Potential and limitations of infrared thermography on unventilated walls

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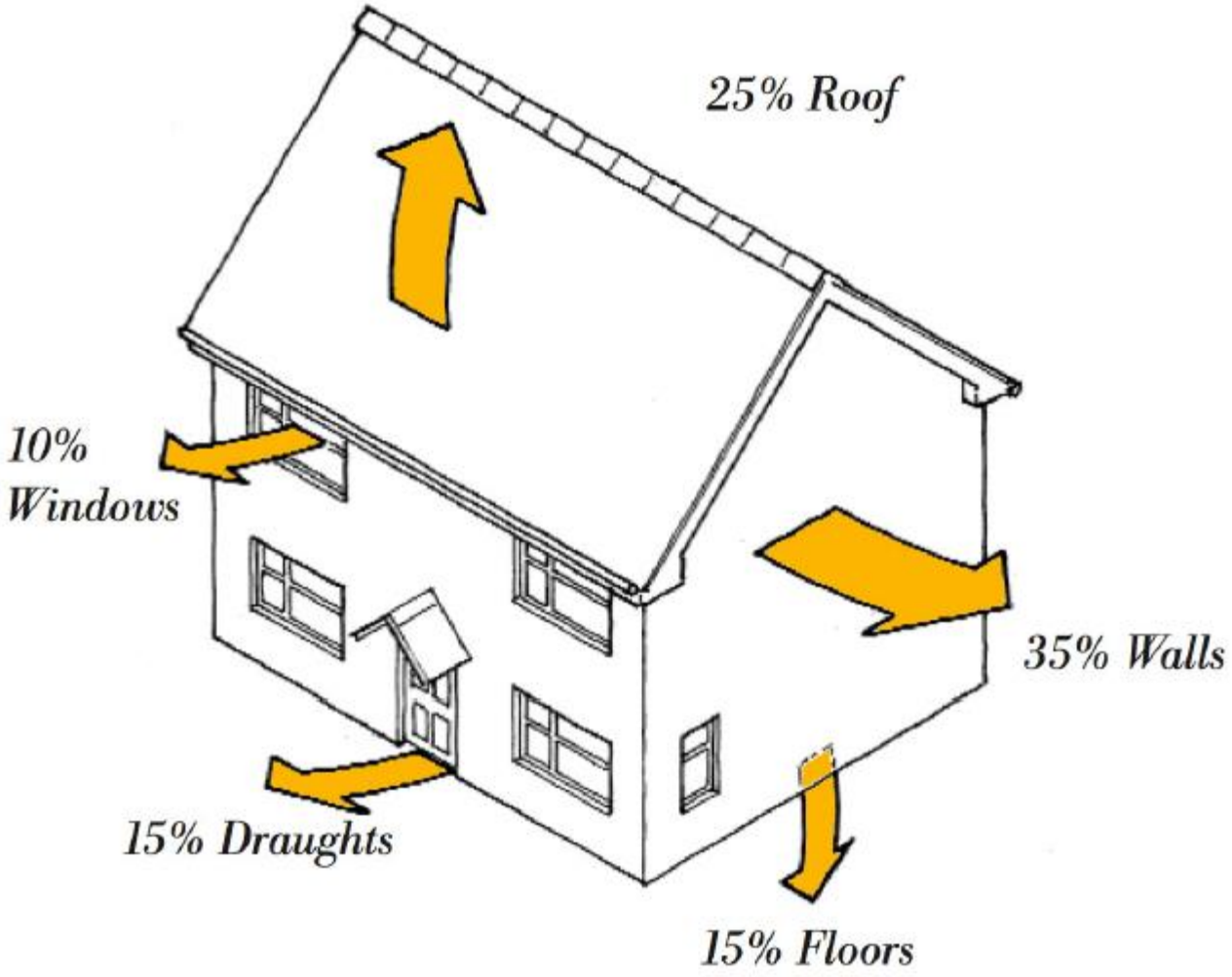
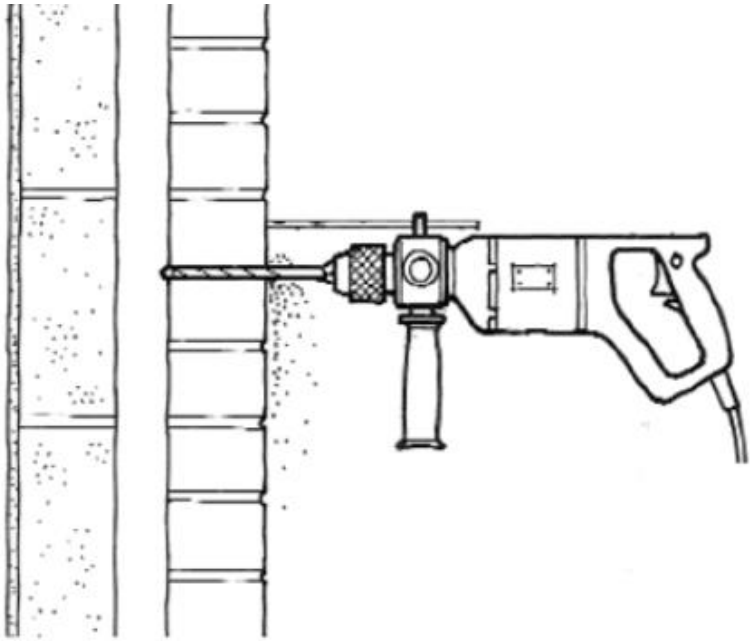
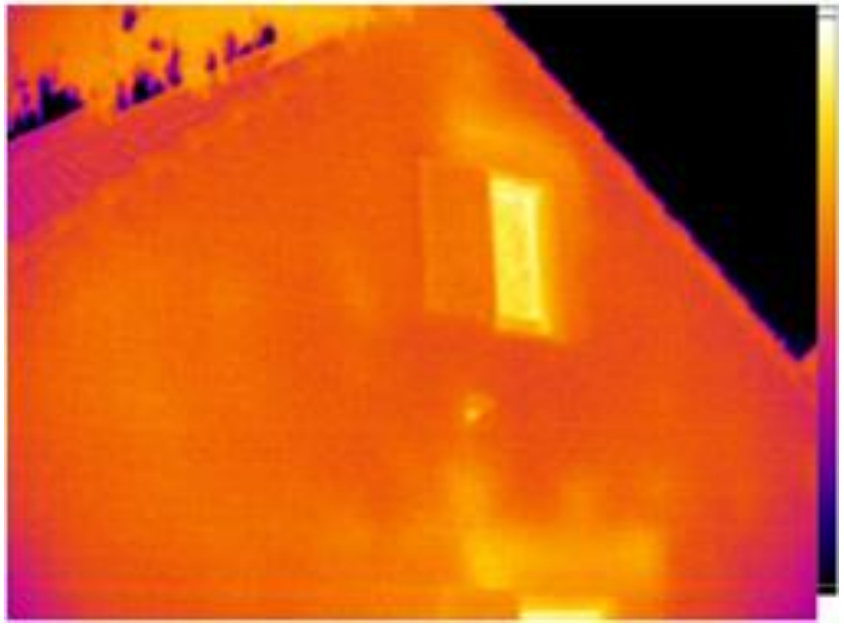

25% Roof
10%
Windows
35% Walls
15% Draughts
15% Floors

Solution?



