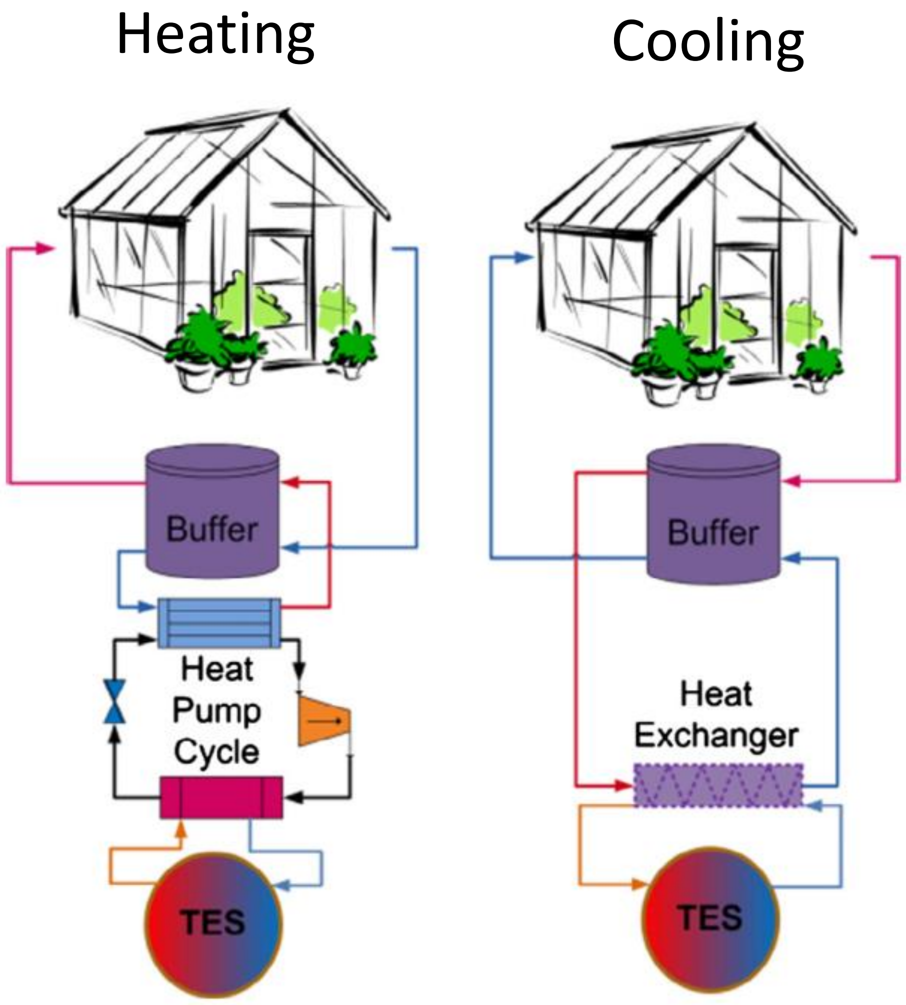
Solutions for Energy-efficient Clean-energy Greenhouses

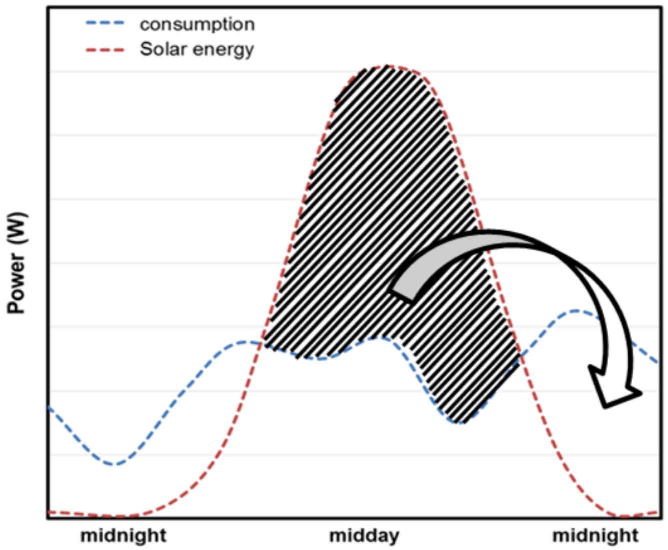
- **Closed GH:**
  1. No ventilation windows
  2. Reduces heat loss
  3. Cooling and dehumidification
  4. Integrated with heat storage
- **Thermal energy storage (TES) reduces energy consumption and GHG by:**
  1. Utilizing **waste heat** or **renewables (Solar energy)**
  2. Mitigate the **mismatch** between **supply and demand**, due to Intermittent output of heat sources.
  3. Time-shift of renewable energy to peak demand



