Urine puddle area determination with use of thermal imaging

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MSc Thesis Arjen van Dueren den Hollander & BSc thesis Roel Vernooij, both part of PhD research

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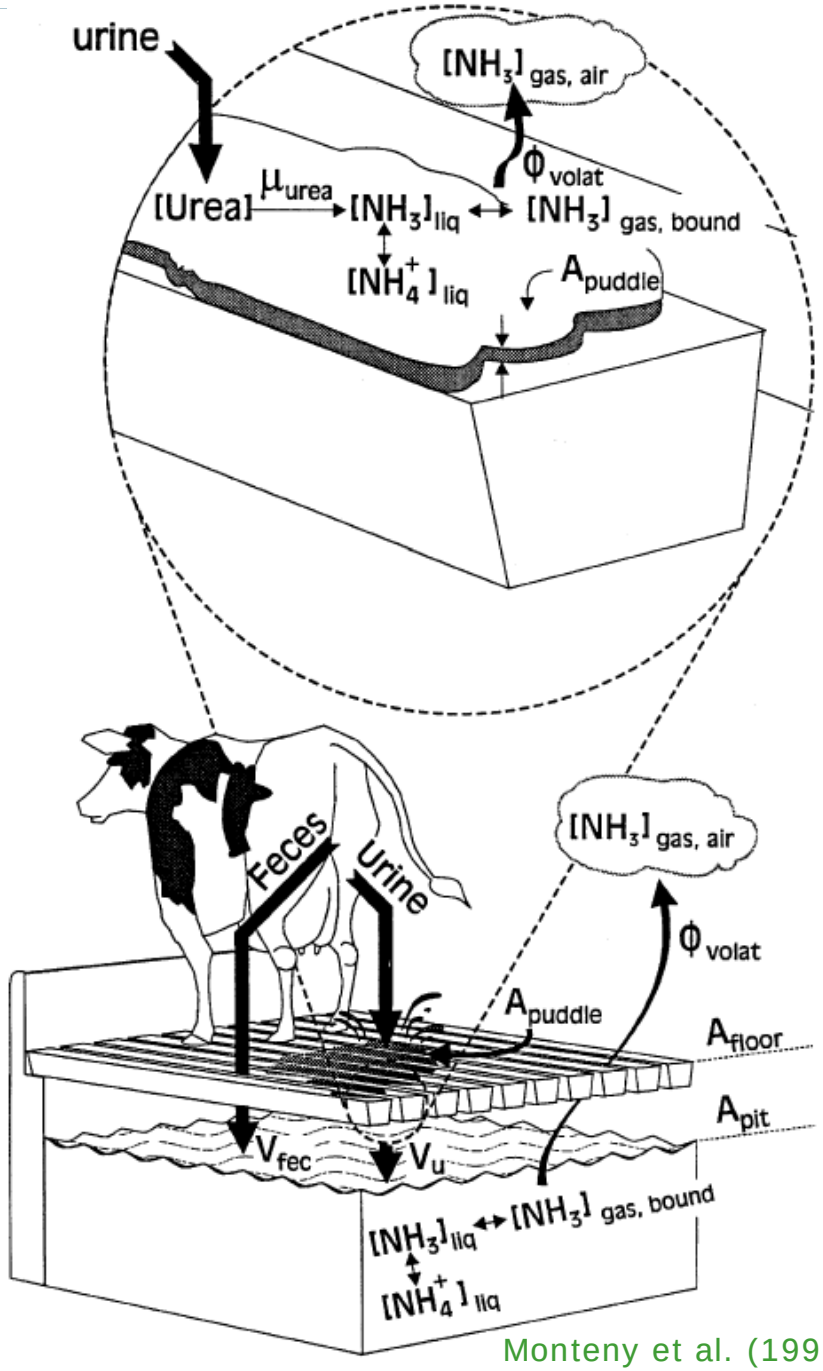
The process

- Urea conversion
  - Urea ⇔ NH_3
- Puddle area [m^2]
- Puddle depth [m]

- pH [-]
- Temperature [°C]
- Air velocity [m/s]



Monteny et al. (1998)

Introduction

- NH_3 emission
  - Acidification & Eutrophication of environment
  - National Emission Ceilings (NECs) in Europe
- NH_3 model
  - To understand the process
  - To estimate emissions
- (Commercial) Dairy cow houses
  - Hardly data available for the model variables
  - Limited measurement methods available

Introduction

- Sensitivity analysis current NH_3 modelling (Snoek et al. 2014)
  1. pH of urine
  2. Puddle depth
  3. Initial urea concentration
  4. Puddle area (A_p)

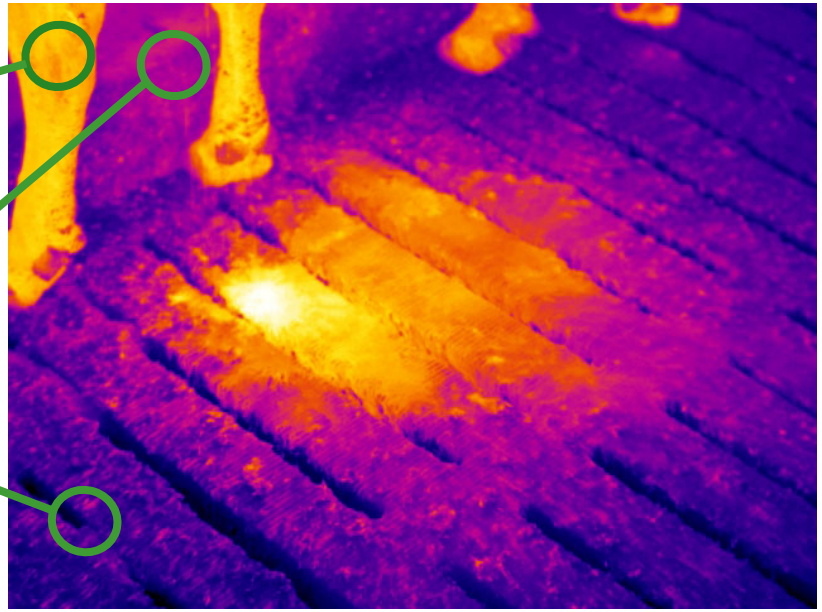
} **NH_3 source**

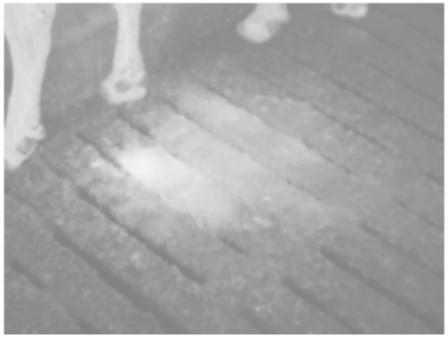
This MSc thesis

"Develop & validate a method to determine the puddle area of fresh dairy cow urine puddles"