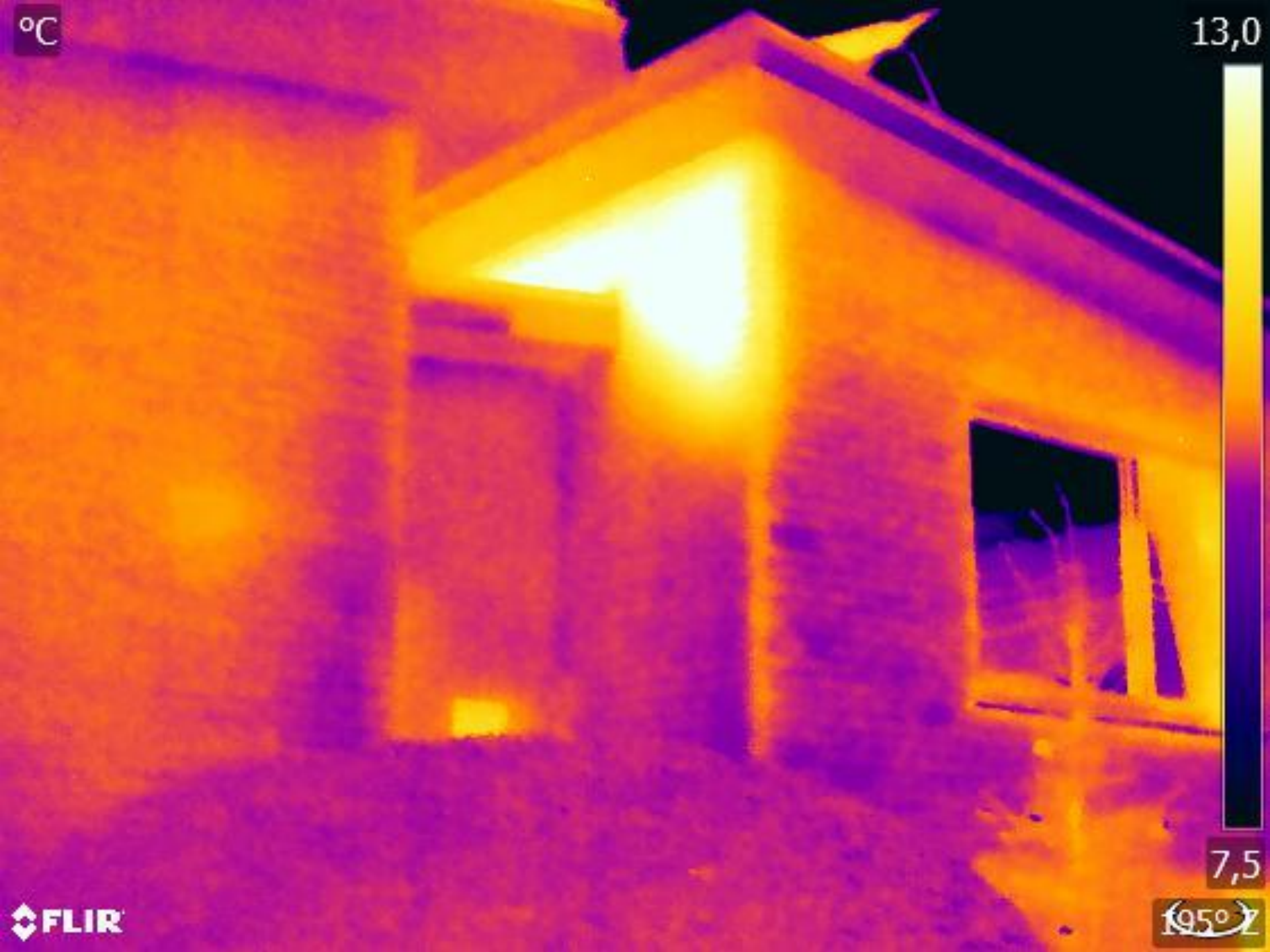
75% of all renovation projects

Practice?



Inspection tools

- Destruction
- Endoscopy
- Thermography?


°C
13,0
7,5
FLIR

Overview

The accuracy of thermography
Emissivity and reflected temperature
Camera use
Boundary conditions

Infrared inspection of cavity filling
Dynamic simulations
Case studies

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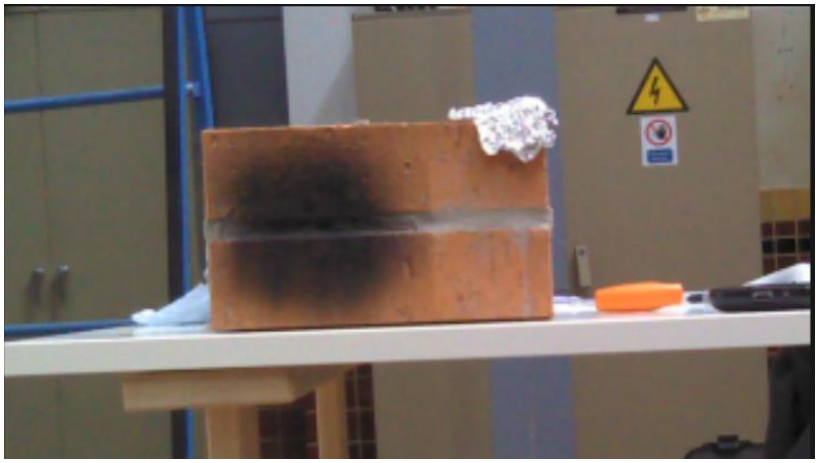
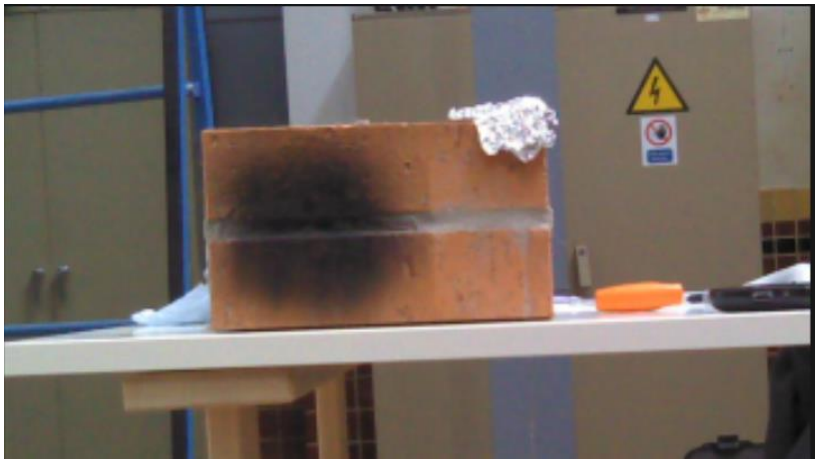
Emissivity and Reflected temperature

$$W_{tot} = \varepsilon . W_{obj} + \rho . W_{amb} + (1 - \tau_{atm}) . W_{atm} \quad [W/m^2]$$



Emissivity and Reflected temperature

$$W_{tot} = \varepsilon . W_{obj} + \rho . W_{amb} + (1 - \tau_{atm}) . W_{atm} \quad [W/m^2]$$