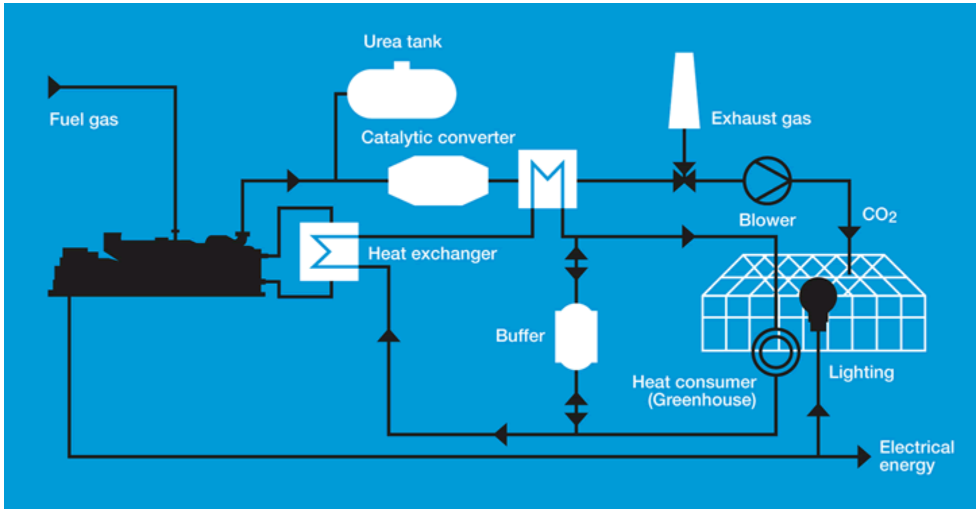
Vadiee A., Martin V., *Applied Energy* 114 (2014) 880

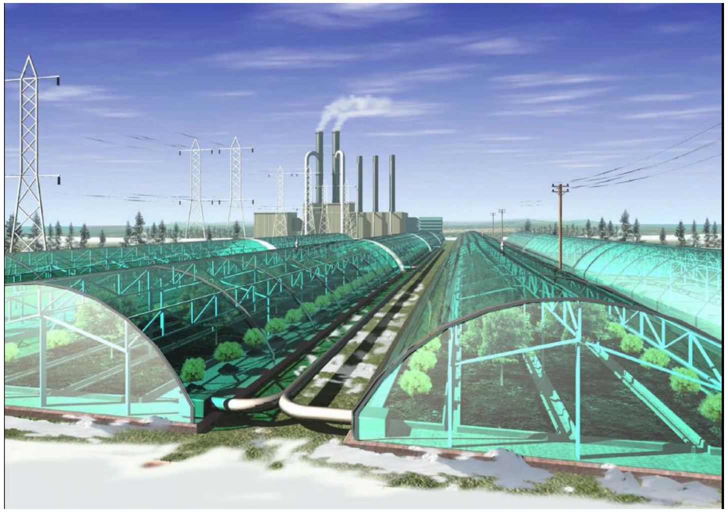
Daily TES Integrated with HVAC of GH

- **Peak load shaving**
  - Heat supply from: Solar energy
    - Daily GH energy consumption in cold weather ~ 9 MJ/m^2 [8]
    - Total solar irradiation in midday: about 10.8 MJ/m^2 [8]
  - Heat demand at: Peak load



- **Greenhouse combined heat and power (Greenhouse CHP)**
  - Heat supply from: waste heat of CHP
  - Heat demand at: Standby mode