Introduction

- Cow legs
- Elevated floor (cubicles)
- Background temperature

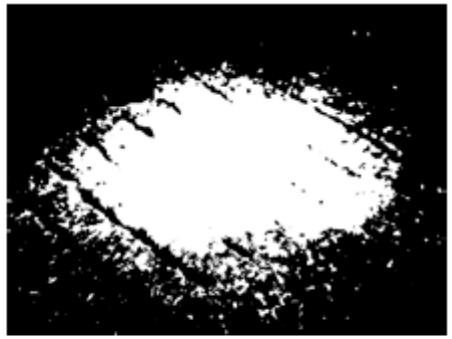




A: Original IR-image
T_{min}=19.9°C;T_{max}=38.4°C

B: Threshold = 24.0°C
= 0.82 m^2

C: Threshold = 24.5°C
= 0.70 m^2



D: Threshold = 25.0°C
= 0.61 m^2

Snoek et al. (2014)

Introduction - desired situation

A validated model which is able to:

- Determine urine puddle area from an IR image with an accuracy of at least 0.1 m^2
- Work with varying temperatures
- Deal with the presence of cow legs and cubicles

Research questions

- How can the area of a urine puddle be determined?
- What is the accuracy of the image processing method that is developed?

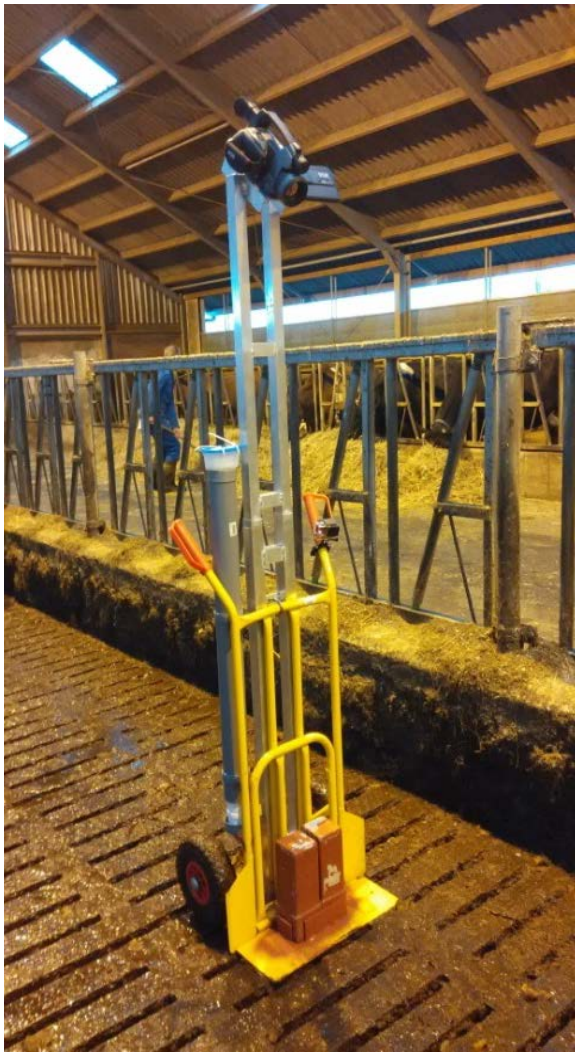
Materials & Methods

Equipment

- FLIR SC660 thermal infrared camera
- IR-images of 640x480
- RGB-images of 2048x1536

- National instruments LabVIEW

- Moveable statue

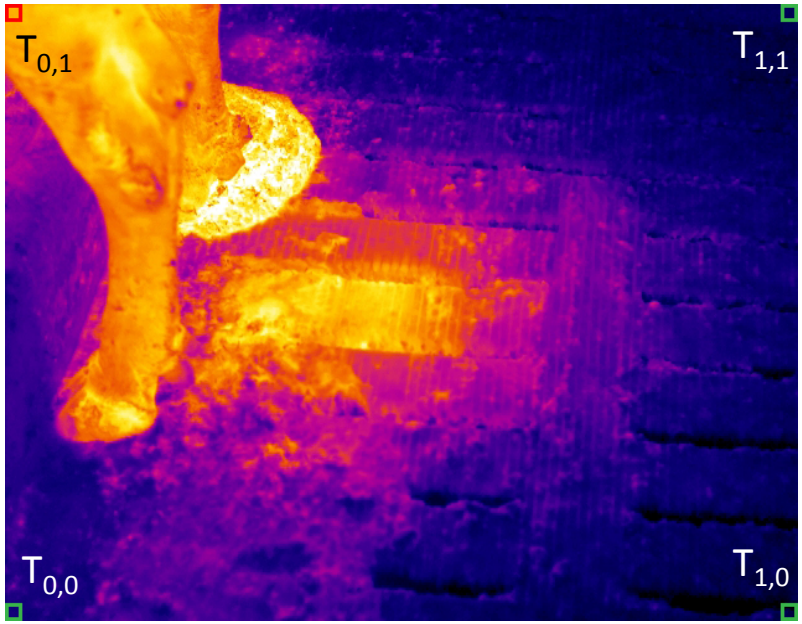


IR-area model - $T_{background}$

$$T_{background} = mean[T_{0,0}, T_{1,0}, T_{1,1}, T_{0,1}]$$

with

$$T_{m,n} - \frac{[T_{0,0} + T_{1,0} + T_{1,1} + T_{0,1}]}{4} < \sigma T_{corners}$$

