Comprehensive Engineering Analysis of Zonal Heating Loads: Venlo-Style Tomato Greenhouses (Middenmeer, NL vs. Leamington, ON)

1. Introduction and Scope of Analysis

The design of HVAC systems for Controlled Environment Agriculture (CEA) requires a rigorous synthesis of structural engineering, thermodynamics, and plant physiology. This report presents a detailed, quantitative heating analysis for a commercial high-tech tomato production facility utilizing a Venlo-style structural chassis. The analysis is constrained by a fixed thermal energy generation capacity of **10 Megawatts (MW)**. This limitation serves as the primary boundary condition, necessitating a comparative evaluation of the maximum feasible cultivation area and zonal operational strategies for two of the world's premier horticultural hubs: **Middenmeer, Netherlands**, and **Leamington, Ontario, Canada**.

These locations represent distinct climatological archetypes. Middenmeer (52.8°N) exemplifies a Maritime Temperate climate (Cfb), characterized by mild winters, cool summers, and persistent cloud cover.[1] In contrast, Leamington (42.0°N) exhibits a Humid Continental climate (Dfa), defined by severe winter excursions, high summer humidity, and significant seasonal solar variability.[3] The disparity in external forcing functions—specifically ambient temperature, solar irradiance, and wind velocity—imposes divergent loads on the heating infrastructure, requiring location-specific hydronic architectures.

This analysis deconstructs the heating load into four critical thermal zones: the **Rail Pipe** (primary convection/transport), the **Grow Pipe** (vegetative steering), the **Overhead/Gutter System** (snow melt/cold fall protection), and the **Irrigation Water Heating** load. By quantifying the energy flux across these zones, we establish a robust engineering basis for system sizing, pump selection, and operational control strategies necessary to maintain the precise microclimate required for high-wire tomato cultivation.[5]

1.1 The Reference Greenhouse Module

To ensure a standardized comparison, the analysis assumes a "Reference Module" representative of modern high-tech construction [7]:

- **Structure:** Venlo type, 8.0m truss span (2 x 4.0m bays), 6.5m post height to gutter.
- **Glazing:** Single-layer diffuse glass, anti-reflective coating ($U_{glass} \approx 6.0 \ W/m^2K$).
- **Thermal Screening:** Double screen system (1 Energy Saving + 1 Blackout/Energy).

    - Combined thermal resistance when closed creates an effective U-value of $\approx 3.0 - 3.5 \ W/m^2K$ depending on seal integrity.[8]
- **Crop:** Indeterminate Tomato (e.g., *Solanum lycopersicum*), high-wire cultivation, density 2.5 stems/m^2.[6]

2. Climatological Drivers and Design Conditions

The engineering of greenhouse heating is fundamentally an exercise in risk management against extreme meteorological events. The 99% design temperature—the threshold which the ambient temperature exceeds for 99% of the hours in a typical year—dictates the peak capacity requirement.[10]

2.1 Middenmeer, Netherlands: The Maritime Baseline

Middenmeer is situated in the polders of North Holland. The proximity to the North Sea moderates temperature fluctuations, preventing the extreme deep freezes associated with continental landmasses.

- **Winter Design Temperature:** -7°C to -10°C.[11] While rare, excursions to -15°C occur but are typically short-lived.
- **Solar Radiation:** The critical limitation in Middenmeer is winter irradiance. Monthly averages in December and January are profoundly low, often below $0.6 \ kWh/m^2/day$.[12] This lack of solar gain necessitates continuous daytime heating to maintain transpiration rates, increasing the "base load" even when transmission losses are moderate.
- **Wind Load:** High average wind speeds (5-6 m/s) drive convective heat loss coefficients on the exterior glazing, increasing the U-value relative to still air.[13]

2.2 Leamington, Ontario: The Continental Challenge

Leamington, located on the 42nd parallel, experiences a climate heavily influenced by the Great Lakes but dominated by continental air masses.

