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Performance Verification of New Research Greenhouse Facilities

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Commissioning new greenhouses involves confirming that all the systems function properly and meet the performance requirements in the specifications.

Our specifications for greenhouse air tightness generally call for a maximum infiltration rate with a minimum wind speed and a defined interior and exterior temperature.

Example: 0.75 air changes per hour @ 20 °C interior and 0 °C and wind > 15 km/h.

Testing can be done by means of tracer gas dilution measurement (ASTM E741-95) with CO_2.

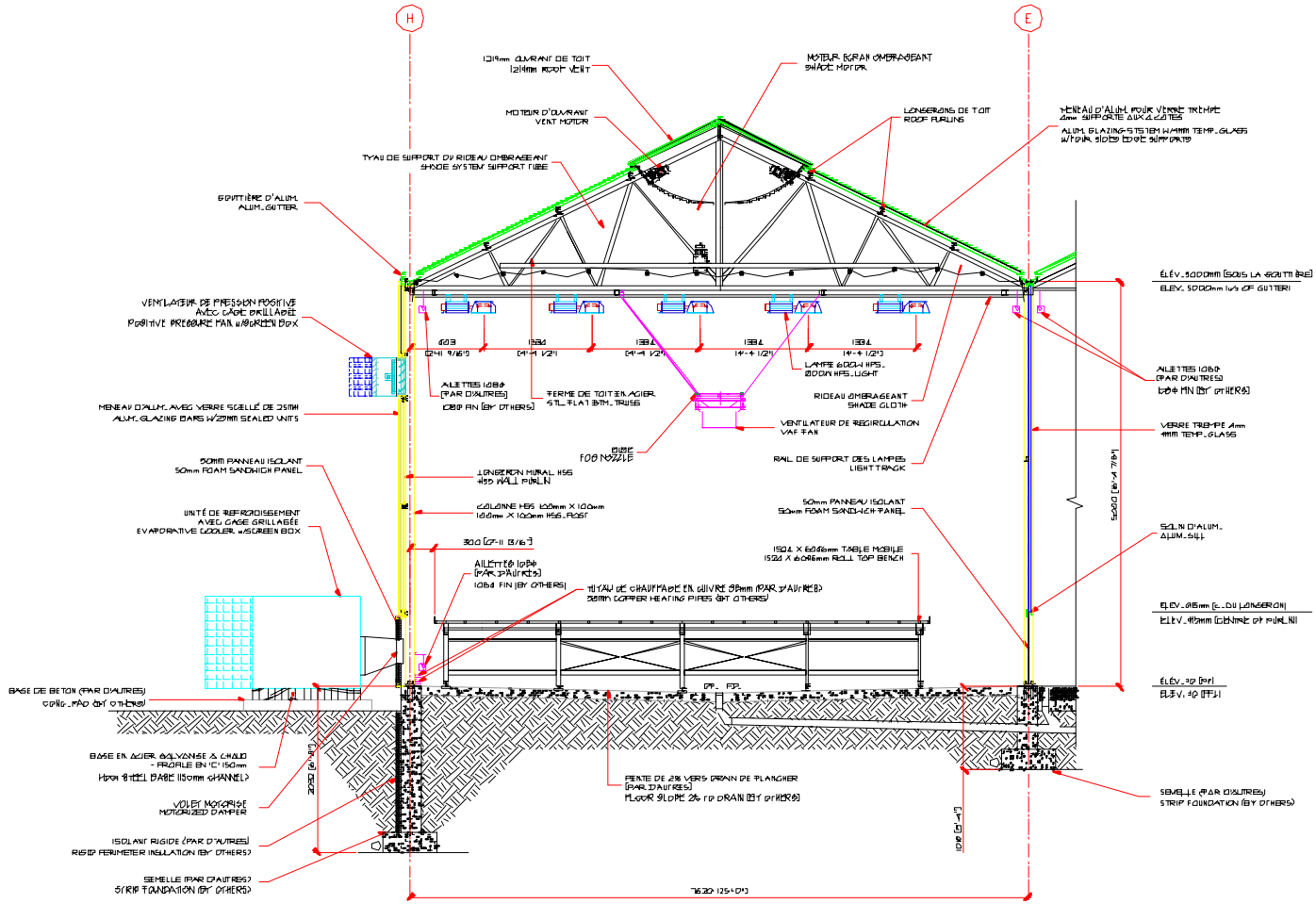
PROBLEM 1: Wind velocity at commissioning is different than the conditions in the specifications.

PROBLEM 2: Outdoor and indoor temperatures can vary significantly. The resulting temperature difference (ΔT) also result in non standard conditions.

PROPOSED SOLUTION: Determine appropriate correction factors to apply to infiltration rates measured with varying wind and ΔT conditions to normalize the results to “standard specification conditions”.

Greenhouse Engineering undertook the design, construction phase services of a major new facility at Université Laval in Quebec city. Commissioning was performed by GHE and the greenhouse contractor in January of 2008.

With the permission and collaboration of the University we carried out repeated air infiltration tests under varying wind and temperature conditions in order to acquire sufficient data to establish normalization factors.