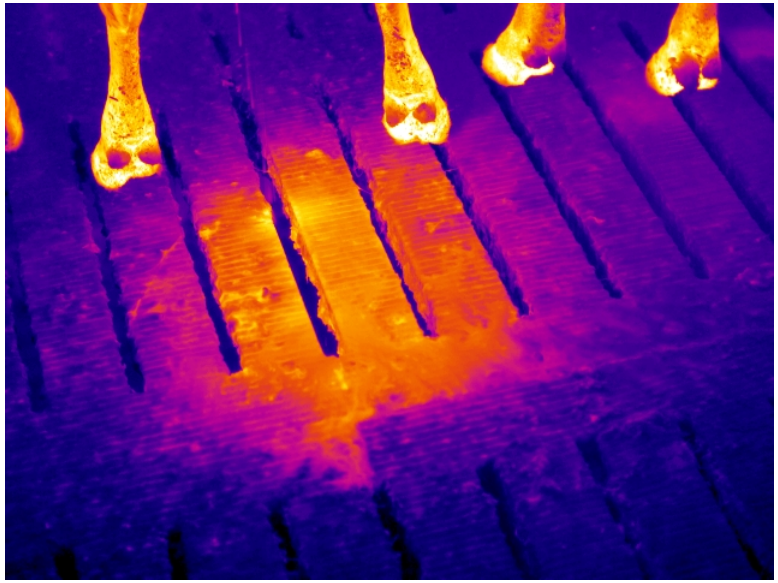


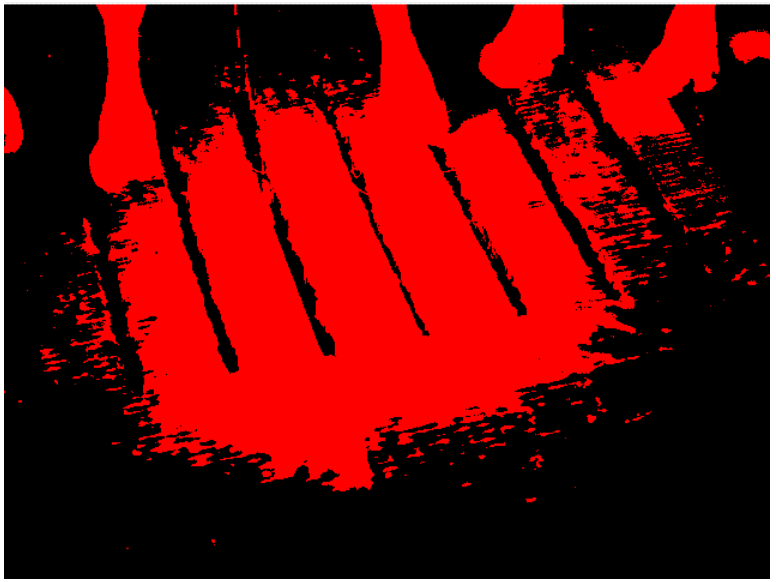
IR-area model - adaptive threshold

$$threshold_{min} = T_{background} + a \cdot \sigma_{img}$$

$$threshold_{max} = T_{max}$$

Select & count pixels: $threshold_{min} < T_{x,y} < threshold_{max}$

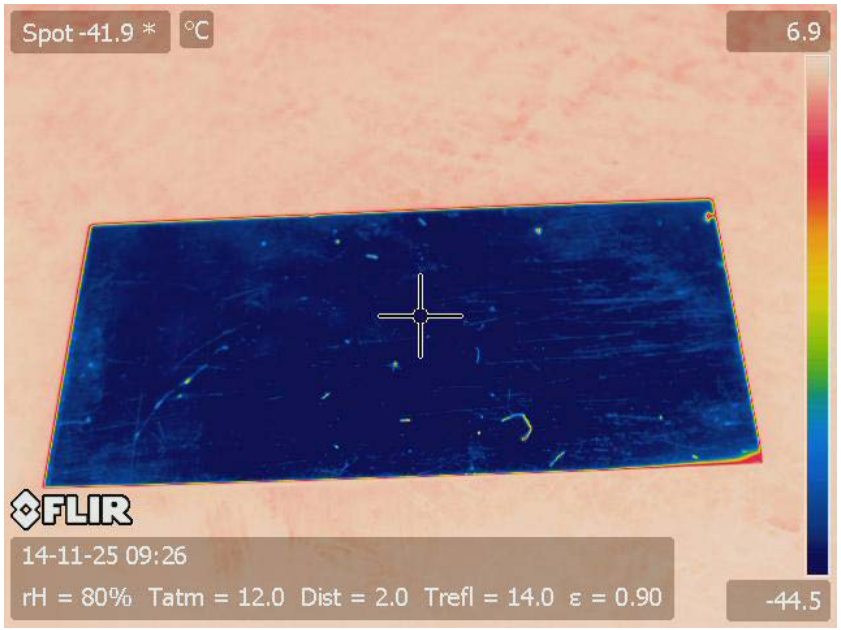




threshold$_{min}$ = 285.6 K (12.6°C)

Image calibration

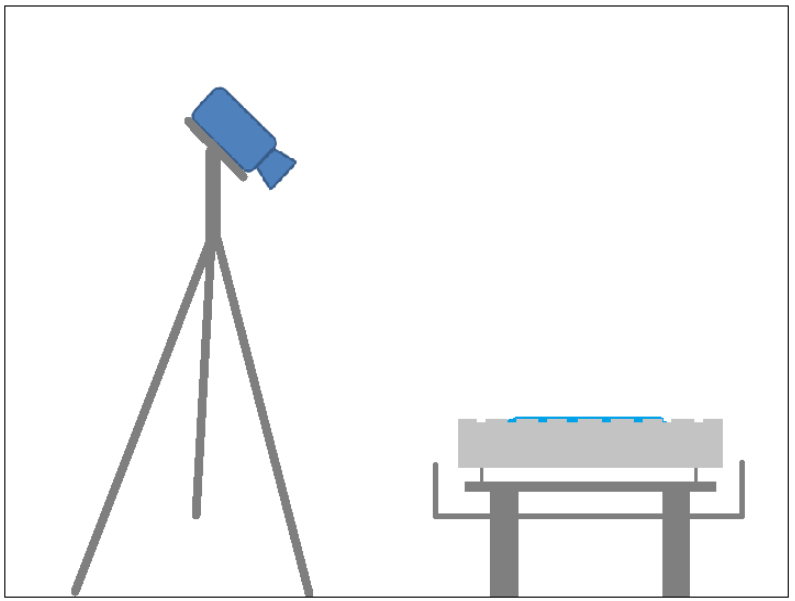
- Convert pixel dimensions into real-world dimensions
- Aluminium rectangle of 0.6 x 1.0 m
- Four point calibration in NI Vision assistant