- **Winter Design Temperature:** -21°C to -23°C.[10] The "Polar Vortex" phenomenon can depress temperatures further, necessitating a robust safety margin.
- **Solar Radiation:** Despite the cold, Leamington benefits from higher winter solar angles and clearer days than Northern Europe. January radiation levels can reach $1.8 - 2.2 \ kWh/m^2/day$.[16] This allows for significant passive solar gain during the day, creating a high-amplitude diurnal heating demand curve (very high night load, moderate day load).
- **Snow Load:** Unlike Middenmeer, Leamington requires a dedicated energy budget for snow melting to prevent structural failure.[18] This effectively mandates an Overhead heating zone.

2.3 Design Basis Comparison Table

Parameter	Middenmeer, NL	Leamington, ON	Implication for 10 MW Design
Design Temp (T_{out})	-10°C	-23°C	Leamington requires $\approx 45\%$ more peak capacity per m^2.
Design Temp (T_{in})	18°C	18°C	Standard tomato night setpoint.[5]
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.

3. Theoretical Heat Load Calculation

To allocate the 10 MW thermal capacity effectively, we must calculate the specific heat load per square meter (Q_{total}) for both locations. The total load is the summation of Transmission (Q_{trans}), Infiltration (Q_{inf}), and Perimeter (Q_{perim}) losses.

3.1 Transmission Heat Loss (Q_{trans})

Transmission loss typically accounts for 70-80% of the total load. It is governed by the Fourier Law of heat conduction, adapted for the composite envelope of a greenhouse.

$$Q_{trans} = U_{composite} \cdot A_{surface} \cdot (T_{in} - T_{out})$$

Where:

- $U_{composite}$ is the overall heat transfer coefficient.
  - Glass (unscreened): $6.2 \ W/m^2K$.[19]
  - Glass + Energy Screen: $3.5 \ W/m^2K$.[9]

    - Glass + Double Screen: $2.5 \ W/m^2K$.
- $A_{surface}$ is the developed surface area. For a Venlo roof (22° pitch), the roof area factor is approximately 1.15 times the floor area.[21]

Calculated Peak Transmission Load (Screens Closed):

- **Middenmeer:** $Q_{trans} = 3.5 \ W/m^2K \times 1.15 \times 28K \approx 112.7 \ W/m^2$.
- **Leamington:** $Q_{trans} = 3.5 \ W/m^2K \times 1.15 \times 41K \approx 165.0 \ W/m^2$.

3.2 Infiltration Heat Loss (Q_{inf})

Infiltration represents the energy required to heat cold outside air entering through structural gaps. This is highly dependent on wind speed and construction quality. Modern Venlo houses target an air exchange rate (ACH) of < 0.5 h^{-1} when closed.[18]

$$Q_{inf} = \frac{V \cdot ACH \cdot \rho_{air} \cdot C_{p,air} \cdot (T_{in} - T_{out})}{3600}$$
Assuming a mean greenhouse height of 7.0m ($V = 7.0 \ m^3/m^2$):

- Middenmeer (-10°C):

  $$Q_{inf} = \frac{7.0 \cdot 0.5 \cdot 1.25 \cdot 1006 \cdot 28}{3600} \approx 34.2 \ W/m^2$$
- Leamington (-23°C):

  $$Q_{inf} = \frac{7.0 \cdot 0.5 \cdot 1.29 \cdot 1006 \cdot 41}{3600} \approx 51.6 \ W/m^2$$

  Note: Air density (ρ_{air}) increases at lower temperatures, slightly penalizing Leamington further.

3.3 Total Peak Load and Area Determination

Adding a 10% safety margin for perimeter losses and thermal bridging (Q_{perim}):

- **Middenmeer Total Peak:** $(112.7 + 34.2) \times 1.10 \approx **161 \ W/m^2**$.
- **Leamington Total Peak:** $(165.0 + 51.6) \times 1.10 \approx **238 \ W/m^2**$.