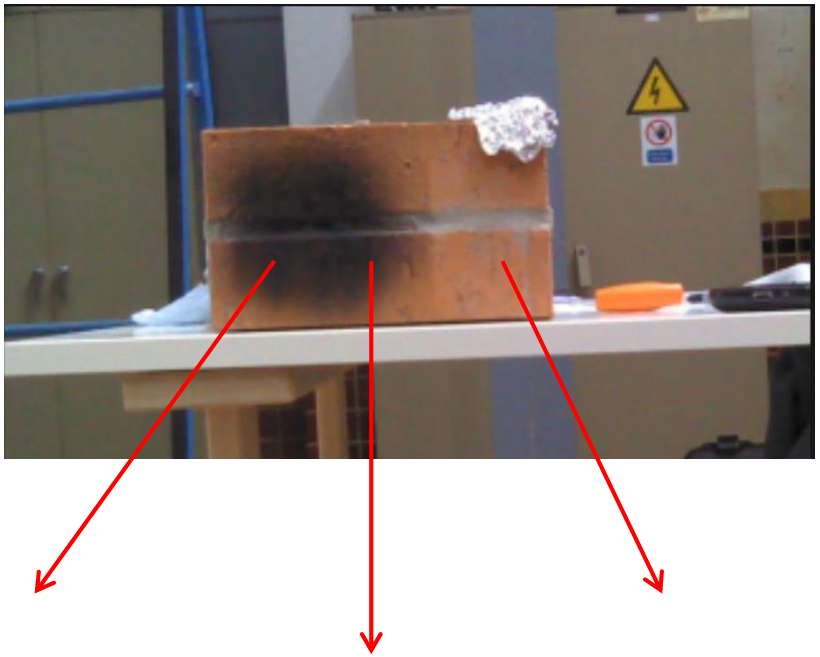
τ_{atm} = 1 in

λ = 3-5 µm and 8-14 µm

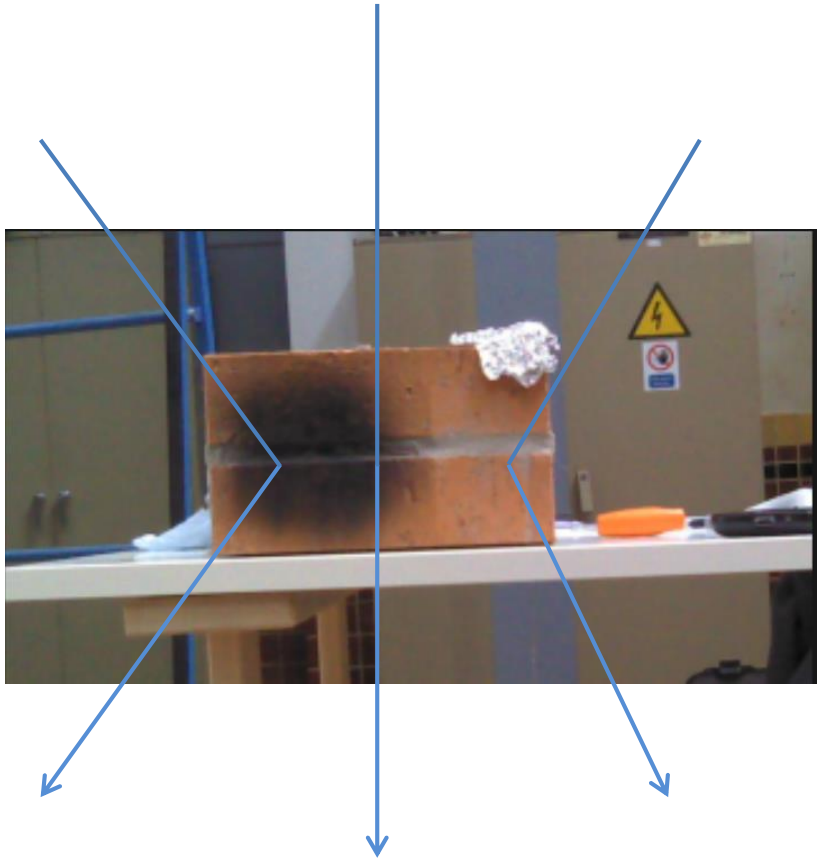
→ Spectrum of IR-camera

Emissivity and Reflected temperature

$$W_{tot} = \varepsilon . W_{obj} + \rho . W_{amb}$$



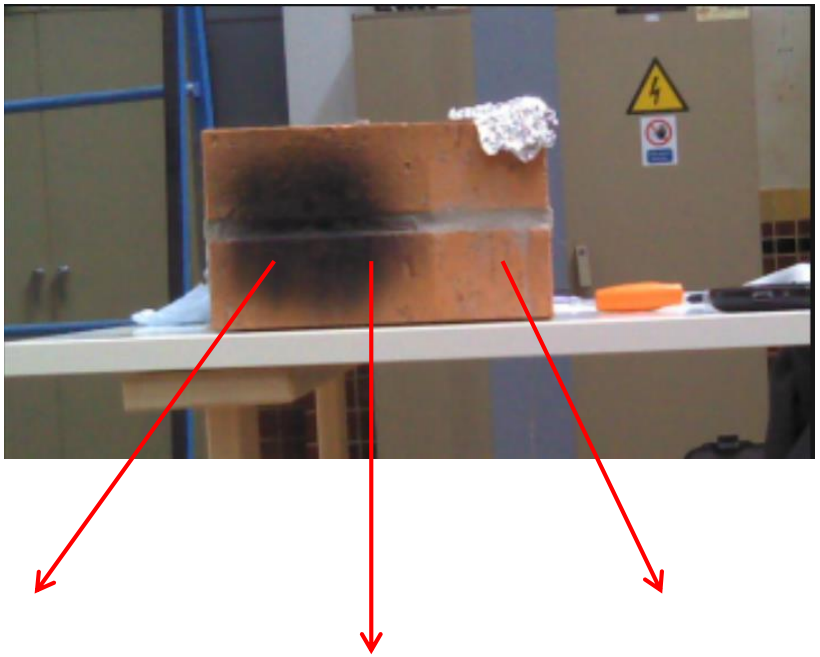
Emissivity ε



Reflection ρ = 1-ε

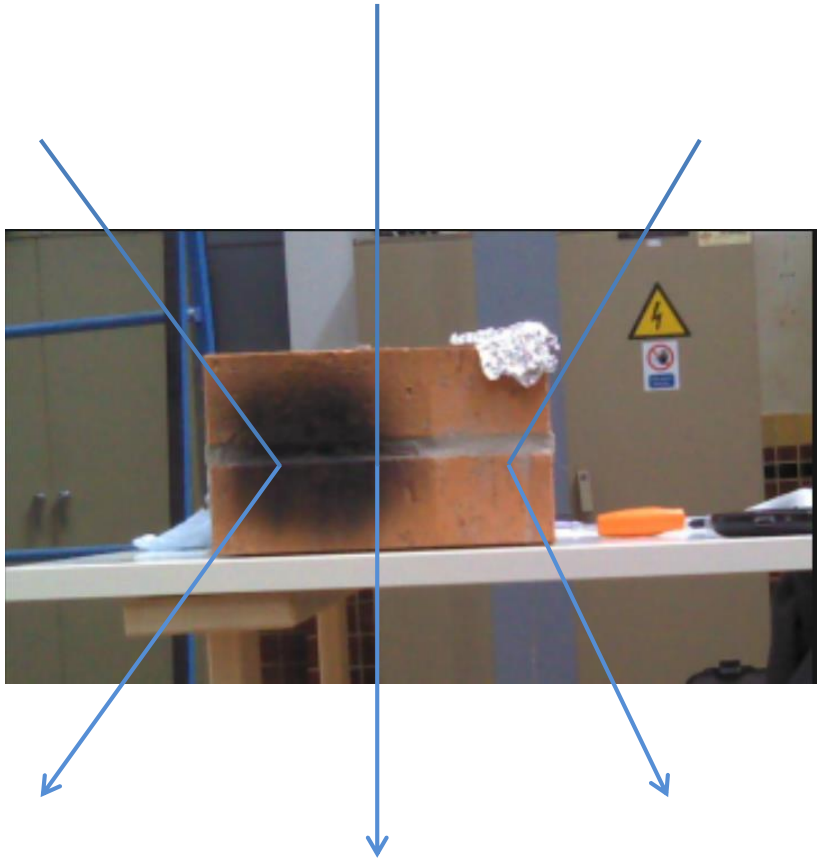
Emissivity and Reflected temperature

$Example: Brick \rightarrow \varepsilon = 0{,}90$



Emissivity ε

$W_{tot} \sim 90\% \, \theta_{obj}$



Reflection ρ = 1-ε

$W_{tot} \sim 10\% \, \theta_{refl}$

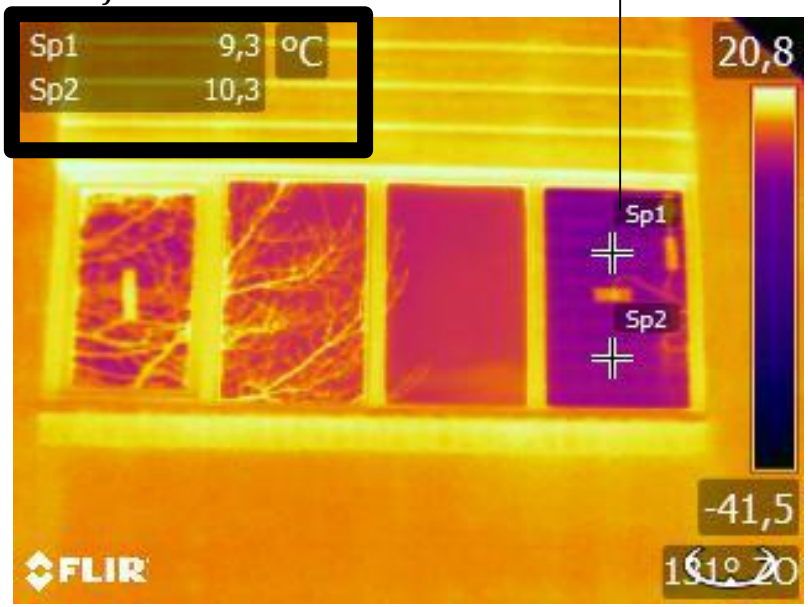
Emissivity and Reflected temperature

Use correct values!