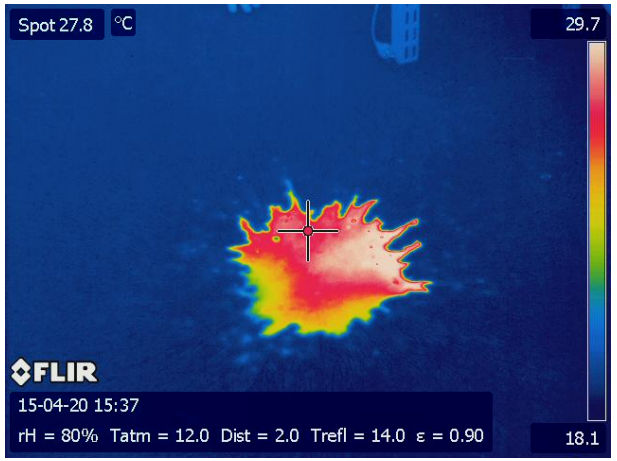


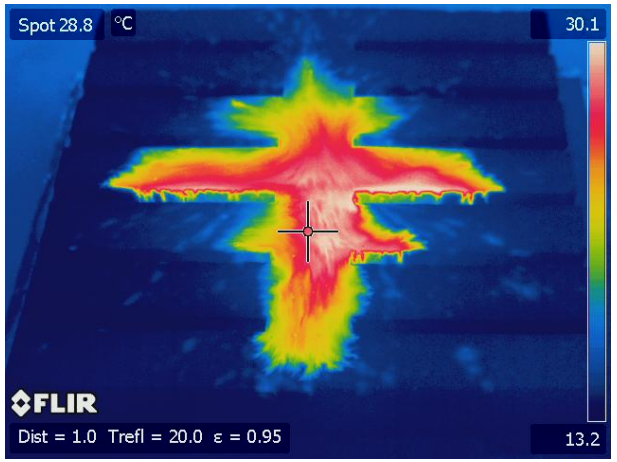
Snoek et al. (2014)

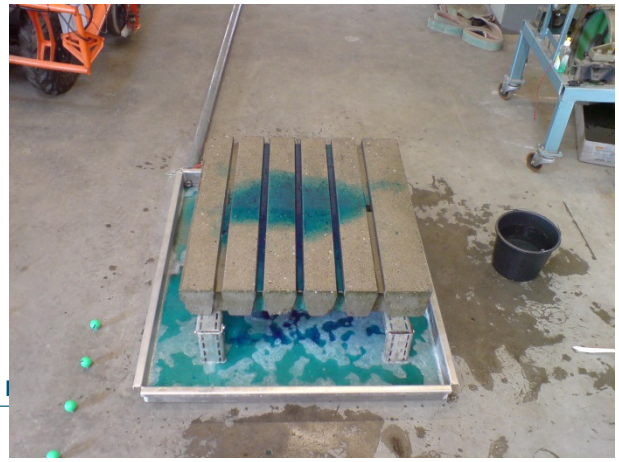
Validation experiment

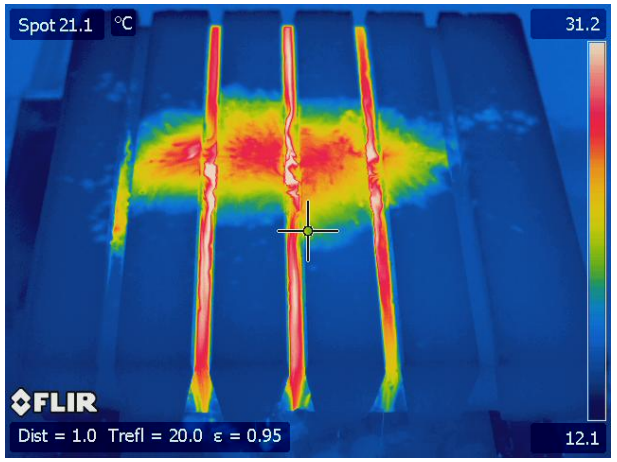
- 90 Artificial urine puddles of warm water with a blue colour dye
  - Colour images => Ground Truth => $A_{p,GT}$ by 3 persons
  - IR images => $A_{p,IR}$
- 3 concrete floor types
  - Slatted
  - Grooved
  - Solid




Spot 27.8 °C
29.7
FLIR
15-04-20 15:37
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
18.1