SECTION DÉTAILLÉE – DETAILED CROSS SECTION 1/CH6

SCALE: 1:25

0mm 500mm 1000mm 1500mm 2000mm 2500mm

UNIVERSITÉ LAVAL

SERRES HAUTES PERFORMANCES

UNIVERSITÉ LAVAL

Brière, Gilbert + Tétreault, Parent, Langue doc + associés

architectes

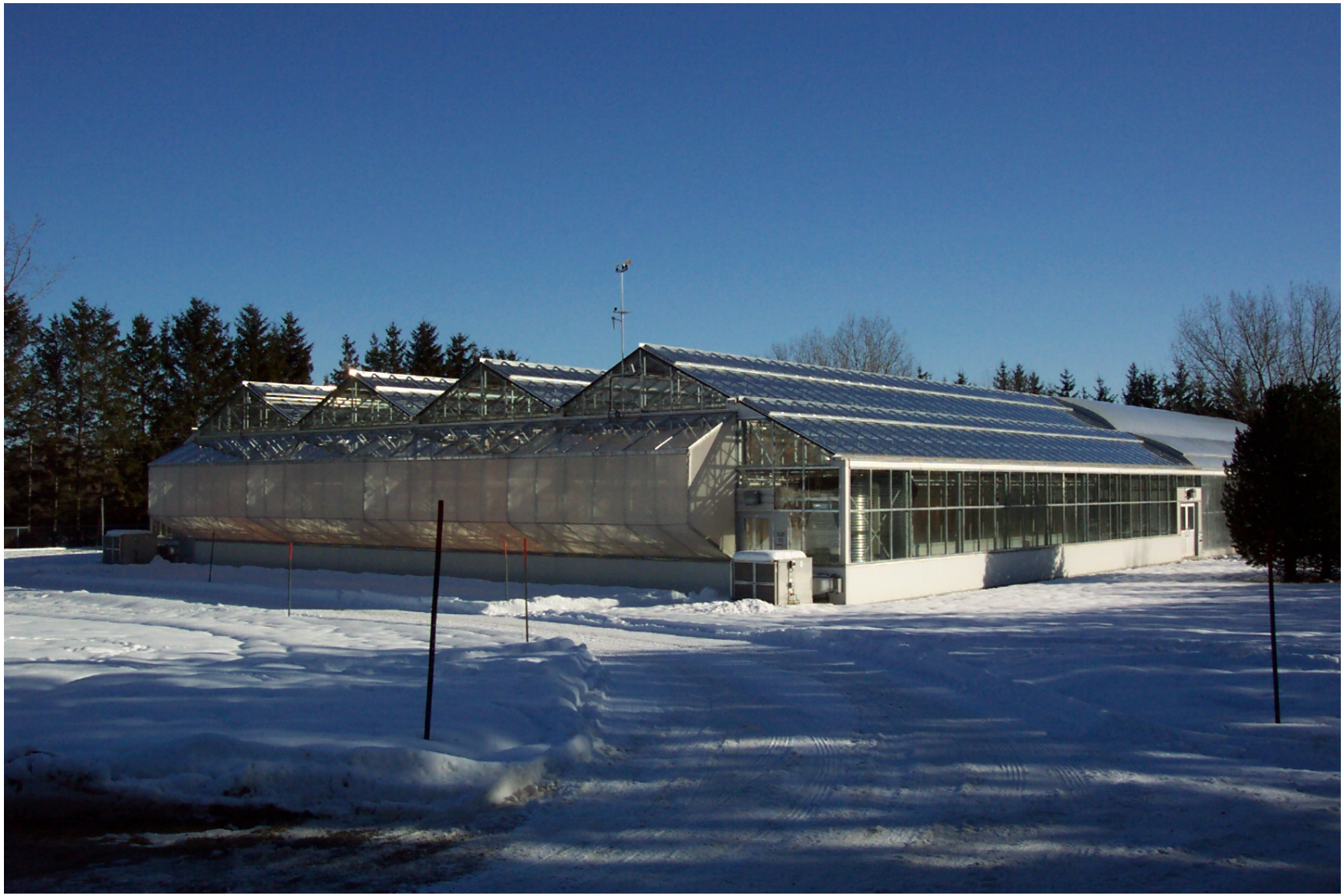
Greenhouse Engineering

GENIVAR

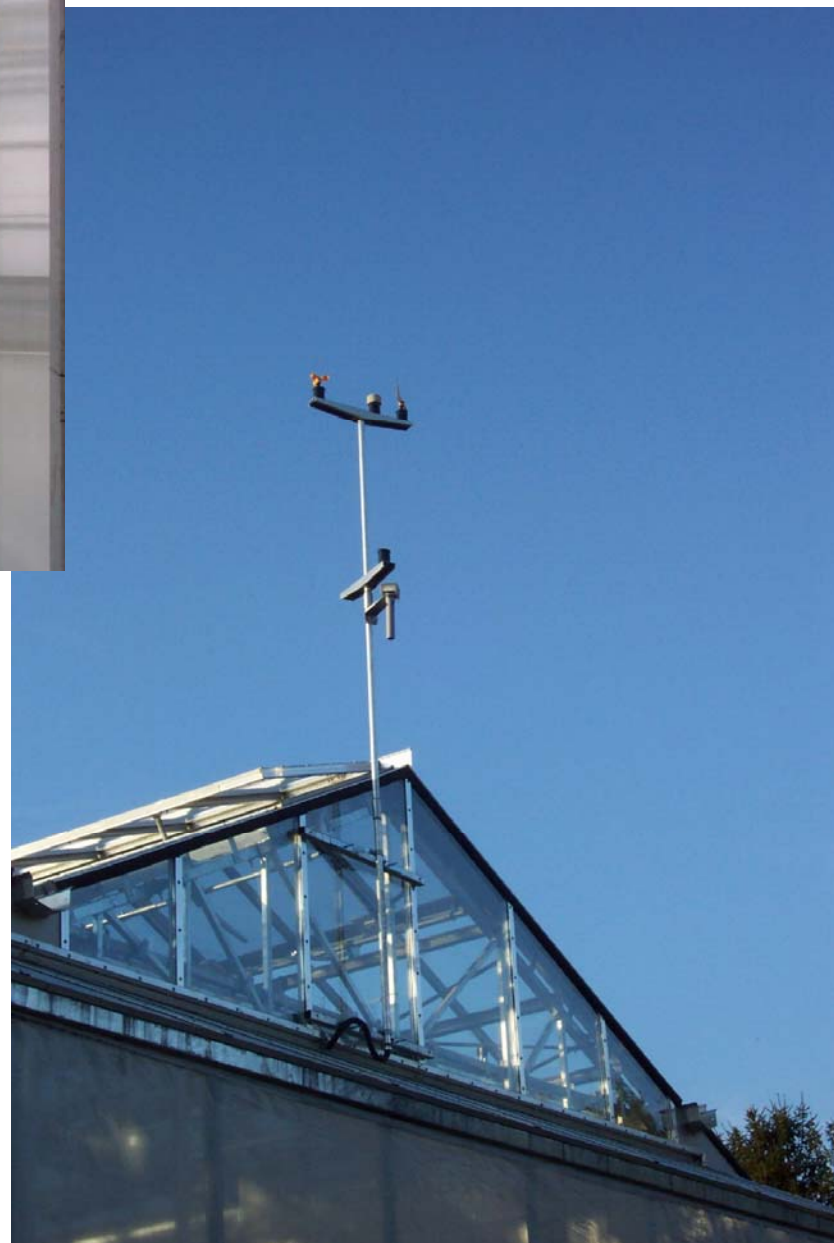
GENIUM inc.