Example: measurements in clear sky

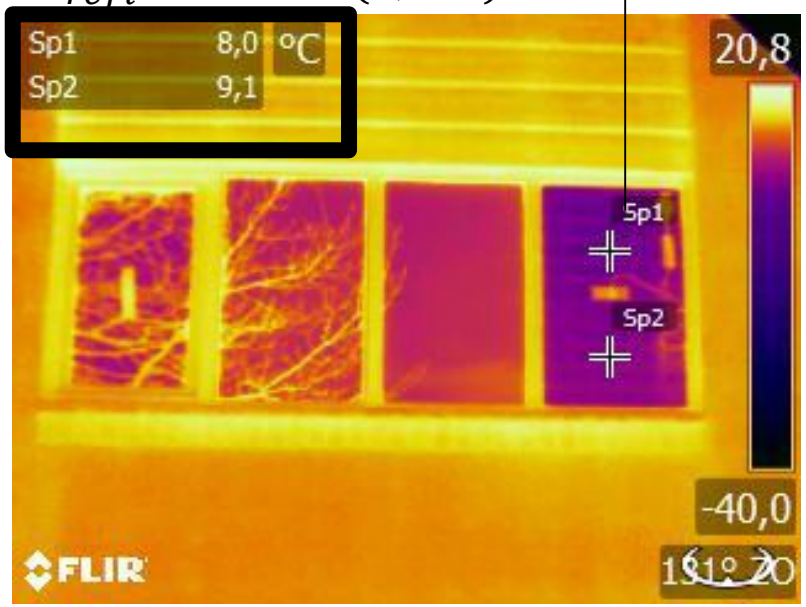
$\varepsilon = 0{,}75$

$\theta_{refl} = -20°C\ (-4{,}0°F)$



$\varepsilon = 0{,}75$

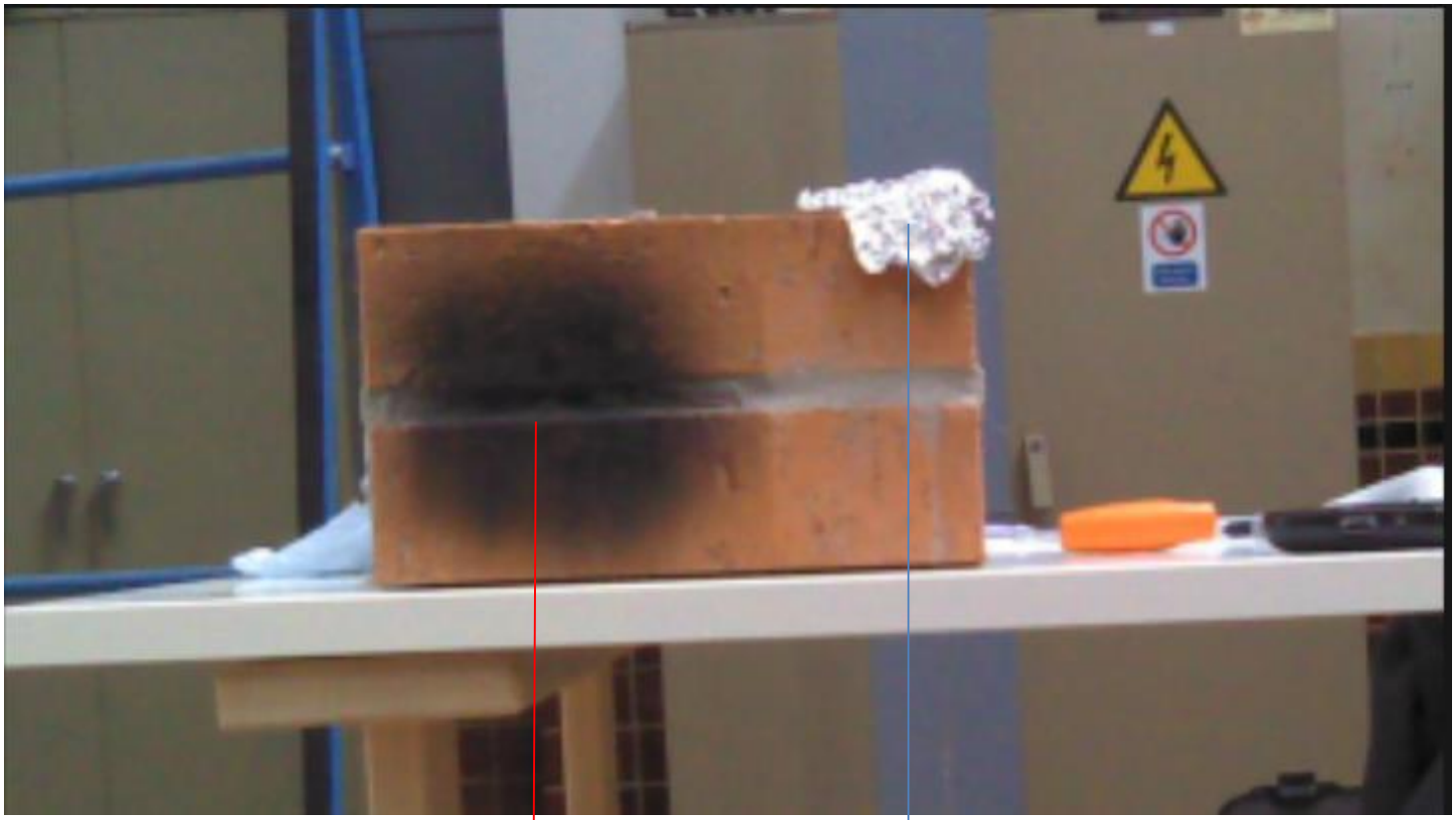
$\theta_{refl} = -15°C\ (5{,}0°F)$



Accuracy difference : 1,2°C (2,16 °F)

Emissivity and Reflected temperature

In-situ determination



Determine ε
ASTM E1993-99a

Determine θ_{refl}
ASTM C1060-11a

Overview

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Infrared inspection of cavity filling

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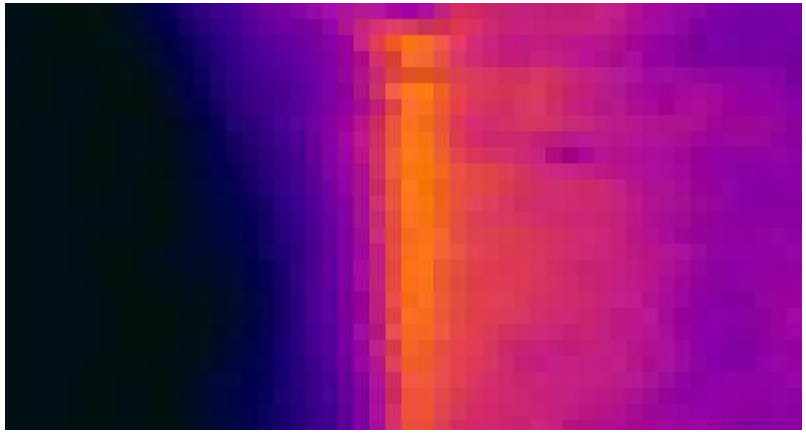
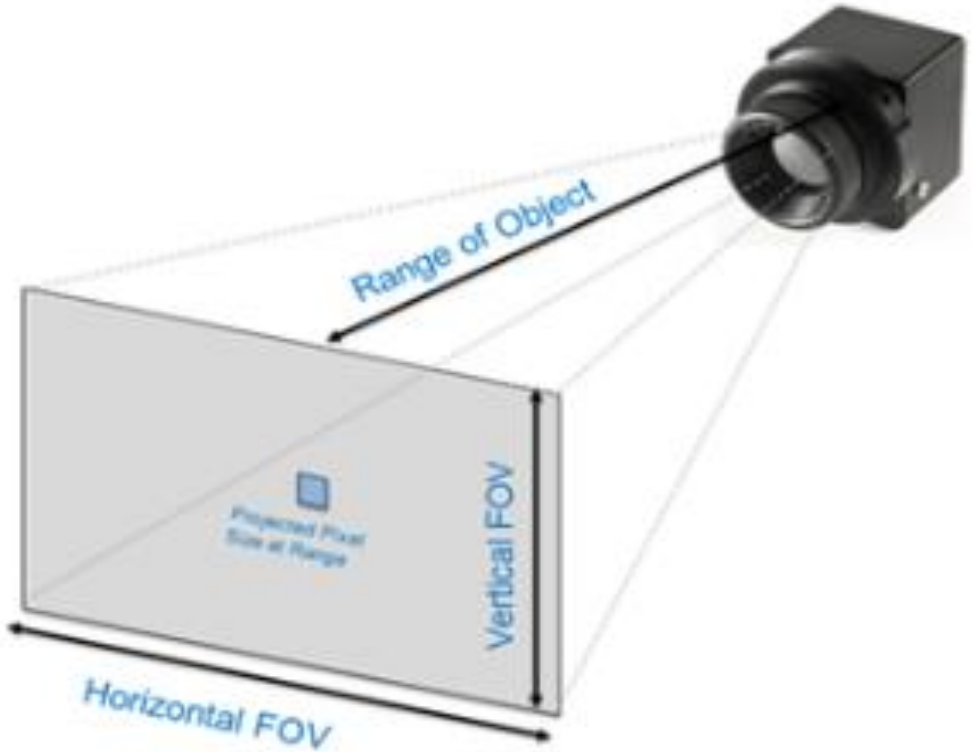
Camera use