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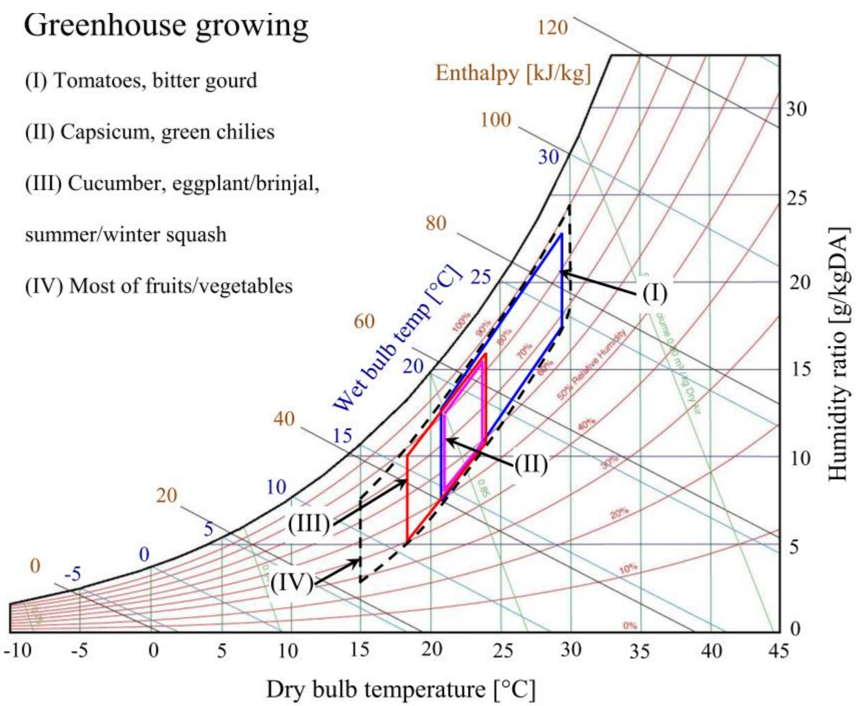
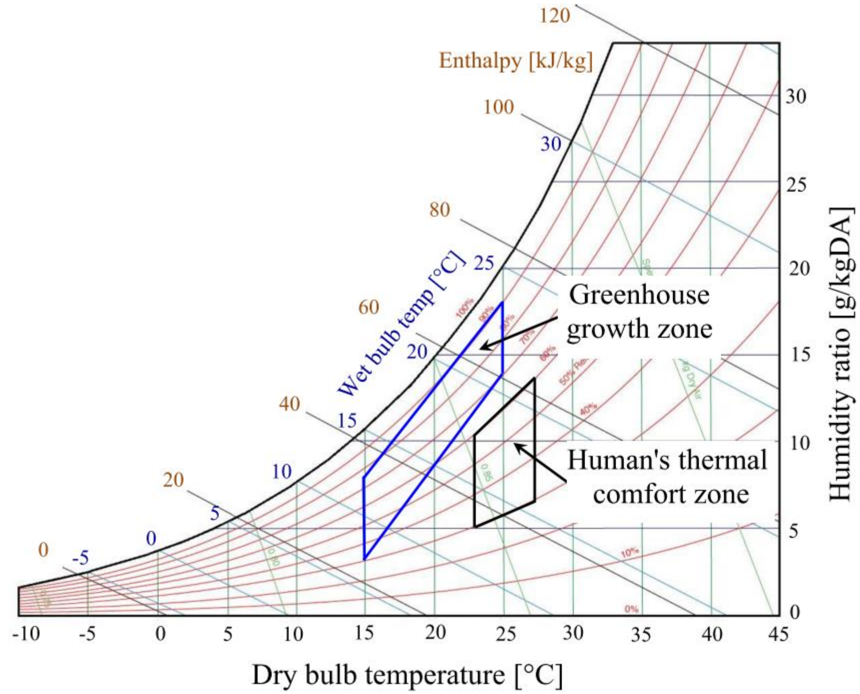


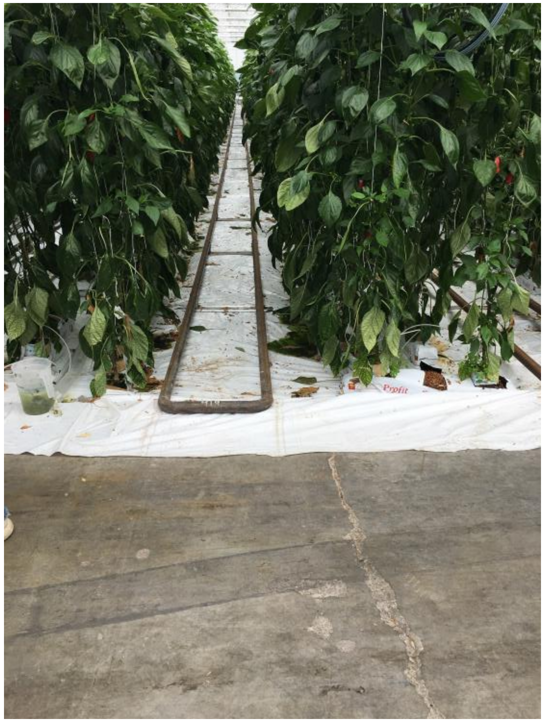
.3 Ideal temperature and relative humidity zones for few greenhouse prod



Closed sorption TES: temperature control in a GH

Why closed system?

- Having one unit for both heating and cooling.
- Keep humidity in the desirable range for plants.
- Existence of water piping for heating in the greenhouses.
- No interest in circulating air in the greenhouse (in the visited GH).
- Possibility of using air-cooled condenser and air-cooled adsorber bed to eliminate need for pumping water or oil in these HEXs.



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