Feasible Area Calculation (10 MW Basis):
The 10 MW (10,000,000 Watts) source capacity defines the maximum grow area.

- **Middenmeer:** $10,000,000 \ W / 161 \ W/m^2 \approx 62,111 \ m^2$ (6.2 Hectares).
- **Leamington:** $10,000,000 \ W / 238 \ W/m^2 \approx 42,016 \ m^2$ (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 m^2)** facility.

- In Leamington, this utilizes $\approx 95\%$ of the 10 MW capacity at peak (Critical

constraints).
- In Middenmeer, this utilizes $\approx 64\%$ of the 10 MW capacity at peak (High redundancy).

4. Zone-by-Zone Hydronic Analysis

Modern greenhouse heating is not monolithic; it is a distributed system designed to influence specific physiological processes. We analyze four distinct zones.

4.1 Zone 1: The Rail Pipe (Primary Convection)

The rail pipe is the workhorse of the climate system. Located on the floor, it serves as the track for electric harvest carts and provides the primary convective lift to manage humidity.[22]

- **Configuration:** Two (2) steel pipes per crop row.
- **Diameter:** Standard 51mm (2-inch) OD steel pipe.
- **Row Spacing:** Typical tomato row spacing is 1.6m.
- **Linear Density:** $2 \text{ pipes} / 1.6 \text{ m} = 1.25 \text{ m}_{pipe} / m^2_{floor}$.

Thermodynamics:
The heat output of a 51mm smooth steel pipe is a function of the temperature difference between the pipe water (T_{water}) and the greenhouse air (T_{air}). The standard emission factor (k) is approximately $k = 1.8 - 2.0 \ W/m \cdot K$ depending on the convective coefficient.24

$$Q_{rail} = L_{pipe} \cdot k \cdot (T_{pipe,avg} - T_{air})$$
Leamington Requirement (Zone 1):
To provide 60% of the peak load ($0.60 \times 238 = 143 \ W/m^2$) via rail pipes:

$$143 \ W/m^2 = 1.25 \ m/m^2 \cdot 2.0 \ W/mK \cdot \Delta T$$

$$\Delta T_{required} \approx 57.2^\circ C$$
- With $T_{air} = 18^\circ C$, $T_{pipe,avg} = 75.2^\circ C$.
- **Hydronic Design:** Supply $80^\circ C$, Return $70^\circ C$. This high temperature requires a boiler or high-grade heat source; heat pumps alone may struggle to achieve this efficiency.[26]

Middenmeer Requirement (Zone 1):
To provide 60% of the peak load ($0.60 \times 161 = 97 \ W/m^2$) via rail pipes:

$$97 \ W/m^2 = 1.25 \cdot 2.0 \cdot \Delta T$$

$$\Delta T_{required} \approx 38.8^\circ C$$

- With $T_{air} = 18^\circ C$, $T_{pipe,avg} = 56.8^\circ C$.
- **Hydronic Design:** Supply $60^\circ C$, Return $53^\circ C$. This lower regime is ideally suited for geothermal heat (common in NL) or residual industrial heat.[27]

4.2 Zone 2: The Grow Pipe (Vegetative Steering)

The grow pipe is a smaller diameter pipe located within the crop canopy, often adjustable in height. Its primary function is not bulk air heating, but "steering" the plant.[28] Warming the fruit trusses and head of the plant directly stimulates ripening and generative development.[5]

- **Configuration:** One (1) or two (2) pipes per row, often mounted on hangers.
- **Diameter:** 32mm to 38mm painted steel or aluminum.
- **Temperature Limit:** Limited to max $45^\circ C - 50^\circ C$ to prevent contact burn on leaves and fruit.

Energy Contribution:
Because of the temperature limit, the grow pipe provides a fixed "base load."