SERRES / GREENHOUSES

6 17




SORTIE



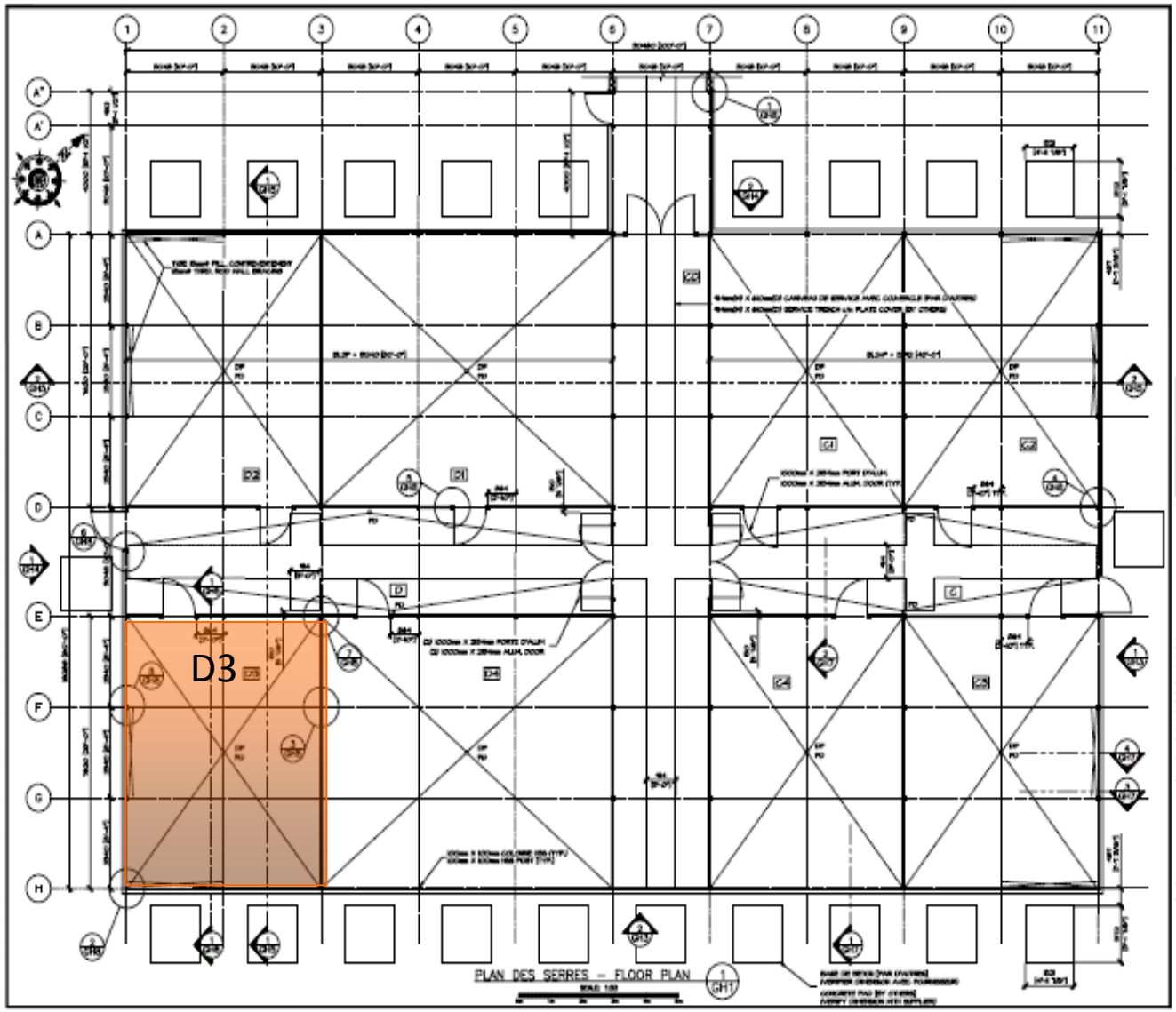
OBJECTIVE

Determine normalization factors for infiltration measurements under varying wind and ΔT conditions.

METHODOLOGY

The greenhouse

- Greenhouse compartment: 20ft x 25ft with 16ft gutter height,
- South-West corner of greenhouse wing,
- No plants were present during the tests,
- No venting, no cooling,
- Internal destratification fans (VAF) always running.



Wind:SW →

↑ Wind: SE

METHODOLOGY

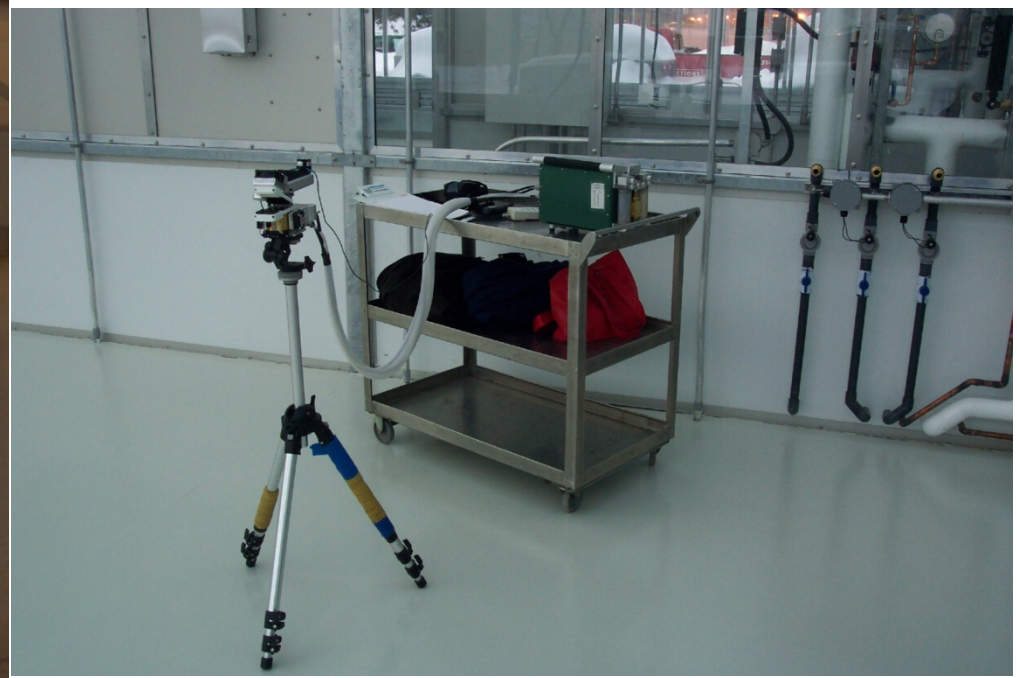
Dilution Tracer Gas Dilution Testing with CO_2

Testing was automated with the Priva control system, on a continuous basis from February 21st to February 26th.

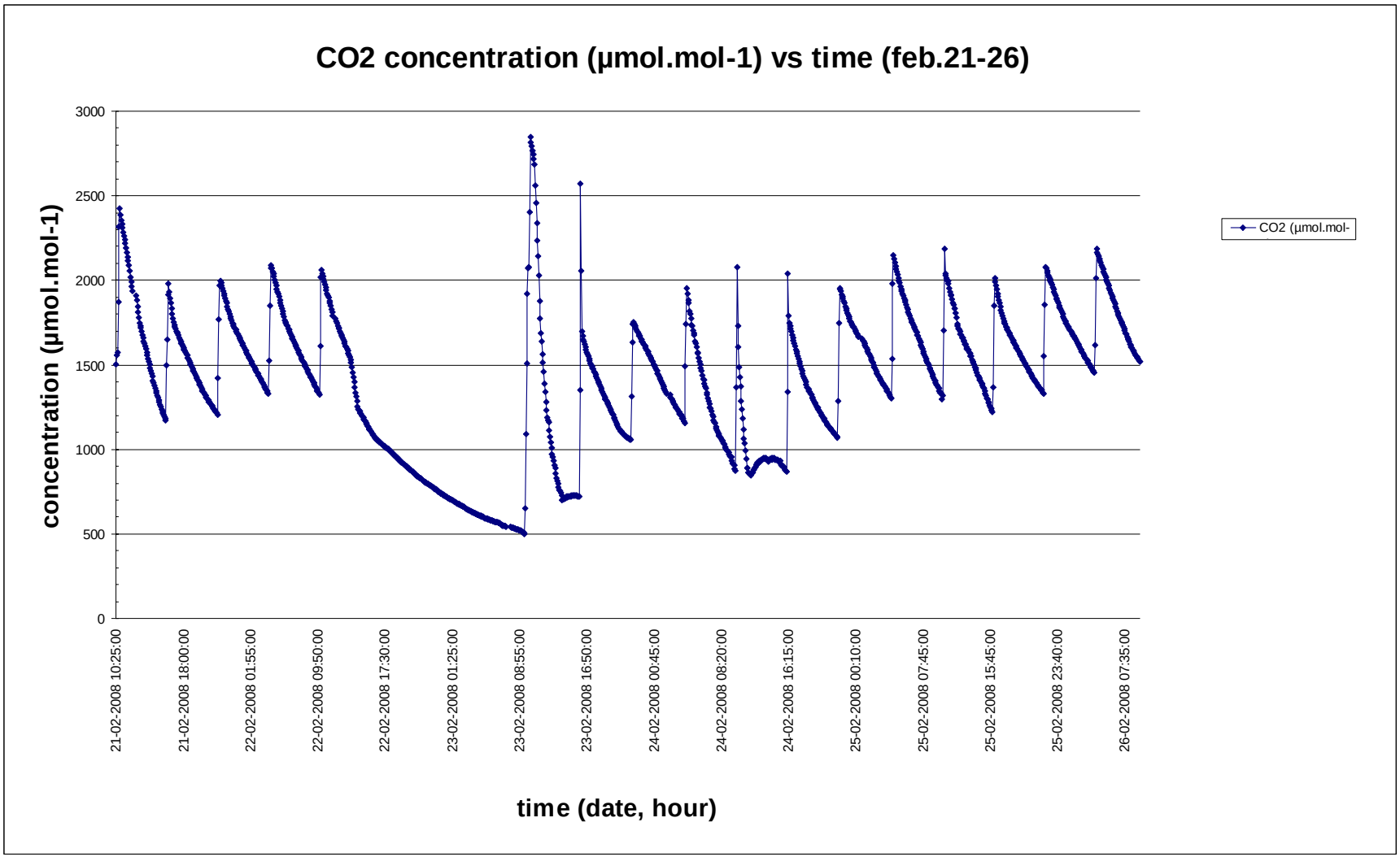
- Every 6 hours CO_2 was injected from a liquid bottle equipped with a pressure regulating valve and a solenoid controlled by the Priva system.
- Injection time was ten (10) minutes, increasing the compartment concentration to ~ 2000 µmol.mol^{-1}.
- readings were taken every five (5) minutes for six (6) hours and consisted of;
  - CO2 concentration (µmol.mol^{-1}),
  - Indoor temperature (°C),
  - Outdoor temperature (°C),
  - Wind speed (m/s).