Camera use

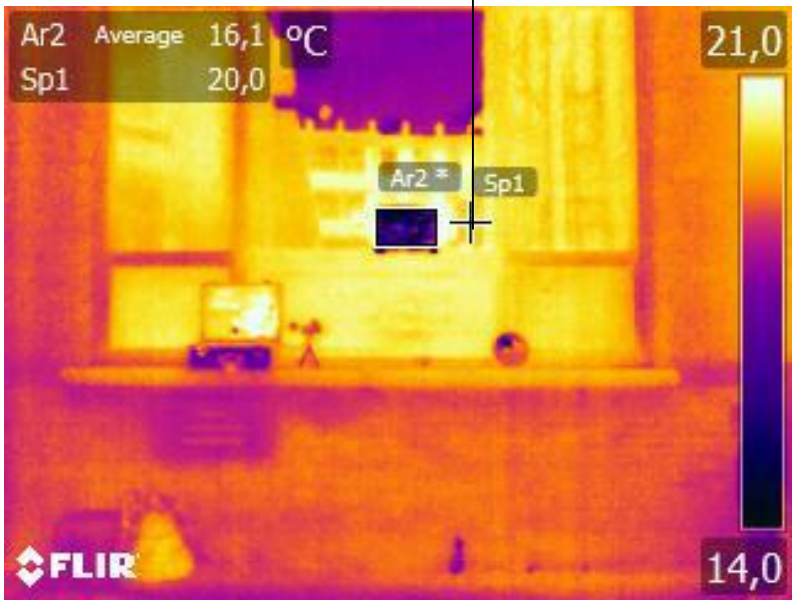


Camera use

Camera use

Different FOV's of the lens

θ_S = 20,0°C (68,0°F)



45°x33,8°

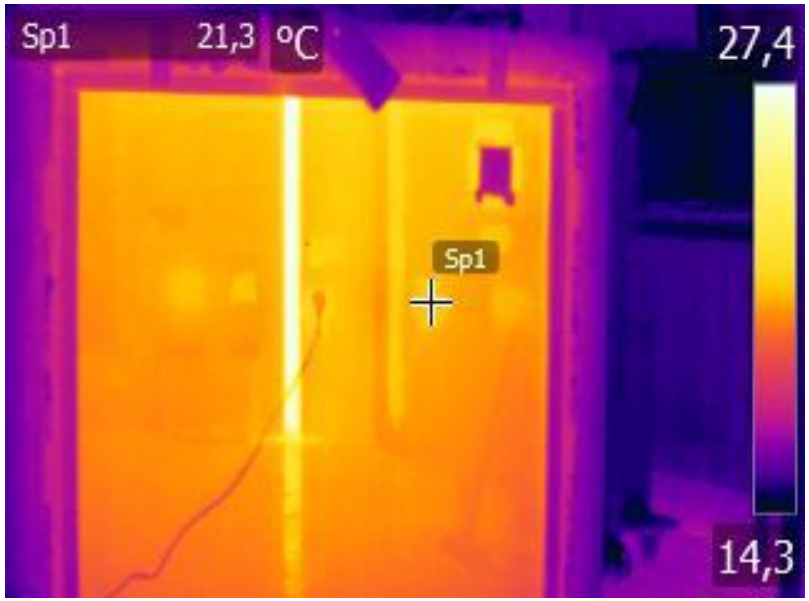
θ_S = 19,4°C (67,3°F)

25°x19°

Camera use

Resolution

640 X 480



320 X 240

Camera use

Standard deviation: ± 2°C (3,6°F)

Noise Equivalent Temperature Difference (NETD)

Imaging Specifications

FEATURES	FLIR E40	FLIR E50	FLIR E60
Temperature range	-4 to 1202°F (-20 to 650°C)	-4 to 1202°F (-20 to 650°C)	-4 to 1202°F (-20 to 650°C)
Thermal sensitivity (N.E.T.D)	<0.07°C at 30°C	<0.05°C at 30°C	<0.05°C at 30°C
Detector Type - Focal plane array; (FPA) uncooled microbolometer	160 x 120 pixels	240 x 180 pixels	320 x 240 pixels
MSX® Thermal Image Enhancement	Yes	Yes	Yes
Picture-in-Picture (P-i-P)	Fixed P-i-P	Scalable P-i-P	Scalable P-i-P
MPEG 4 Video Recording	Yes	Yes	Yes
Video Camera w/Lamp & Laser	3.1MP/LED Lamp/Laser pointer	3.1MP/LED Lamp/Laser pointer	3.1MP/LED Lamp/Laser pointer
Digital Zoom	2X Continuous	4X Continuous	4X Continuous
Image annotation	Voice (60s)/Text Comments	Voice (60s)/Text Comments	Voice (60s)/Text Comments
Moveable Spot	3 Spotmeters	3 Spotmeters	3 Spotmeters
Area Box	3 Area Boxes (full image with min/max/avg)	3 Area Boxes (full image with min/max/avg)	3 Area Boxes (full image with min/max/avg)
Delta T	Yes	Yes	Yes
Data Communication Interface	USB-mini, USB-A, Composite Video, Bluetooth, Wi-Fi	USB-mini, USB-A, Composite Video, Bluetooth, Wi-Fi	USB-mini, USB-A, Composite Video, Bluetooth, Wi-Fi

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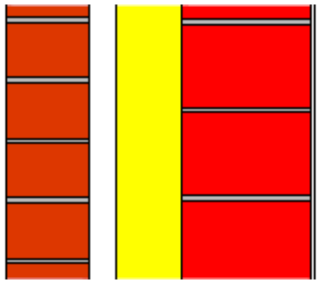
$\theta_i - \theta_e$
> 10°C (18 °F)

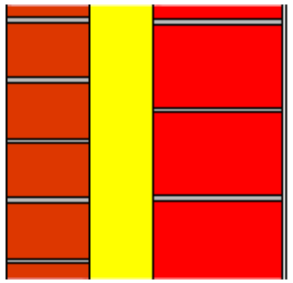
Weather conditions
No sun, no clear sky, no wind

→ How long does the influence remain?