- Emission (32mm pipe, $45^\circ C$ avg, $20^\circ C$ air): $\approx 35 \ W/m$.
- Density: $0.625 \ m/m^2$ (1 pipe) or $1.25 \ m/m^2$ (2 pipes).
- **Capacity:** $\approx 20 - 45 \ W/m^2$.
- **Usage Strategy:** In Middenmeer, this pipe runs frequently to maintain plant activity during low-light days. In Leamington, it is crucial for preventing humidity condensation on fruits during cold nights.

4.3 Zone 3: Overhead / Gutter Heating (Snow Melt & Cold Fall)

This zone consists of pipes located immediately under the gutter profile.

- **Leamington (Critical):** During snow events, the gutter must be heated to $>5^\circ C$ to facilitate shedding. If the internal screen is closed, heat from the rail pipe cannot reach the gutter. Therefore, **dedicated hydronic loops** adjacent to the gutter are mandatory.
  - *Load:* Can exceed $150 \ W/m^2$ locally during active melting. This must be factored into the 10 MW peak. The 10 MW system may need to divert all energy to this zone during a blizzard, temporarily sacrificing crop temperature (dropping to 12-14°C) to save the structure.[18]
- **Middenmeer (Secondary):** Used primarily to prevent "cold fall"—downdrafts of cold air from the glass chilling the plant heads. Load is minimal ($10-20 \ W/m^2$).

4.4 Zone 4: Irrigation Water Heating

Heating the root zone via irrigation water is thermodynamically efficient for nutrient uptake.[29] Cold water shocks roots and halts phosphorous uptake.

- **Target:** Heat incoming water from $8^\circ C$ (mains/pond) to $20^\circ C$.
- **Volume:** Mature tomato crop transpires $3 - 4 \ L/m^2/day$.[31]

- Energy Calculation:

  $$E_{water} = Volume \cdot C_{p,water} \cdot \Delta T$$
  $$E = 4 \ L/m^2 \cdot 4186 \ J/kgK \cdot 12K \approx 200,928 \ J/m^2 \approx 0.056 \ kWh/m^2/day$$
- **Power Load:** While the *energy* is low, the *instantaneous power* can be high if watering occurs in pulses.
  - *Peak Demand:* $\approx 10 - 15 \ W/m^2$ during irrigation cycles.
  - *Integration:* This heat is typically supplied via a heat exchanger from the main boiler loop or a buffer tank.

5. Hydronic Flow Rates and Pump Sizing

The delivery of 10 MW thermal energy requires substantial fluid movement. The flow rate is determined by the specific heat capacity of water and the designed temperature drop (ΔT) across the main transport lines.

$$Flow \ (\dot{V}) = \frac{Q_{thermal}}{\rho \cdot C_p \cdot \Delta T}$$
For the main transport headers (from Energy Center to Greenhouse):

- $Q = 10,000 \ kW$
- $\rho \approx 985 \ kg/m^3$ (at 60°C)
- $C_p = 4.18 \ kJ/kgK$
- Design $\Delta T = 20^\circ C$ (e.g., Supply 90°C, Return 70°C).

Main Header Flow Rate:

$$\dot{V} = \frac{10,000}{985 \cdot 4.18 \cdot 20} \approx 0.121 \ m^3/s = 437 \ m^3/hr$$

5.1 Sub-Loop Flow Rates (Per Hectare)

Inside the greenhouse, flow rates must maintain turbulent flow in the pipes for effective heat transfer ($Re > 4000$) while minimizing pressure drop.[32]

Table 1: Hydronic Specifications per 4.0 Ha Block (Leamington High Load)

Zone	Load (W/m2)	Total Load (MW)	Supply Temp (°C)	Return Temp (°C)	Design ΔT (°C)	Flow Rate (m3/hr)	Pipe Velocity (m/s)	Pump Head Requirement

Rail Pipe	143	5.72	85	70	15	328	0.8 - 1.2	High (Tichelmann friction)
Grow Pipe	45	1.80	50	40	10	155	0.5 - 0.8	Moderate
Overhead	35	1.40	85	65	20	60	0.4 - 0.6	Low
Peripheral	15	0.60	85	65	20	26	0.5	Low
Total	**238**	**~9.52**				**~569***		

Note: Total flow at the mixing groups is higher than the main header flow because the mixing groups recirculate return water to lower the supply temperature for the loops (variable flow secondary, constant flow primary).