Spot 28.8 °C
30.1
FLIR
Dist = 1.0 Trefl = 20.0 ε = 0.95
13.2




Spot 21.1 °C
31.2
FLIR
Dist = 1.0 Trefl = 20.0 ε = 0.95
12.1

IR-area model - determine a

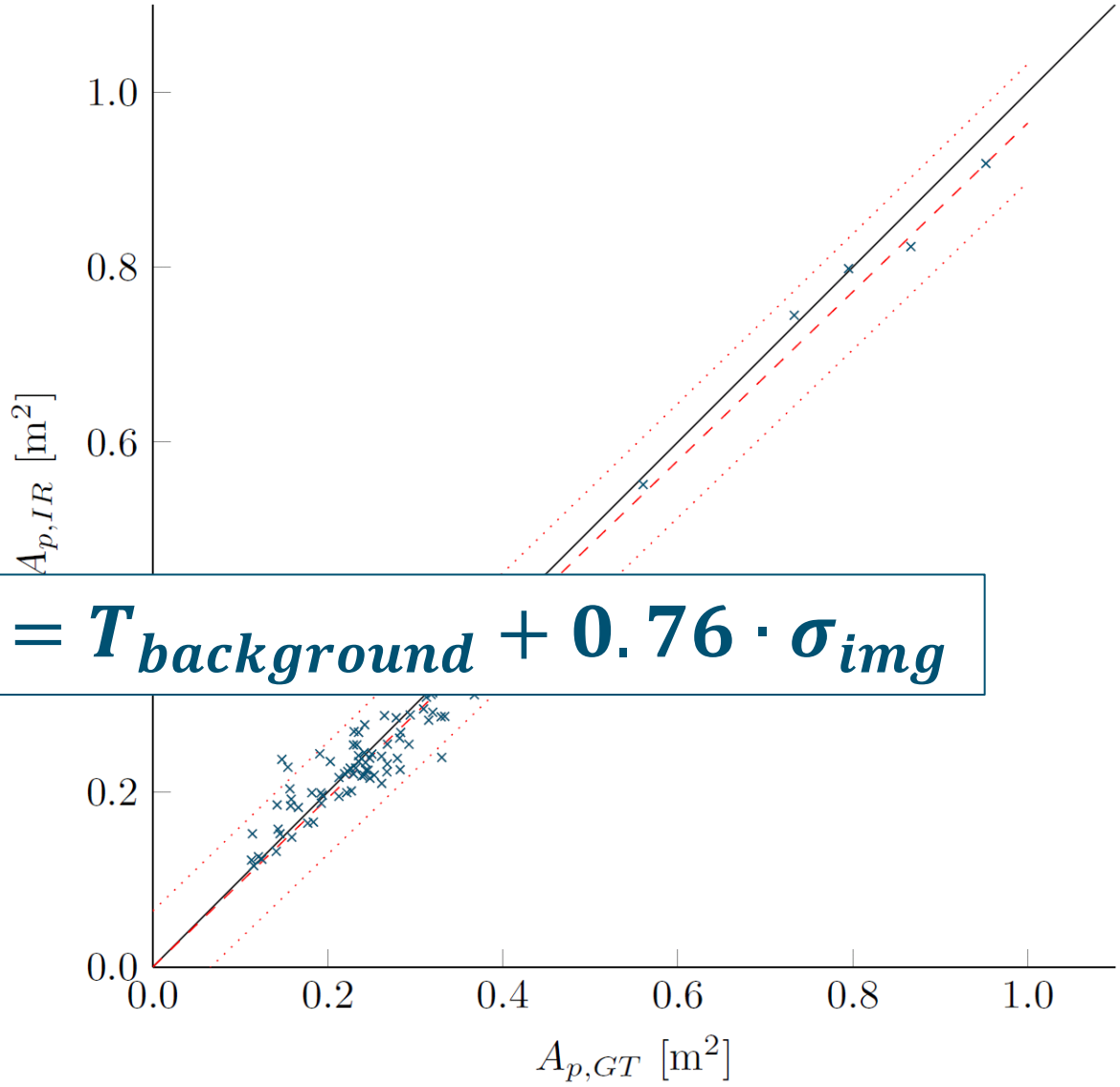
$$\mathrm{RD} = \left| \frac{A_{p,GT} - A_{p,IR}}{A_{p,GT}} \right|$$

- RD = relative difference
- $A_{p,IR}$ for range of a from 0.00 to 2.00
- $A_{p,GT} = A_{p,IR}$
  - Checked with scatter plot
  - $y = x = 1$

Results

Determine a

- $a = 0.76;\ \overline{RD} < 0.001$
- $A_{p,IR} = A_{p,GT} \cdot 0.965$
- $\boldsymbol{threshold_{min} = T_{background} + 0.76 \cdot \sigma_{img}}$



Cow leg removal

- Selection of ‘hot’ pixels

Cow leg removal

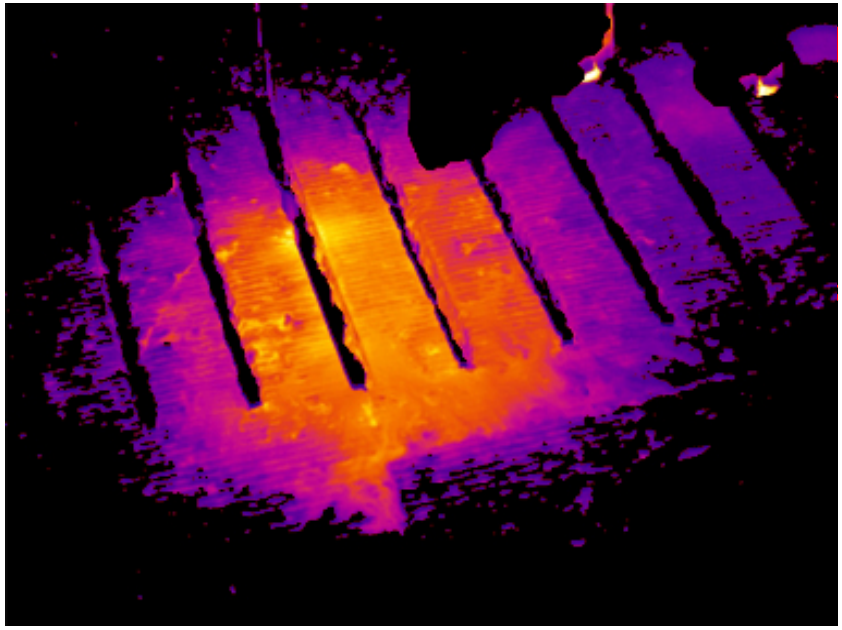
- Erosion to separate particles

Cow leg removal

- Selecting only border objects
- Dilation operation

Cow leg removal

- Result



threshold$_{min}$: 282 K (9°C)

Area = 0.78 m2

Discussion

- Few large artificial puddles

- (unwanted) Heat sources in practise:
  - Cow legs
  - Faeces
  - Cow body radiation
  - Bedding material
  - removal method works => not validated (yet)

Conclusions

- *How can the area of a urine puddle be determined?*
  - Adaptive thresholding
  - $T_{background} + 0.76 \cdot \sigma_{img} < T_{x,y} < T_{max}$

- *What is the accuracy of the image processing method that is developed?*
  - 1 pixel = $6.5 \cdot 10^{-6}$ m^2
  - Accuracy ≤0.1 m^2