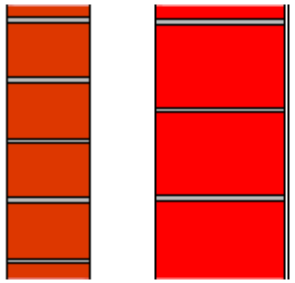
Boundary conditions



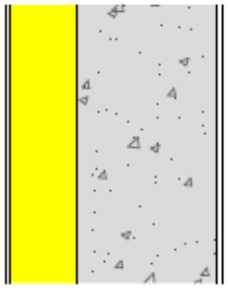
U = 0,22 W/m²K
E = 531,21 J/m²K√s



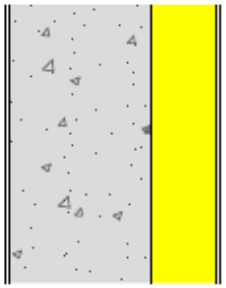
U = 0,22 W/m²K
E = 531,21 J/m²K√s



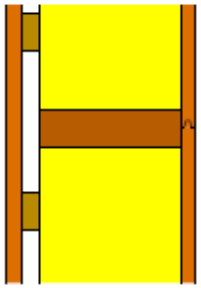
U = 1,00 W/m²K
E = 531,21 J/m²K√s



U = 0,22 W/m²K
E = 32,40 J/m²K√s



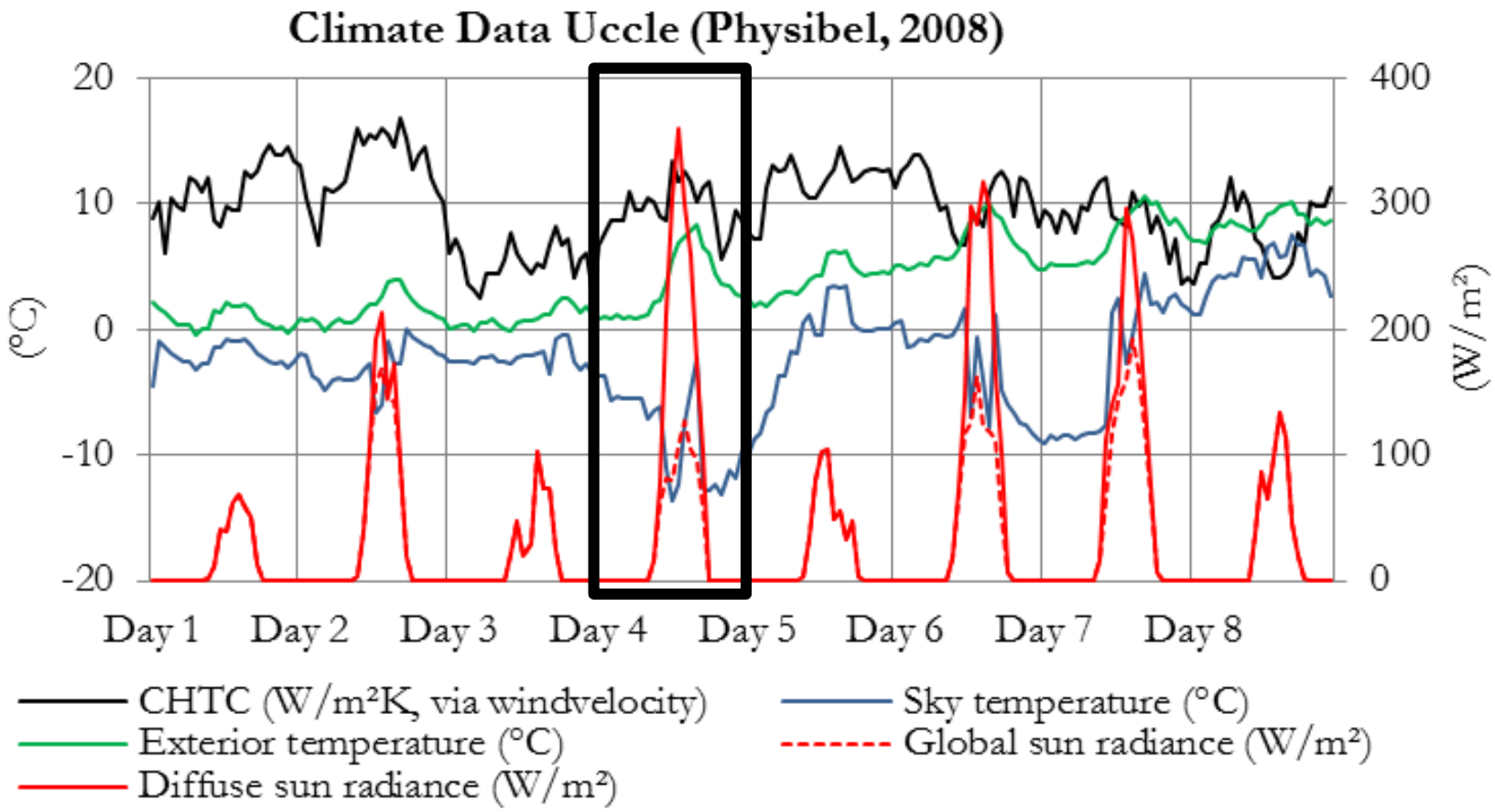
U = 0,22 W/m²K
E = 2500 J/m²K√s



U = 0,22 W/m²K
E = 32,40 J/m²K√s

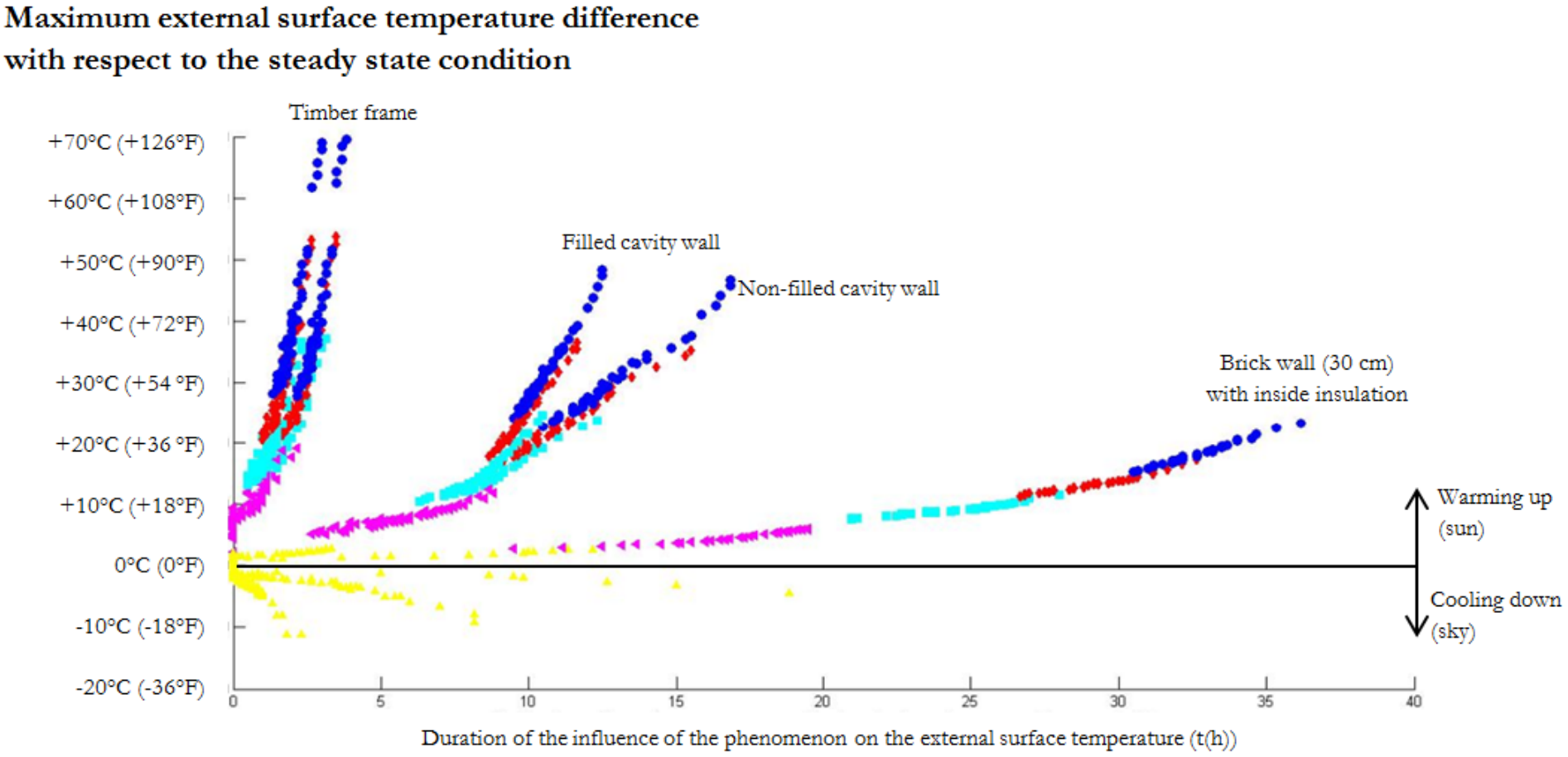
(Van De Vijver, 2014)