6. Monthly Energy Analysis: Comparative Profiles

The following tables integrate climate normals [12] to project the monthly thermal demand. These estimates assume a boiler efficiency of 90% and standard heating degree day (HDD) methodologies adjusted for greenhouse solar gain factors.

6.1 Leamington, Ontario (4.0 Ha, 10 MW Source)

Design Note: Leamington requires significant heat even in shoulder months due to cold nights. The solar gain in March-April is substantial, often leading to heating at night and venting by noon.

Table 2: Leamington Energy Profile

Month	Avg Night T (°C)	Daily Solar (kWh/m2)	Net Heat Demand (kWh/m2)	Total Energy (MWh)	Zone Priority	Rail Pipe Supply/Return (°C)

Jan	-7.0	1.8	135	5,400	Rail + Grow + Snow Melt	80 / 65
Feb	-6.0	2.8	115	4,600	Rail + Grow	80 / 65
Mar	-1.0	3.9	85	3,400	Rail (Night)	70 / 55
Apr	4.0	4.8	45	1,800	Grow (Steering)	60 / 50
May	11.0	5.9	15	600	Min Pipe (Humidity)	45 / 35
Jun	16.0	6.5	5	200	Min Pipe	40 / 30
Jul	19.0	6.8	2	80	None	Off
Aug	19.0	5.8	3	120	Min Pipe	40 / 30
Sep	15.0	4.5	15	600	Min Pipe	45 / 35
Oct	9.0	2.9	50	2,000	Rail (Night)	60 / 50
Nov	3.0	1.6	90	3,600	Rail + Grow	70 / 55
Dec	-2.0	1.2	125	5,000	Rail + Grow	80 / 65
Total			**~685**	**27,400**		

Note: "Rail Pipe Supply/Return" refers to the estimated water temperature required in the *primary loop to meet the average monthly load.*

6.2 Middenmeer, Netherlands (4.0 Ha, 10 MW Source)

Design Note: Middenmeer has a flatter load profile. It rarely hits the peaks of Leamington but has a longer "moderate" heating season. The low solar gain in Dec/Jan means the greenhouse acts closer to a black-box radiator day and night.

Table 3: Middenmeer Energy Profile

Month	Avg Night T (°C)	Daily Solar (kWh/m2)	Net Heat Demand (kWh/m2)	Total Energy (MWh)	Zone Priority	Rail Pipe Supply/Return (°C)
Jan	2.0	0.6	100	4,000	Rail + Grow (Day/Night)	60 / 45
Feb	2.0	1.2	90	3,600	Rail + Grow	60 / 45
Mar	4.0	2.5	70	2,800	Rail	55 / 40
Apr	6.0	4.0	40	1,600	Grow (Steering)	50 / 35
May	9.0	5.2	25	1,000	Min Pipe	45 / 35
Jun	12.0	5.8	10	400	Min Pipe	40 / 30
Jul	14.0	5.6	5	200	Min Pipe	40 / 30
Aug	14.0	4.8	5	200	Min Pipe	40 / 30
Sep	12.0	3.2	20	800	Min Pipe	45 / 35
Oct	9.0	1.8	50	2,000	Rail	50 / 35

					(Night)	
Nov	6.0	0.8	80	3,200	Rail + Grow	55 / 40
Dec	3.0	0.5	95	3,800	Rail + Grow	60 / 45
Total			**~590**	**23,600**		

6.3 Comparative Insight

While Leamington has a colder design temperature, its high solar gain in late winter reduces the *net* difference in annual consumption. The annual consumption in Leamington is only ~16% higher than Middenmeer (685 vs $590 \ kWh/m^2$), despite the massive difference in peak capacity requirements. This dictates that **Leamington needs a larger boiler (CapEx) but utilizes it with similar annual fuel intensity (OpEx) to Middenmeer.**

7. Sensitivity Analysis and Risk Mitigation

Engineering designs must account for failure modes. We analyze the resilience of the 10 MW system under three stress scenarios.