PRIVA


WARNING
THIS UNIT HAS BEEN PRESET FOR
GREENHOUSE OPERATION
DO NOT ADJUST
CO2
2073 PPM



RESULTS


CO2 concentration (µmol.mol-1) vs time (feb.21-26)
concentration (µmol.mol-1)
3000
2500
2000
1500
1000
500
0
21-02-2008 10:25:00
21-02-2008 18:00:00
22-02-2008 01:55:00
22-02-2008 09:50:00
22-02-2008 17:30:00
23-02-2008 01:25:00
23-02-2008 08:55:00
23-02-2008 16:50:00
24-02-2008 00:45:00
24-02-2008 08:20:00
24-02-2008 16:15:00
25-02-2008 00:10:00
25-02-2008 07:45:00
25-02-2008 15:45:00
25-02-2008 23:40:00
26-02-2008 07:35:00
time (date, hour)
CO2 (µmol.mol-

RESULTS

- Total number of data sets logged, ($C0_2$, interior, exterior temperature and wind speed), raw data: 1722.
- 604 data sets were rejected (due to injecting periods, abnormal readings due to user errors)

ANALYSIS

The infiltration rate (S) is expressed as

$S = (3600\ t^{-1})\ \ln\ \{(C_{Start} - C_{Ambient}) / (C_{End} - C_{Ambient})\}$,