Recommendations

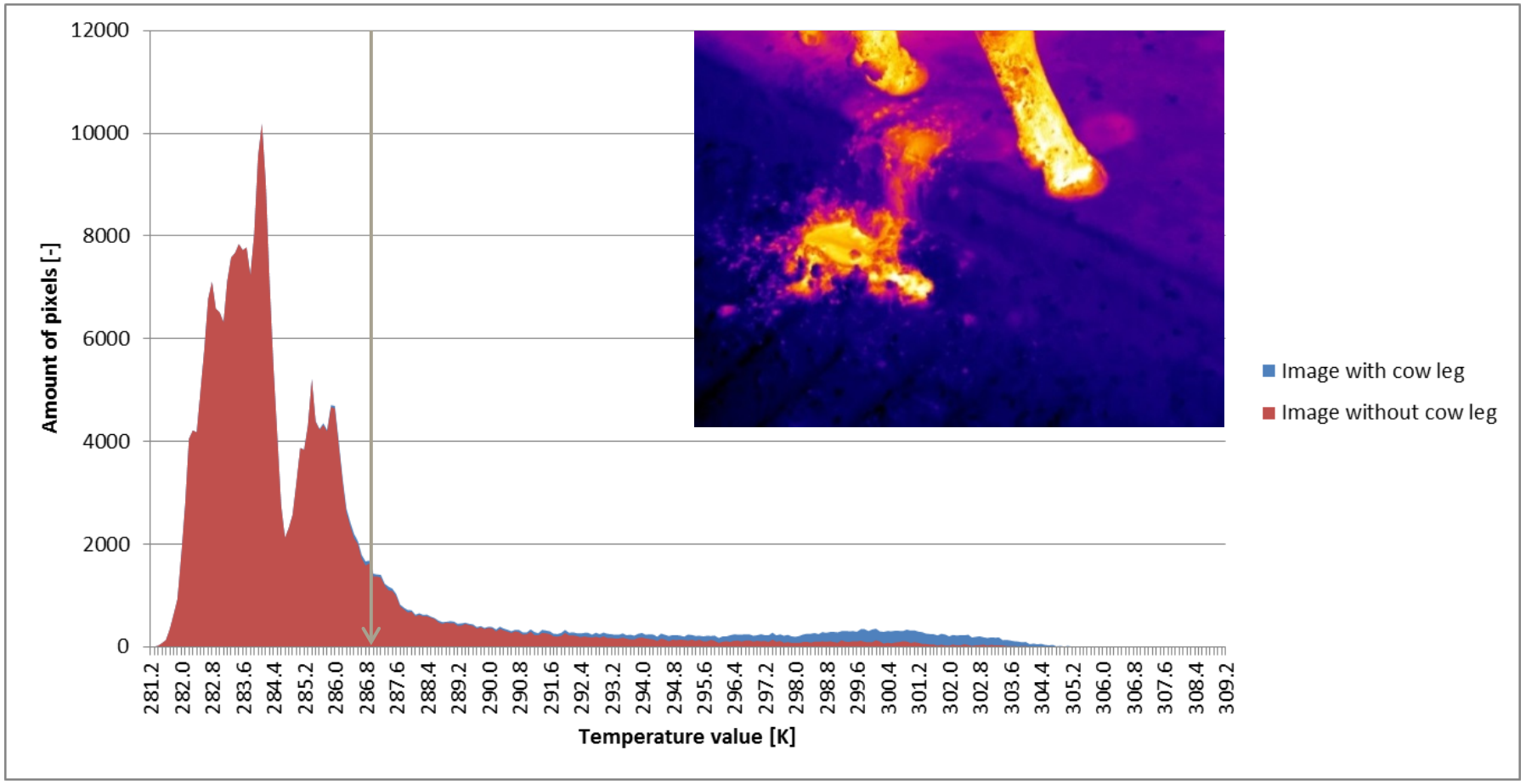
- Image calibration
  - Extra calibration image inside cubicle
  - Calibration files for ‘not central position’ puddle
- Validate cow leg removal method

  OR take images without warm objects (cow legs, faeces)
- Determine optimal background temperature, apply correction for other temperatures