Boundary conditions



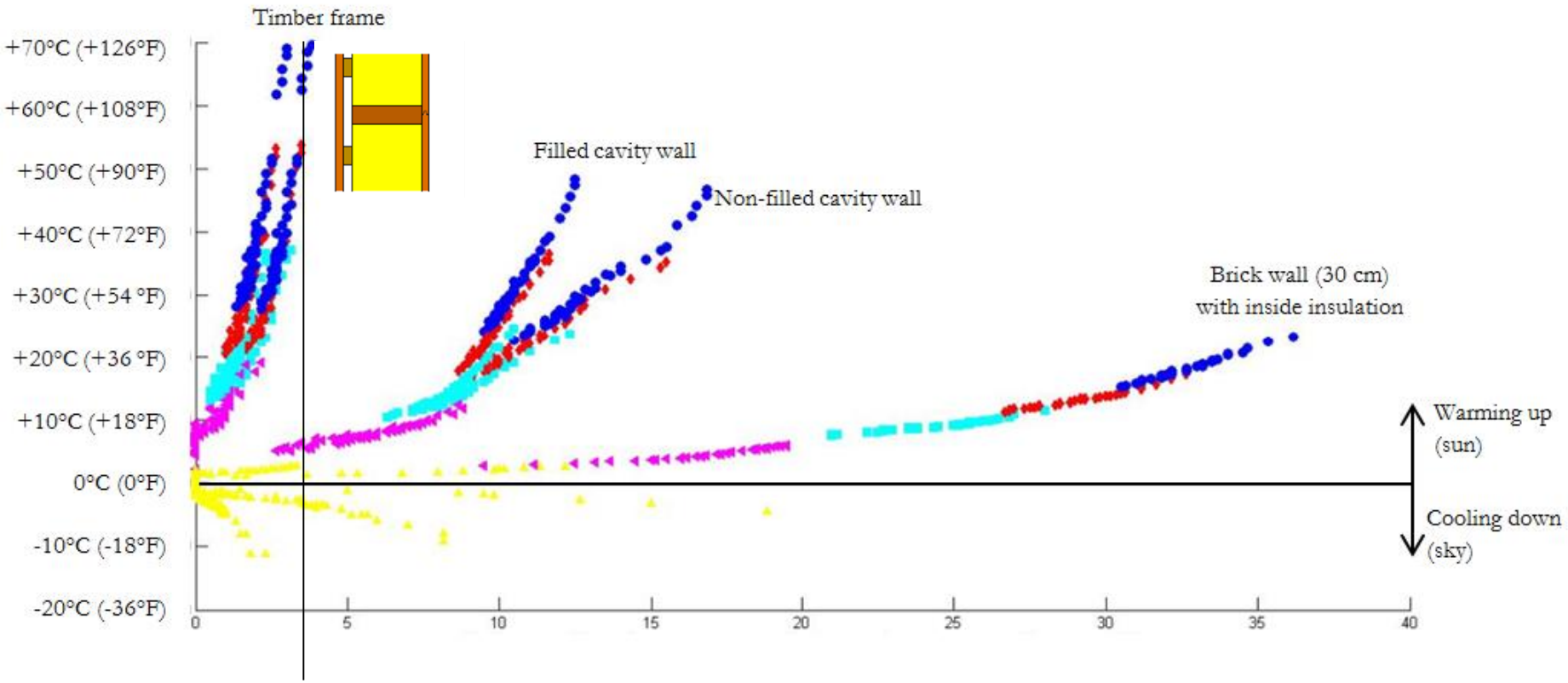
(Van De Vijver, 2014)

Boundary conditions



(Van De Vijver, 2014)

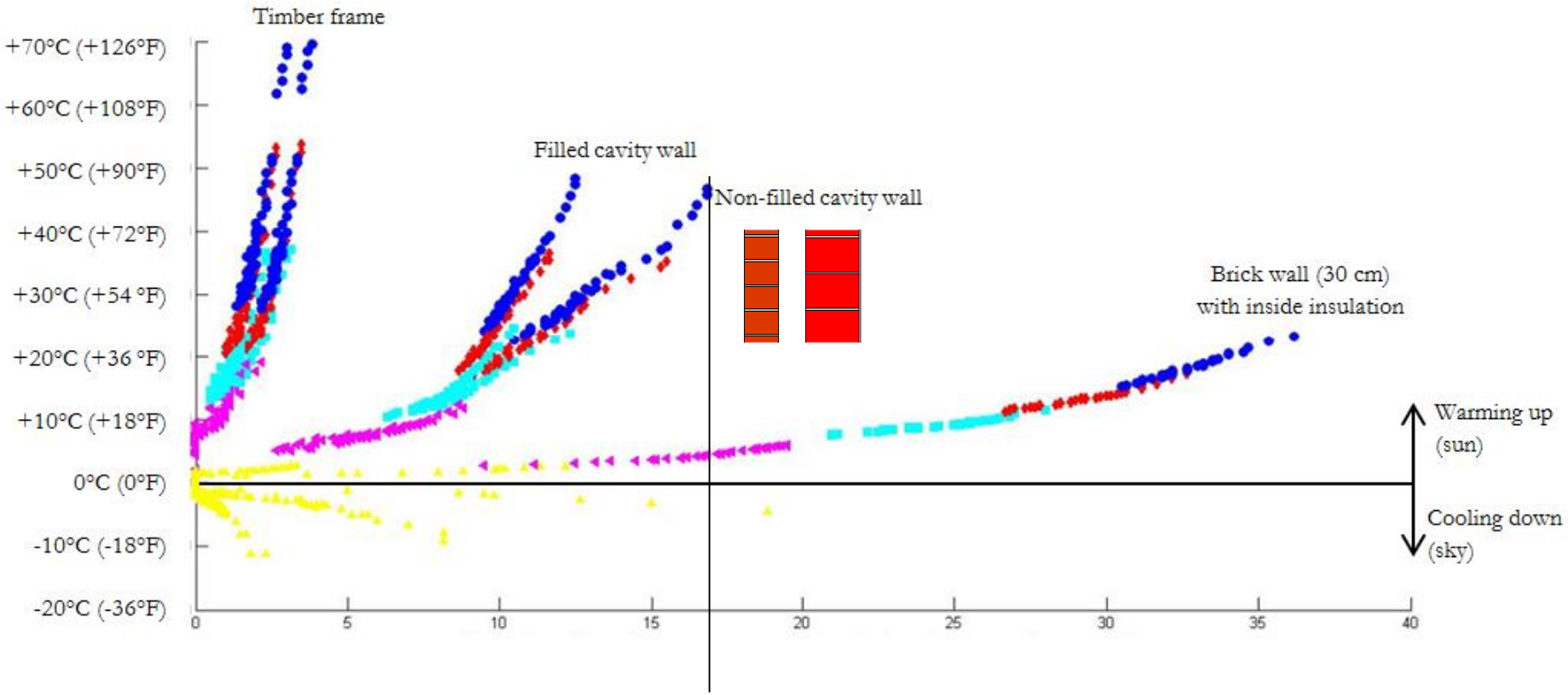
Boundary conditions



4 hours waiting
in heavy clouded
windless weather

(Van De Vijver, 2014)

Boundary conditions



17 hours waiting
in heavy clouded
windless weather

(Van De Vijver, 2014)