where

t = test duration (s),

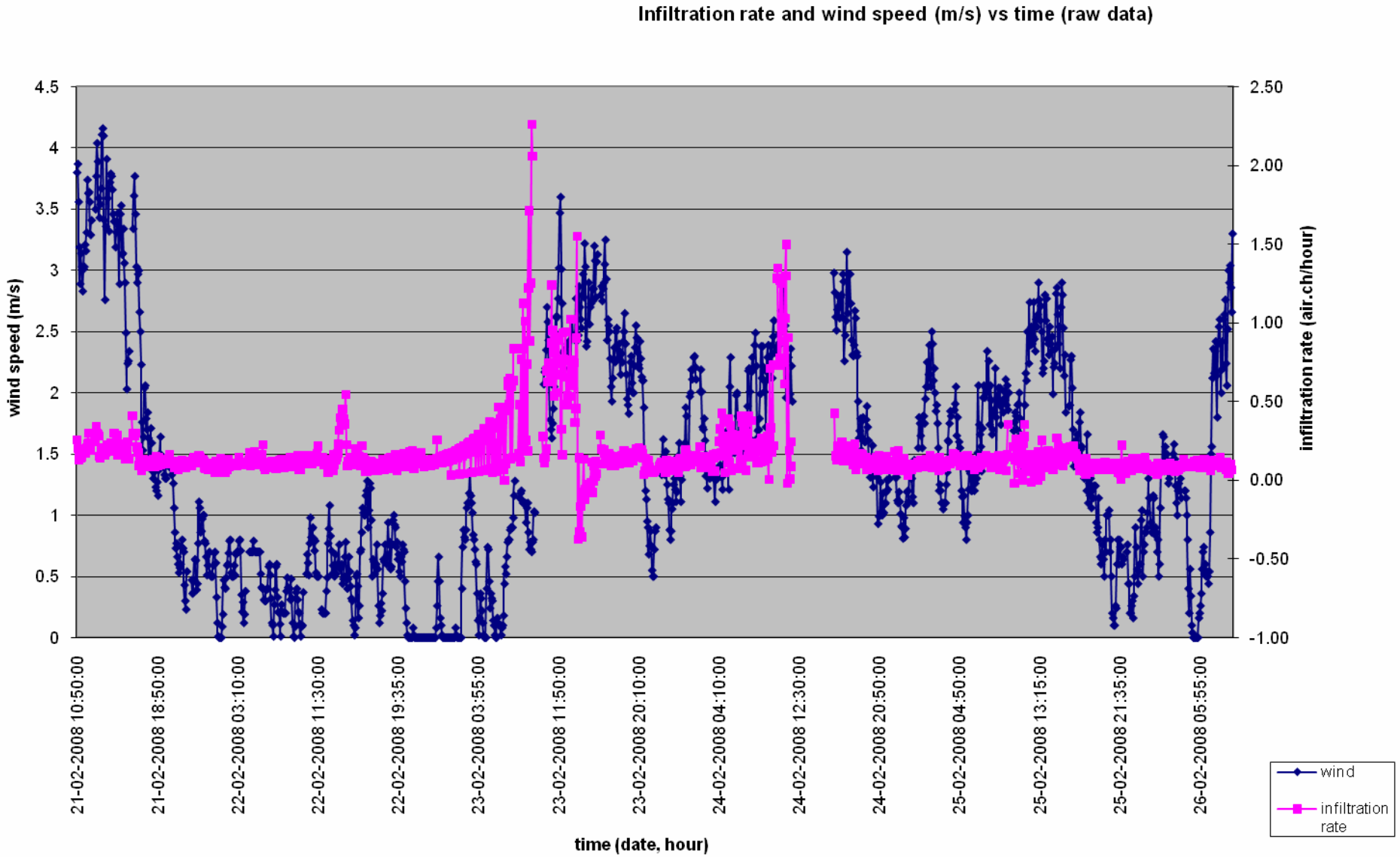
S = infiltration rate (h^{-1}),

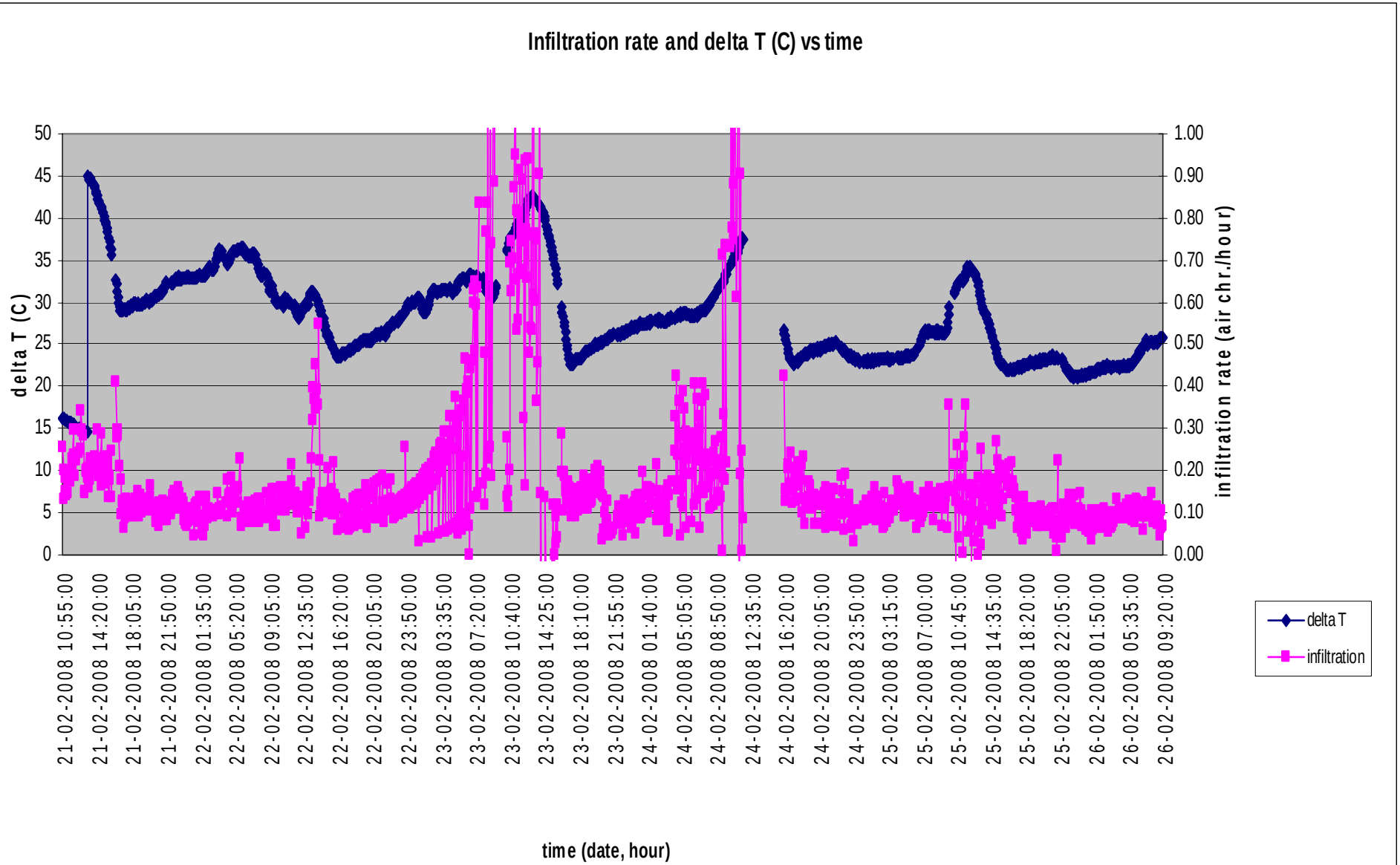
C_{Start}= CO_2 concentration at the beginning of the test ($\mu mol.mol^{-1}$),

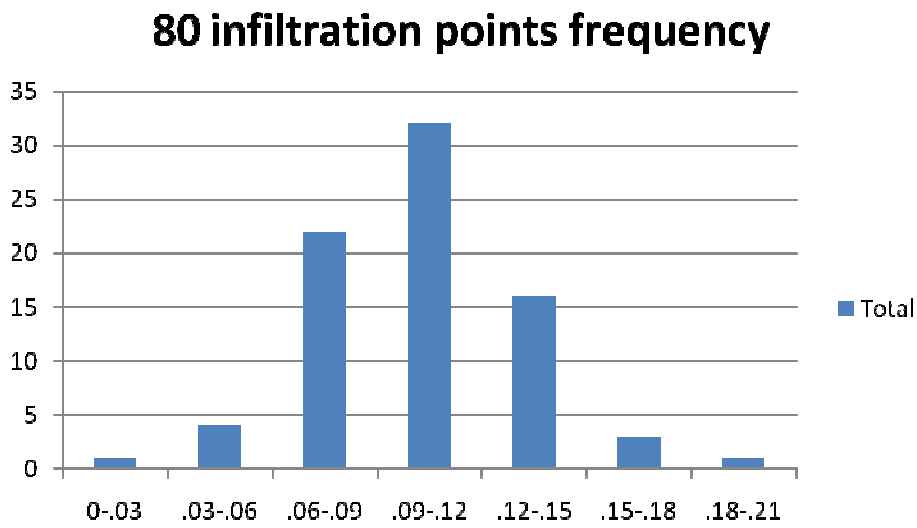
C_{End} = CO_2 concentration at the end of the test ($\mu mol.mol^{-1}$),

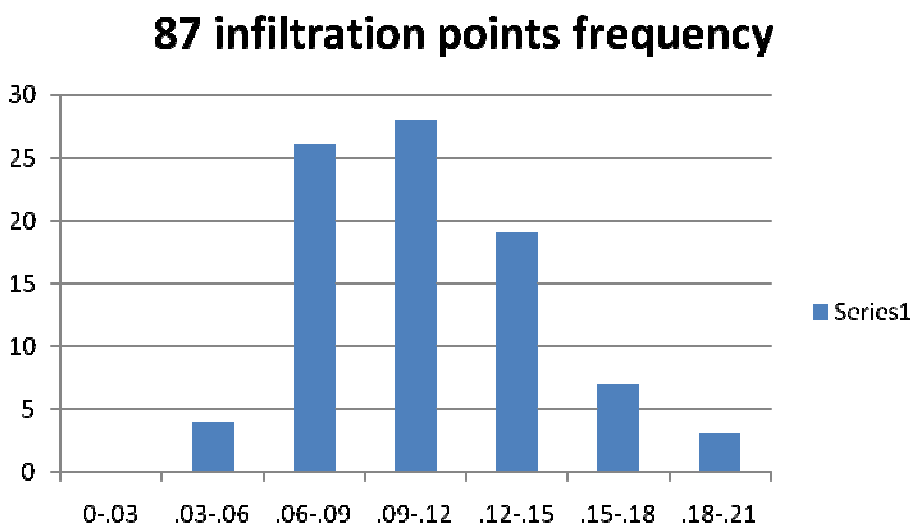
$C_{Ambient}$= CO_2 concentration of the ambient air ($\mu mol.mol^{-1}$).