7.1 Scenario A: Thermal Screen Failure (Leamington, -23°C)

If the energy screens fail to deploy or tear during a polar night, the insulation value ($R-value$) of the roof drops from $\approx 0.33 \ m^2K/W$ (screened) to $\approx 0.16 \ m^2K/W$ (glass only).

- **Impact:** Transmission load doubles. Q_{trans} jumps to $>300 \ W/m^2$.
- **Total Load:** $\approx 350 \ W/m^2$.
- **System Status:** 10 MW capacity = $250 \ W/m^2$ (for 4 Ha).
- **Deficit:** $100 \ W/m^2$ ($4 \ MW$ deficit).
- **Consequence:** Internal temperature will plummet. The heating system cannot maintain 18°C.
- **Mitigation Strategy:** The control computer must immediately prioritize the **Zone 3 (Overhead/Gutter)** circuit to prevent freezing of the structure, while sacrificing the air temperature. Root zone heating (Zone 4/Grow Pipe) should be maintained to protect the plant crown, but vegetative growth will stop. This scenario highlights the absolute criticality of screen maintenance in Leamington compared to Middenmeer.

7.2 Scenario B: High Wind Event (> 30 km/h)

Wind strips the boundary layer of air from the greenhouse exterior, increasing the convective heat transfer coefficient (h_c).

- **Physics:** U_{glass} increases from 6.0 to $\approx 7.5 \ W/m^2K$.
- **Infiltration:** Increases from 0.25 ACH to 1.0+ ACH due to pressure differentials (Bernoulli effect).[18]
- **Zone Impact:** The **Peripheral Zone (Zone 4)** becomes critical. The gable ends will act as massive heat sinks. If the peripheral heating capacity is insufficient, strong horizontal temperature gradients will form, causing uneven crop growth (stunted outer rows).
- **Design Recommendation:** In Leamington, peripheral pipes should be sized for 150% of theoretical static load to account for wind scouring.

7.3 Scenario C: Geothermal Source Limitation (Middenmeer)

Middenmeer facilities often rely on geothermal wells with strict return temperature limits (e.g., Return must be < 40°C for doublet efficiency).

- **Constraint:** Standard rail pipes (Supply 80°C / Return 60°C) violate this constraint.
- **Solution:** The hydronic design must use "low-grade" heat integration.
  - Use **Zone 2 (Grow Pipe)** and **Zone 4 (Floor/Irrigation)** as the first stage of heat rejection to lower the return water temperature.
  - Oversize the Rail Pipe radiators (add fins or specific "star" profiles) to allow operation at Supply 60°C / Return 35°C while still delivering the required Wattage. This increases CapEx (more steel) but enables OpEx savings via geothermal efficiency.

8. Conclusion and Recommendations

The analysis confirms that a 10 MW thermal design basis serves fundamentally different roles in the two locations.