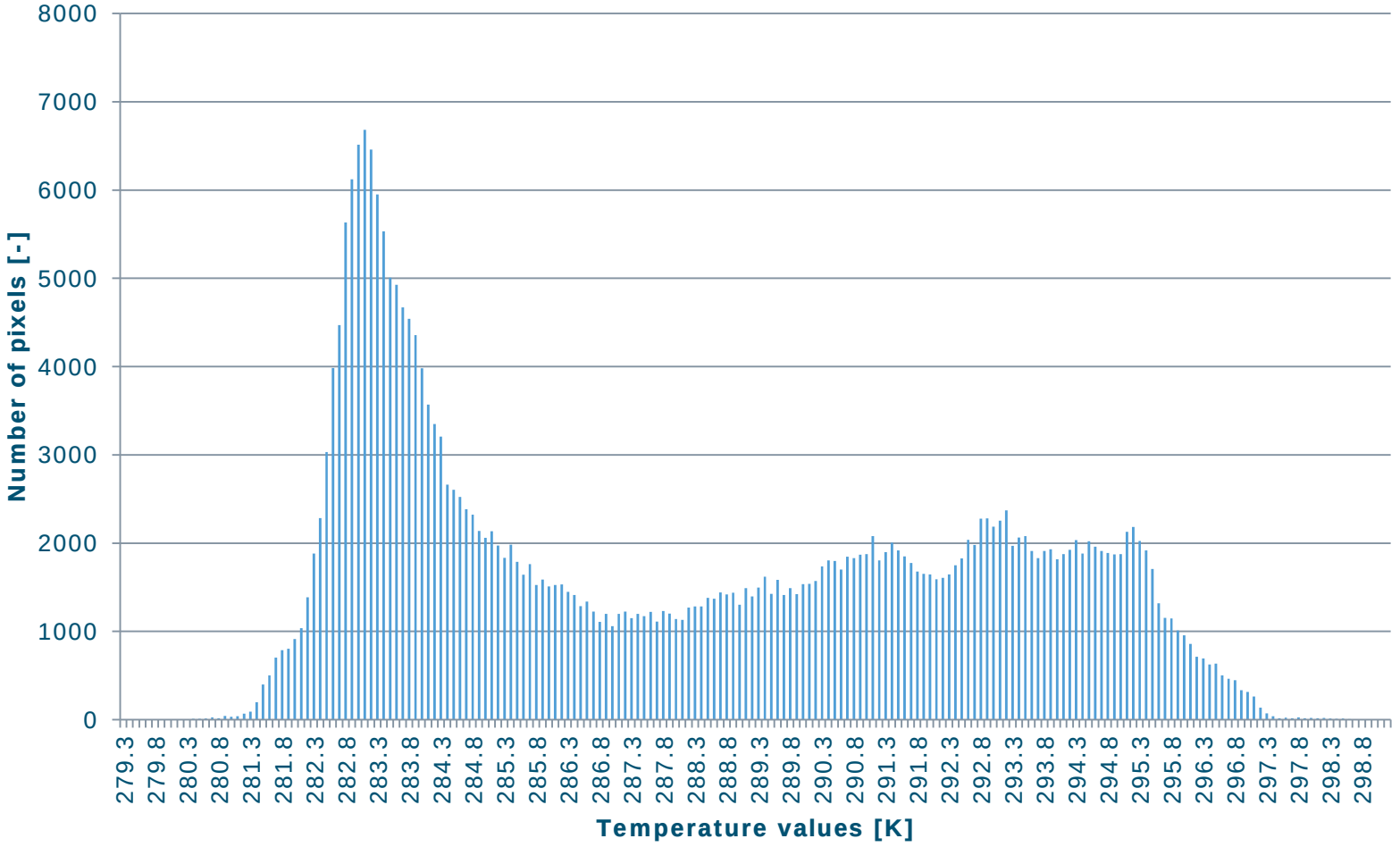
Take home

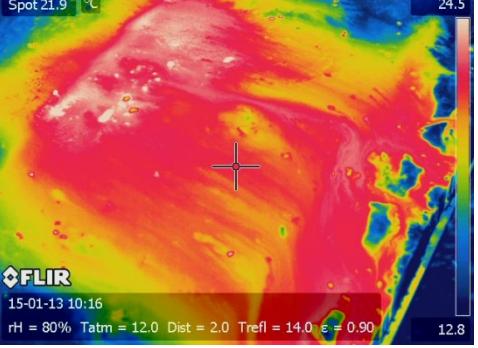
We can now “see” & measure the area of fresh dairy cow urine puddles

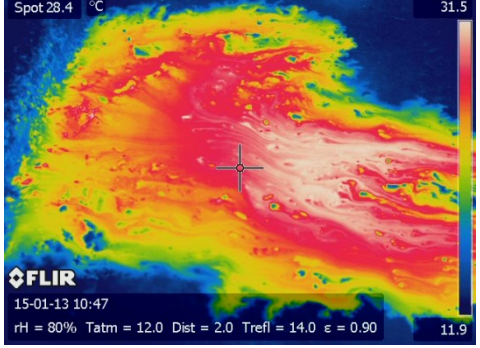
Histogram of image TZN10

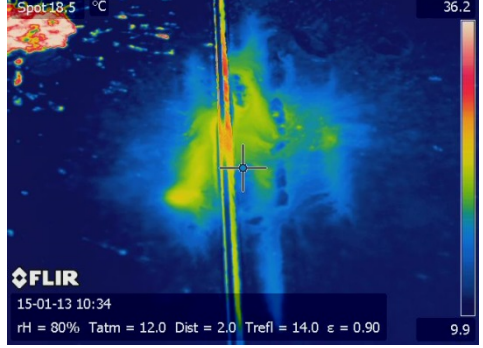


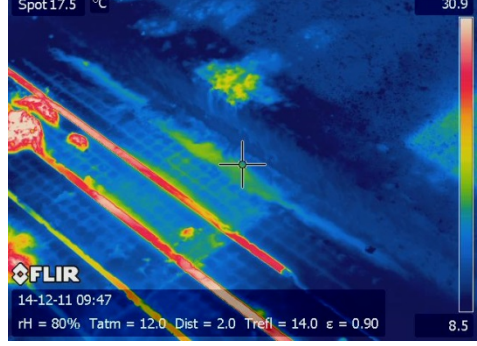
Histogram of image EB11

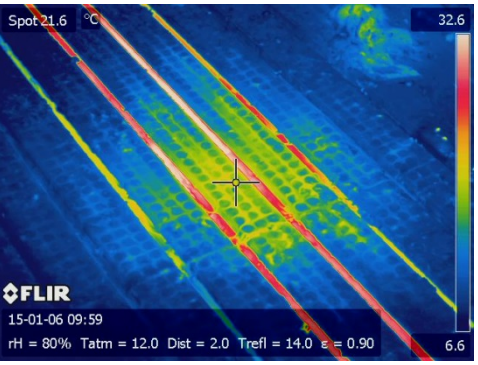


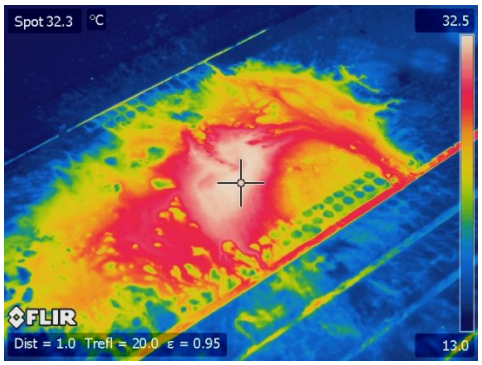

Spot 21.9 °C
24.5
FLIR
15-01-13 10:16
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
12.8

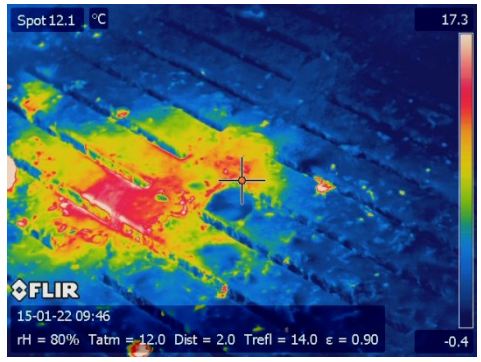

Spot 28.4 °C
31.5
FLIR
15-01-13 10:47
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
11.9

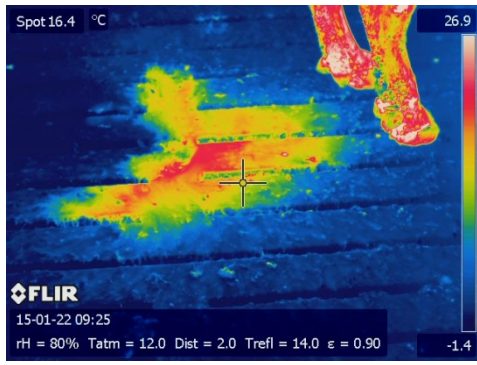

Spot 18.5 °C
36.2
FLIR
15-01-13 10:34
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
9.9