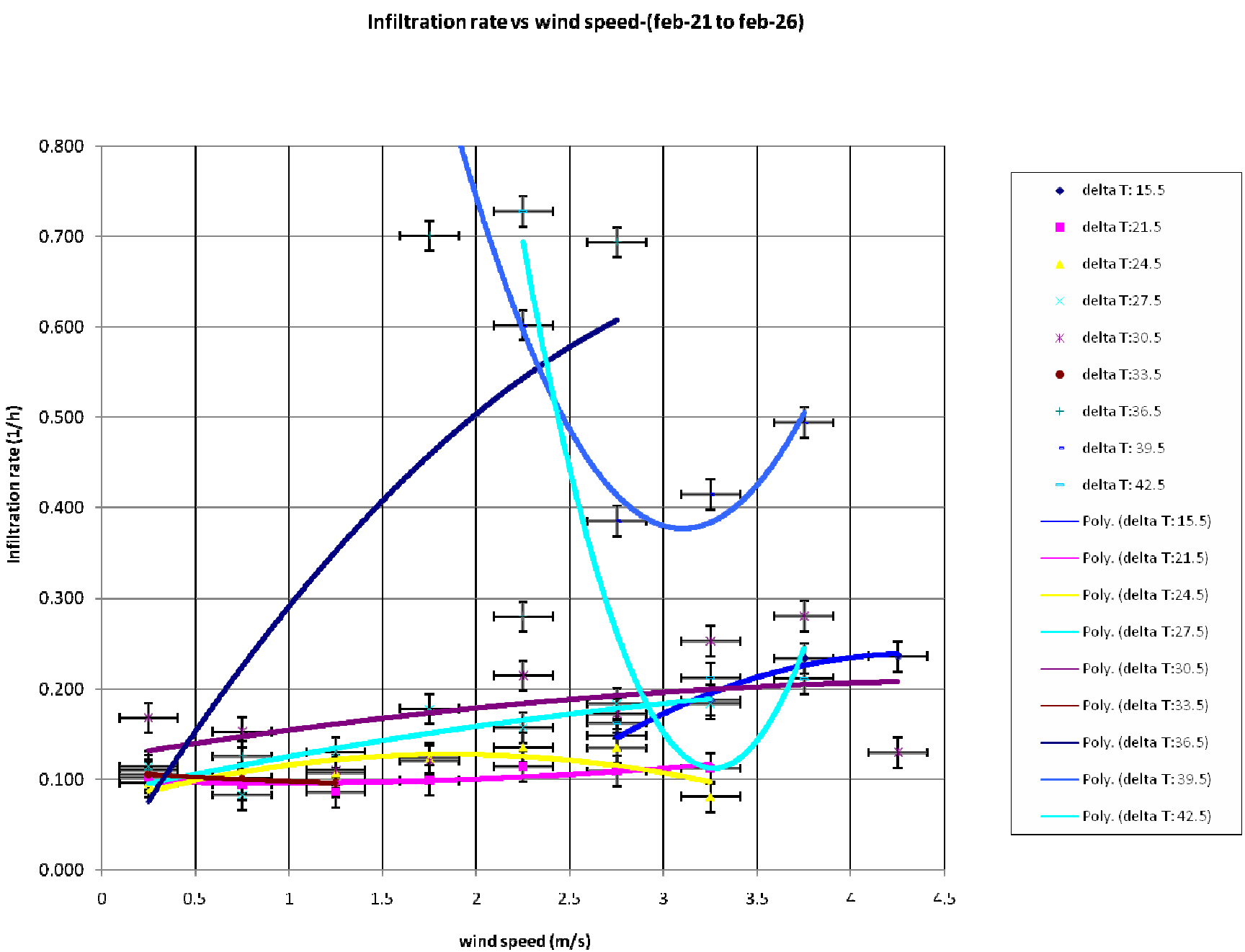
Ref: ASTM, E-741-95

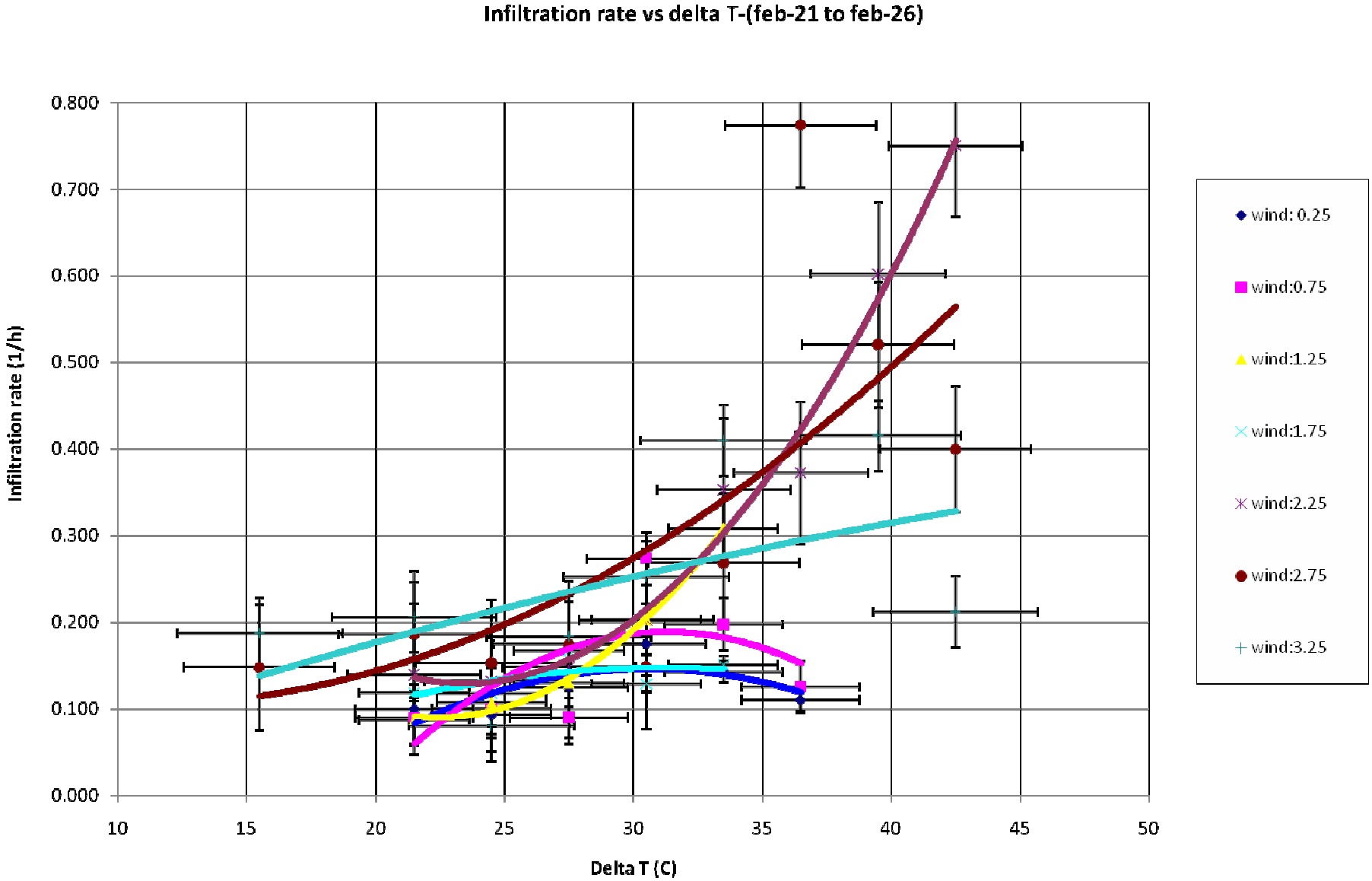

Infiltration rate and wind speed (m/s) vs time (raw data)
wind speed (m/s)
infiltration rate (air.ch/hour)
time (date, hour)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
21-02-2008 10:50:00
21-02-2008 18:50:00
22-02-2008 03:10:00
22-02-2008 11:30:00
22-02-2008 19:35:00
23-02-2008 03:55:00
23-02-2008 11:50:00
23-02-2008 20:10:00
24-02-2008 04:10:00
24-02-2008 12:30:00
24-02-2008 20:50:00
25-02-2008 04:50:00
25-02-2008 13:15:00
25-02-2008 21:35:00
26-02-2008 05:55:00
wind
infiltration rate


Infiltration rate and delta T (C) vs time
delta T (C)
infiltration rate (air chr./hour)
time (date, hour)
delta T
infiltration
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
21-02-2008 10:55:00
21-02-2008 14:20:00
21-02-2008 18:05:00
21-02-2008 21:50:00
22-02-2008 01:35:00
22-02-2008 05:20:00
22-02-2008 09:05:00
22-02-2008 12:35:00
22-02-2008 16:20:00
22-02-2008 20:05:00
22-02-2008 23:50:00
23-02-2008 03:35:00
23-02-2008 07:20:00
23-02-2008 10:40:00
23-02-2008 14:25:00
23-02-2008 18:10:00
23-02-2008 21:55:00
24-02-2008 01:40:00
24-02-2008 05:05:00
24-02-2008 08:50:00
24-02-2008 12:35:00
24-02-2008 16:20:00
24-02-2008 20:05:00
24-02-2008 23:50:00
25-02-2008 03:15:00
25-02-2008 07:00:00
25-02-2008 10:45:00
25-02-2008 14:35:00
25-02-2008 18:20:00
25-02-2008 22:05:00
26-02-2008 01:50:00
26-02-2008 05:35:00
26-02-2008 09:20:00