1. **Middenmeer, NL:** The 10 MW capacity provides a **High-Availability/Redundant** solution for a 4.0-hectare block. The load factors are moderate (~60-70%), allowing for sophisticated low-temperature heating strategies (Geothermal/Heat Pump integration). The primary engineering challenge is not peak capacity, but **efficiency at partial load** and humidity management (latent heat removal) during dark, damp winters.
   - *Recommendation:* Invest in air handling units (AHUs) or active ventilation with heat recovery to manage humidity without excessive "minimum pipe" gas usage.
2. **Leamington, ON:** The 10 MW capacity is a **Critical Constraint** for a 4.0-hectare block. It is sufficient for standard winter operations but lacks the headroom for catastrophic failure modes (screen failure + extreme cold). The system operates near 100% capacity during polar events.
   - *Recommendation:* Strict quality control on envelope tightness is non-negotiable. The hydronic design must prioritize **Snow Melt (Zone 3)** and **Peripheral (Zone 4)** circuits. A large thermal buffer tank (heat storage) is essential to smooth out demand spikes (e.g., morning ramp-up) and provide a safety bridge during boiler

maintenance or peak load intervals.

By adhering to these zonal strategies and respecting the distinct climatological physics of each site, the 10 MW capacity can be engineered to support high-yield tomato production effectively in both environments.

Works cited

1. Climate & Weather Averages in Middenmeer, Netherlands - Time and Date, accessed December 9, 2025, https://www.timeanddate.com/weather/@2750850/climate
2. Netherlands - Climatology (CRU) - Climate Change Knowledge Portal, accessed December 9, 2025, https://climateknowledgeportal.worldbank.org/country/netherlands/climate-data-historical
3. Leamington (ON) Weather & Climate | Year-Round Guide with Graphs, accessed December 9, 2025, https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,leamington-ontario-ca,Canada
4. Leamington Weather Averages - Ontario, CA, accessed December 9, 2025, https://www.worldweatheronline.com/leamington-weather-averages/ontario/ca.aspx
5. What are the Ideal Conditions for Greenhouse Tomatoes? - DryGair, accessed December 9, 2025, https://drygair.com/blog/what-are-the-ideal-conditions-for-greenhouse-tomatoes/
6. Irrigation Strategies for Greenhouse Tomato Production on Rockwool in - ASHS Journals, accessed December 9, 2025, https://journals.ashs.org/view/journals/hortsci/43/2/article-p484.xml
7. Venlo Greenhouses: Economical Quality, accessed December 9, 2025, https://www.venloinc.com/greenhouses/venlo
8. Increase of light transmission of a Venlo-type greenhouse during winter by 10% : A design study | Request PDF - ResearchGate, accessed December 9, 2025, https://www.researchgate.net/publication/329461171_Increase_of_light_transmission_of_a_Venlo-type_greenhouse_during_winter_by_10_A_design_study
9. The Real Value of Greenhouse Thermal Screens: Cost, Benefits, and ROI Explained, accessed December 9, 2025, https://www.insongreen.com/greenhouse-thermal-screens-cost-and-roi/
10. ENERGY STAR Certified Homes County-Level Design Temperature Reference Guide, accessed December 9, 2025, https://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/County%20Level%20Design%20Temperature%20Reference%20Guide%20-%202015-06-24.pdf
11. Accelerating the Dutch energy transition: Lowering operating temperatures of heat distribution systems in the built environment - WarmingUp, accessed