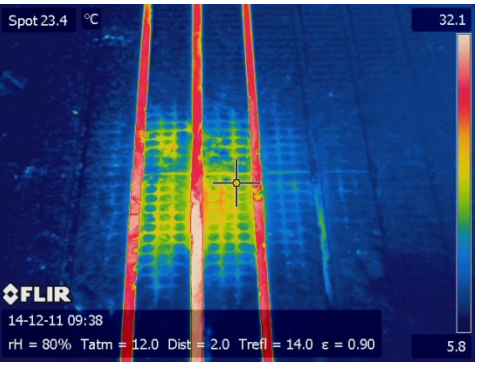

Spot 17.5 °C
30.9
FLIR
14-12-11 09:47
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
8.5

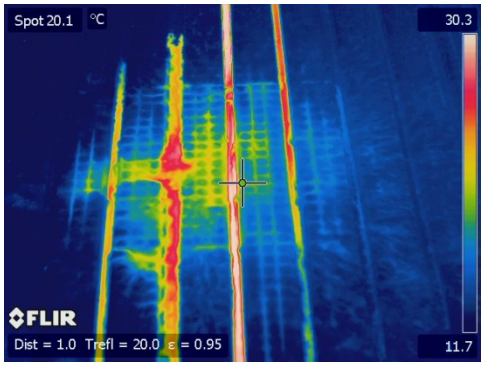

Spot 21.6 °C
32.6
FLIR
15-01-06 09:59
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
6.6

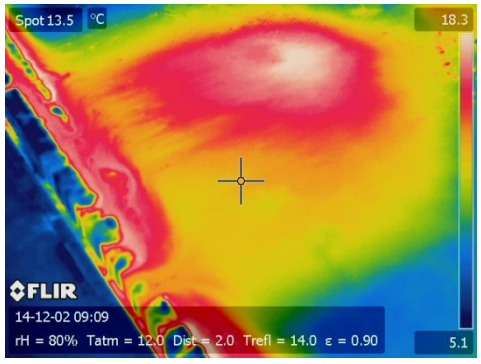

Spot 32.3 °C
32.5
FLIR
Dist = 1.0 Trefl = 20.0 ε = 0.95
13.0

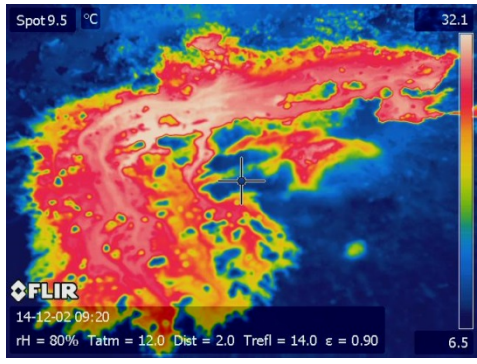

Spot 12.1 °C
17.3
FLIR
15-01-22 09:46
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
-0.4

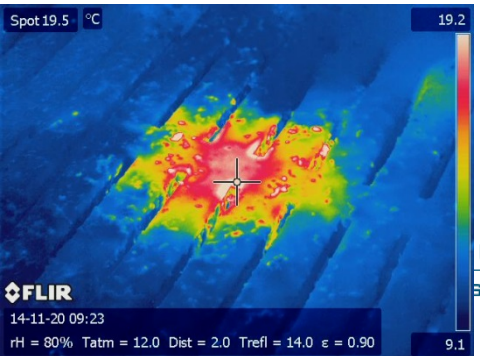

Spot 16.4 °C
26.9
FLIR
15-01-22 09:25
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
-1.4

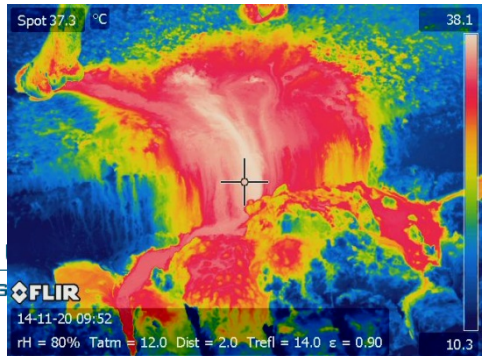

Spot 23.4 °C
32.1
FLIR
14-12-11 09:38
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
5.8

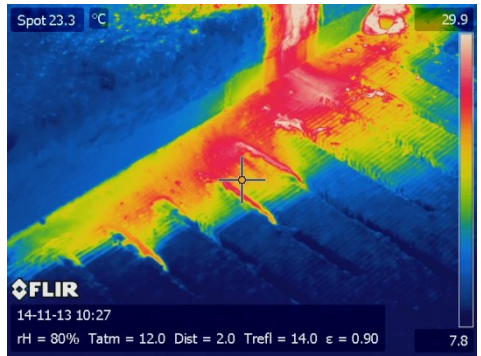

Spot 20.1 °C
30.3
FLIR
Dist = 1.0 Trefl = 20.0 ε = 0.95
11.7

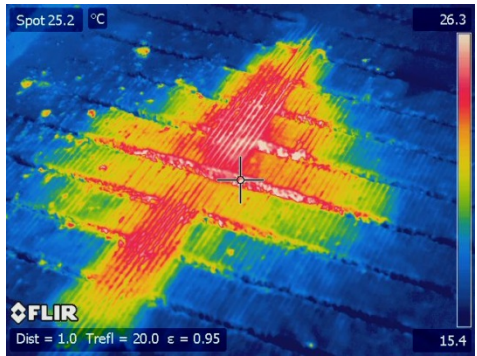

Spot 13.5 °C
18.3
FLIR
14-12-02 09:09
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
5.1


Spot 9.5 °C
32.1
FLIR
14-12-02 09:20
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
6.5


Spot 19.5 °C
19.2
FLIR
14-11-20 09:23
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
9.1


Spot 37.3 °C
38.1
FLIR
14-11-20 09:52
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
10.3


Spot 23.3 °C
29.9
FLIR
14-11-13 10:27
rH = 80% Tatm = 12.0 Dist = 2.0 Trefl = 14.0 ε = 0.90
7.8


Spot 25.2 °C
26.3
FLIR
Dist = 1.0 Trefl = 20.0 ε = 0.95
15.4