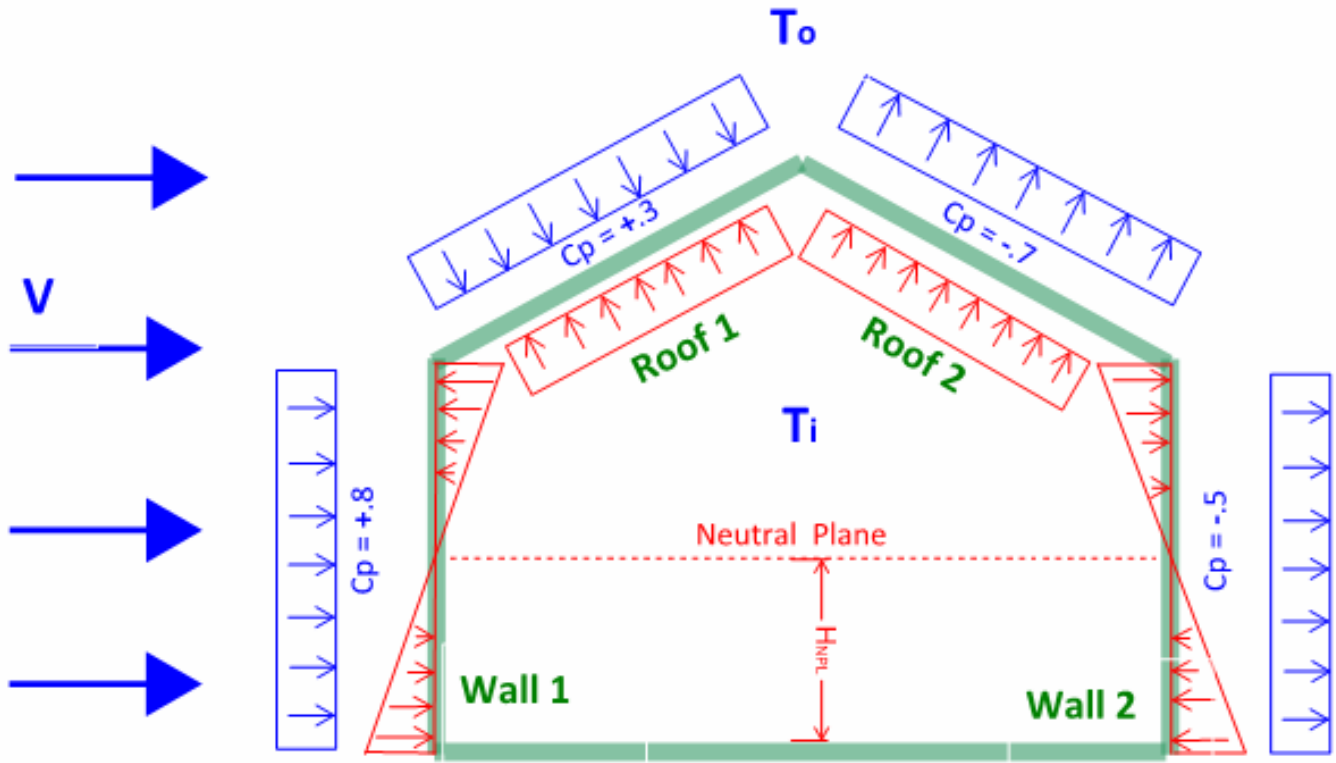

80 infiltration points frequency
35
30
25
20
15
10
5
0
0-.03
.03-.06
.06-.09
.09-.12
.12-.15
.15-.18
.18-.21
Total


87 infiltration points frequency
30
25
20
15
10
5
0
0-.03
.03-.06
.06-.09
.09-.12
.12-.15
.15-.18
.18-.21
Series1


Infiltration rate vs wind speed-(feb-21 to feb-26)
Infiltration rate (1/h)
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
wind speed (m/s)
delta T: 15.5
delta T:21.5
delta T:24.5
delta T:27.5
delta T:30.5
delta T:33.5
delta T:36.5
delta T: 39.5
delta T: 42.5
Poly. (delta T: 15.5)
Poly. (delta T:21.5)
Poly. (delta T:24.5)
Poly. (delta T:27.5)
Poly. (delta T:30.5)
Poly. (delta T:33.5)
Poly. (delta T:36.5)
Poly. (delta T: 39.5)
Poly. (delta T: 42.5)


Infiltration rate vs delta T-(feb-21 to feb-26)
Infiltration rate (1/h)
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
10
15
20
25
30
35
40
45
50
Delta T (C)
wind: 0.25
wind:0.75
wind:1.25
wind:1.75
wind:2.25
wind:2.75
wind:3.25

MODEL



$$P_w = \frac{C_p \rho_o V^2}{2}$$

$$P_s = \rho_o g \frac{(To - Ti)}{Ti} (H_{NPL} - H)$$

P_s = net stack pressure (Pa)

P_w = pressure exerted by the wind (Pa)

V = wind speed (m/s)

ρ_o = outside air density (Kg/m^3)

C_p = wind pressure coefficient (ref. NGMA)

To , Ti = outside and inside air temperatures (°K)

H_{NPL} = distance of the Neutral Pressure Level(m) from reference

H = distance to Neutral Pressure (m) Level

g = 9.8 m/s^2

MODEL

The total pressure, ΔP, driving infiltration will be the sum of the wind pressure and the stack effect:

$$\Delta P = P_w - P_s = \frac{C_p \rho V^2}{2} + \rho_o g \frac{(To - Ti)}{Ti} (H_{NPL} - H)$$

The fluid equation for flow complex openings is can be expressed as :