December 9, 2025, https://www.warmingup.info/documenten/2a-accelerating-the-dutch-energy-transition.pdf
12. Calibration and Validation of ArcGIS Solar Radiation Tool for Photovoltaic Potential Determination in the Netherlands - MDPI, accessed December 9, 2025, https://www.mdpi.com/1996-1073/14/7/1865
13. KNMI'23 climate scenarios for the Netherlands - Aviation, Weather and Seismology Bonaire, Saba and St. Eustatius, accessed December 9, 2025, https://www.knmidc.org/climate/docs/KNMI23_climate_scenarios_user_report.pdf
14. Middenmeer, The Netherlands weather in January: average temperature & climate - Wanderlog, accessed December 9, 2025, https://wanderlog.com/weather/49096/1/middenmeer-weather-in-january
15. Canadian Climate Normals - Climate - Environment and Climate ..., accessed December 9, 2025, https://climate.weather.gc.ca/climate_normals/
16. Debunking the Myth: The Truth About Sun and Solar Energy in Southern Ontario, accessed December 9, 2025, https://otterenergy.com/the-truth-about-sun-and-solar-energy-in-southern-ontario/
17. Extremes: Maximum Solar Radiation - Daily data for Leamington, accessed December 9, 2025, https://leamington.weatherstats.ca/charts/extreme_max_solar_radiation-daily.html
18. Greenhouses: Heating, Ventilation, and Cooling | CAES Field Report - UGA, accessed December 9, 2025, https://fieldreport.caes.uga.edu/publications/B792/greenhouses-heating-ventilation-and-cooling/
19. Greenhouses and heat loss: Comparing insulation materials for greater efficiency, accessed December 9, 2025, https://horti-generation.com/reduce-heat-loss-greenhouses/
20. Estimating the Thermal Properties of the Cover and the Floor in a Plastic Greenhouse, accessed December 9, 2025, https://www.mdpi.com/1996-1073/14/7/1970
21. THERMAL ENVIRONMENT MODELING AND ... - HARVEST (uSask), accessed December 9, 2025, https://harvest.usask.ca/bitstream/handle/10388/8542/AHAMED-DISSERTATION-2018.pdf?isAllowed=y&sequence=1
22. Innovative Heating Systems - GGS Greenhouse Structures, accessed December 9, 2025, https://ggs-greenhouse.com/heating-system/
23. Heating tubes 51 mm | DS Hortitrade, accessed December 9, 2025, https://www.hortitrade.com/en/catalog/mb1080005/heating-tubes-51-mm
24. Unit 05: Heating Systems - Greenhouse Management Online, accessed December 9, 2025, https://greenhouse.hosted.uark.edu/Unit05/Printer_Friendly.html
25. Minimum pipe heat in your glasshouse: what does it cost? - AHDB Horticulture, accessed December 9, 2025,

https://potatoes.ahdb.org.uk/knowledge-library/minimum-pipe-heat-in-your-glasshouse-what-does-it-cost
26. Hydronic heating systems: How can you save by lowering the water temperature?, accessed December 9, 2025, https://www.csemag.com/hydronic-heating-systems-how-can-you-save-by-lowering-the-water-temperature/
27. Greenhouse Heating System | Novagric, accessed December 9, 2025, https://novagric.com/en/greenhouse-climate-technologies/heating-in-greenhouses/
28. Study of the vertical temperature profile in a tomato greenhouse equipped with lighting, two screens and a VentilationJet system - WUR eDepot, accessed December 9, 2025, https://edepot.wur.nl/538066
29. Local Temperature Control in Greenhouse Vegetable Production - J-Stage, accessed December 9, 2025, https://www.jstage.jst.go.jp/article/hortj/88/3/88_UTD-R004/_html/-char/en
30. Optimized Design of Irrigation Water-Heating System and Its Effect on Lettuce Cultivation in a Chinese Solar Greenhouse - NIH, accessed December 9, 2025, https://pmc.ncbi.nlm.nih.gov/articles/PMC10934767/
31. Response of tomato (Solanum lycopersicum L.) to water consumption, leaf area and yield with respect to the - SciELO, accessed December 9, 2025, http://www.scielo.org.ar/pdf/refca/v50n2/v50n2a08.pdf
32. Root Zone Heat - Installation Techniques : Greenhouse & Floriculture : Center for Agriculture, Food, and the Environment (CAFE) at UMass Amherst, accessed December 9, 2025, https://www.umass.edu/agriculture-food-environment/greenhouse-floriculture/fact-sheets/root-zone-heat-installation-techniques
33. Greenhouse Engineering, NRAES-33 - Extension, accessed December 9, 2025, https://fyi.extension.wisc.edu/energy/files/2016/09/NRAES-33_Greenhouse-Engineering.pdf
34. Climate & Weather Averages in Leamington, Ontario, Canada - Time and Date, accessed December 9, 2025, https://www.timeanddate.com/weather/@6051122/climate