$$Q = C A_e \sqrt{2\rho} \Delta P^n$$

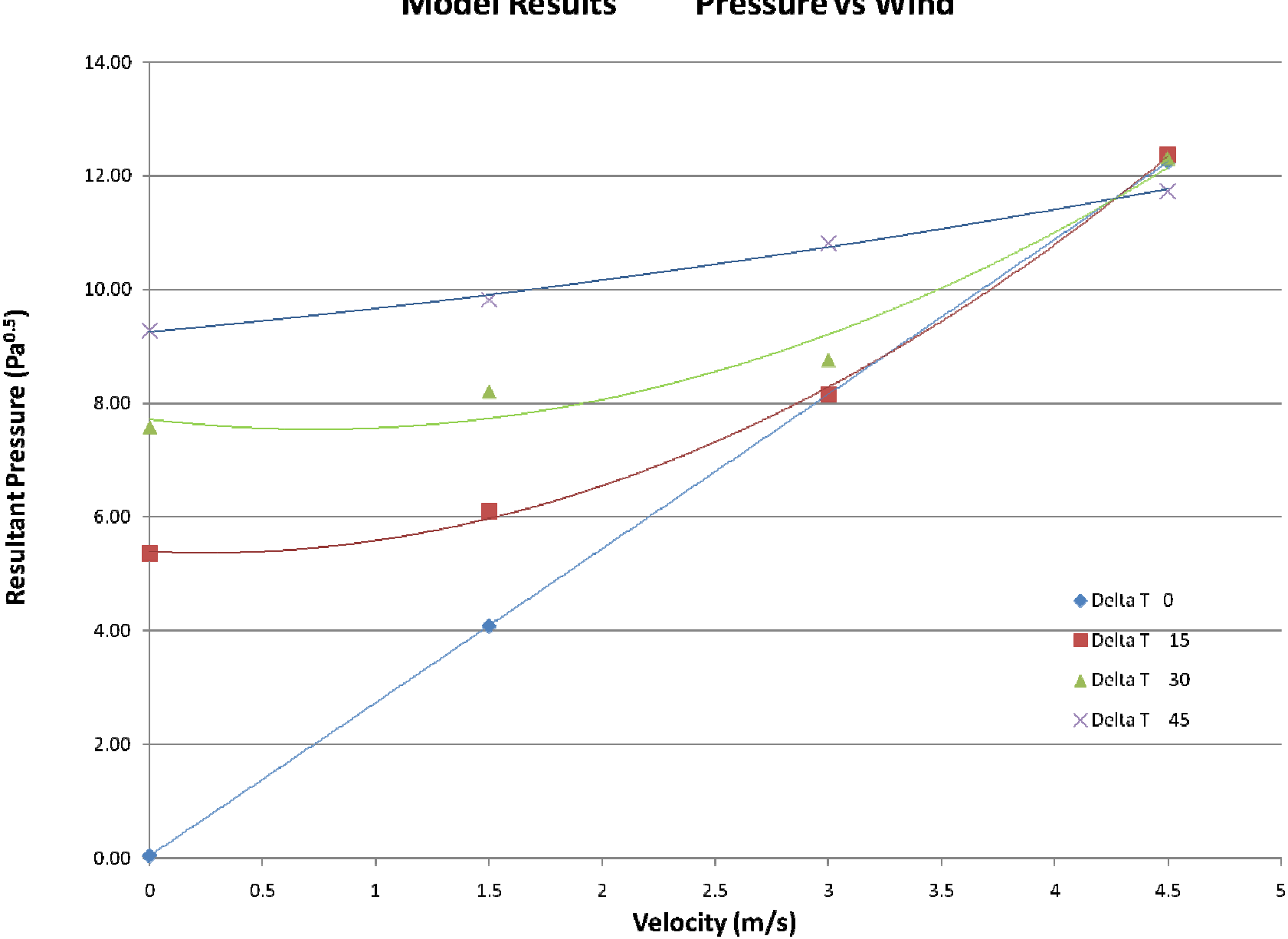
C = flow coefficient

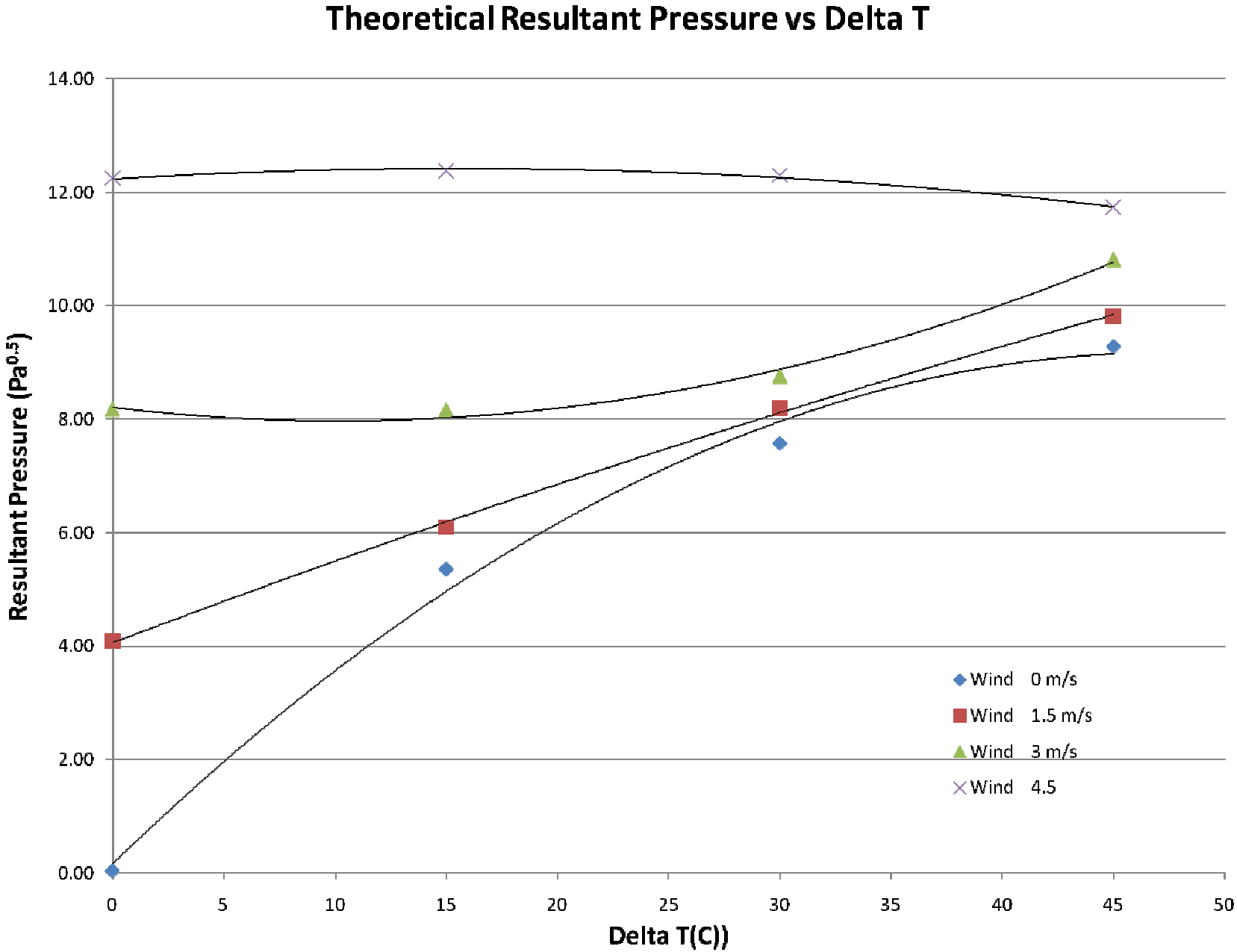
A_e = effective area of the orifice

n = flow exponent varies from 0.5 (turbulent) to 1 (laminar)

Combining:

$$Q = C * A_e * \sqrt{2\rho} \left\{ \frac{C_p \rho V^2}{2} + \rho_o g \frac{\Delta T}{Ti} (H_{NPL} - H) \right\}^n$$


Model Results Pressure vs Wind
Resultant Pressure (Pa^0.5)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Velocity (m/s)
Delta T 0
Delta T 15
Delta T 30
Delta T 45


Theoretical Resultant Pressure vs Delta T
Resultant Pressure (Pa^0.5)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
5
10
15
20
25
30
35
40
45
50
Delta T(C))
Wind 0 m/s
Wind 1.5 m/s
Wind 3 m/s
Wind 4.5

CONCLUSIONS

- Wind and stack effects are not additive linearly.
- Wind and stack effects interact, even to the extent of negative contribution.
- For moderate temperature differentials (15 C - 30 C), infiltration rate and wind speed are not strongly correlated.
- At moderate wind speed (4.5 m/s), infiltration rate is insensitive to the full range of temperature differentials measured and predicted.
- The model developed does not yet match the experimental results.
- However, both model and experimental results confirm unexpected interactions between wind and stack effects.

RECOMMENDATIONS

- The model should be extended to different configurations of greenhouse.
- Further measurements, especially those at lower and positive temperature differentials, should be made.
- Further measurements in different structures should be made.
- A more extensive literature review is required.
- The specification requirements for infiltration testing should be changed to allow for either wind or stack effects but not both simultaneously.

- Dr. Jean Caron,
  Université Laval
  Québec,
  Canada

Thank you

Les Industries Harnois inc

- Marco Rondeau, controls technician

ghe
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