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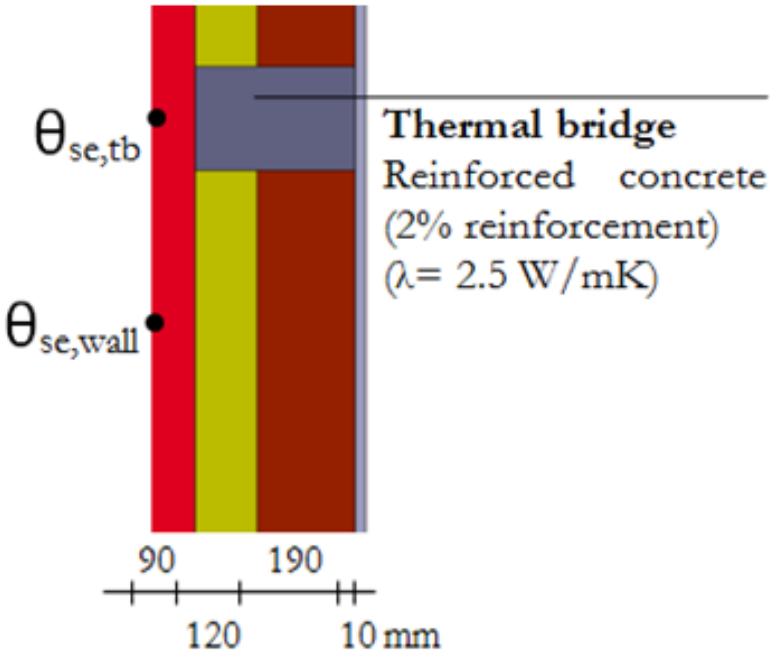
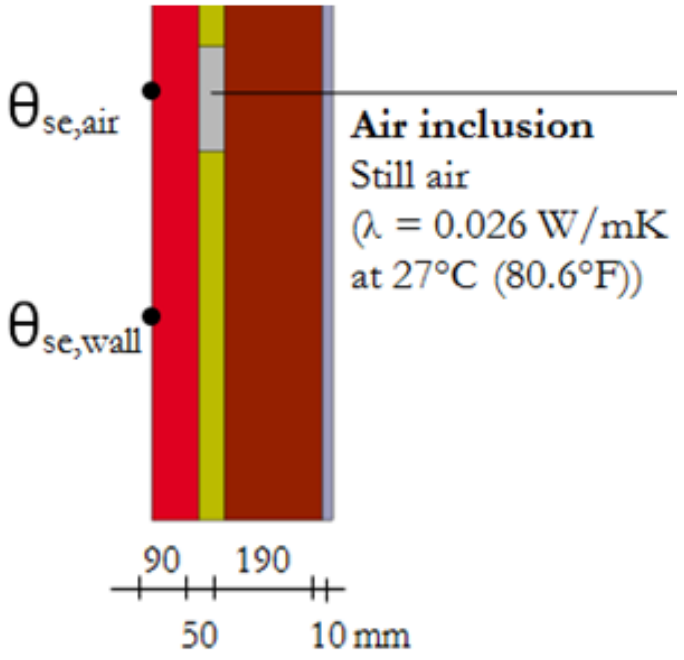
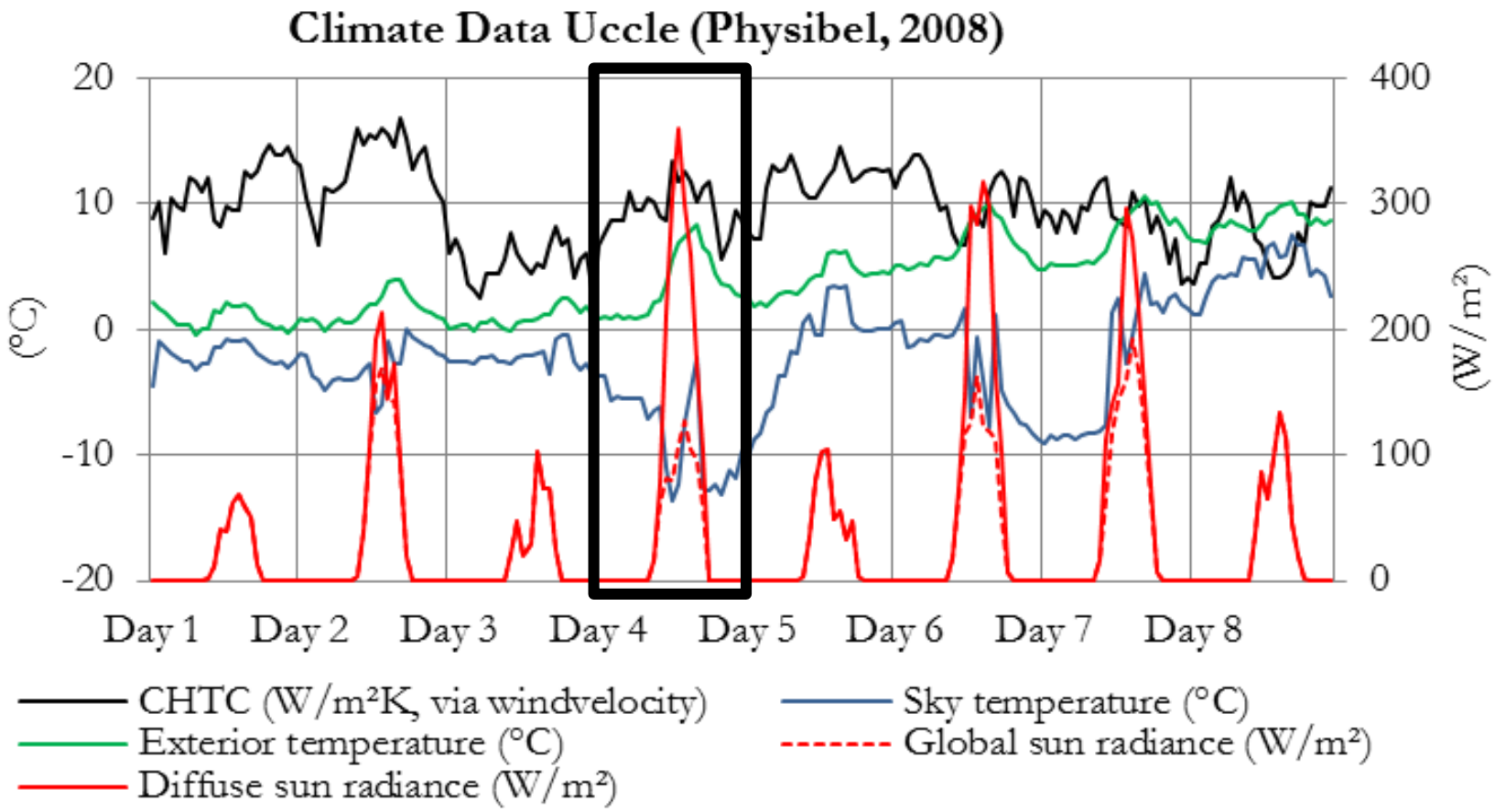
Dynamic simulations



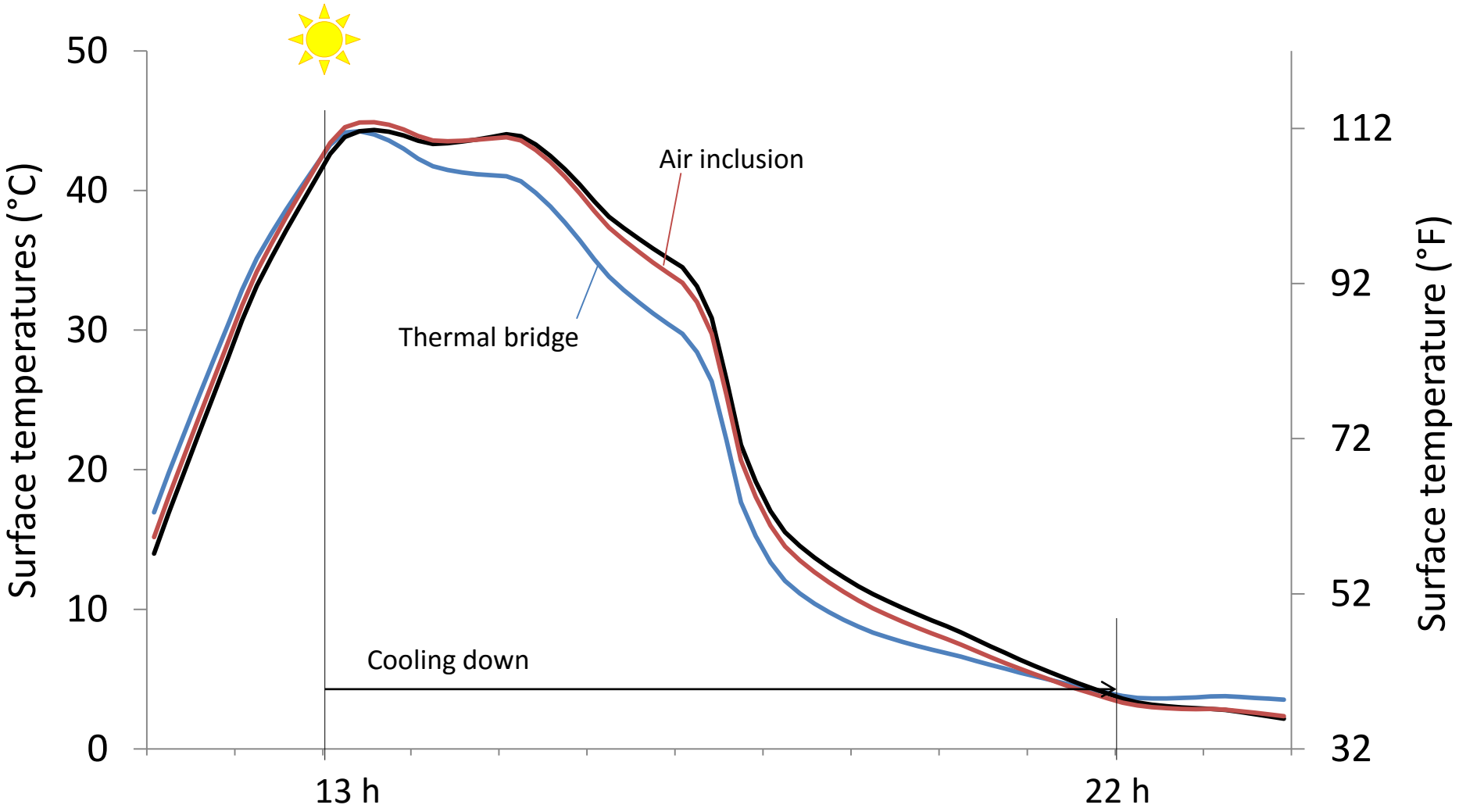


Dynamic simulations



Dynamic simulations

Maximal sun radiation, Clear sky, No wind



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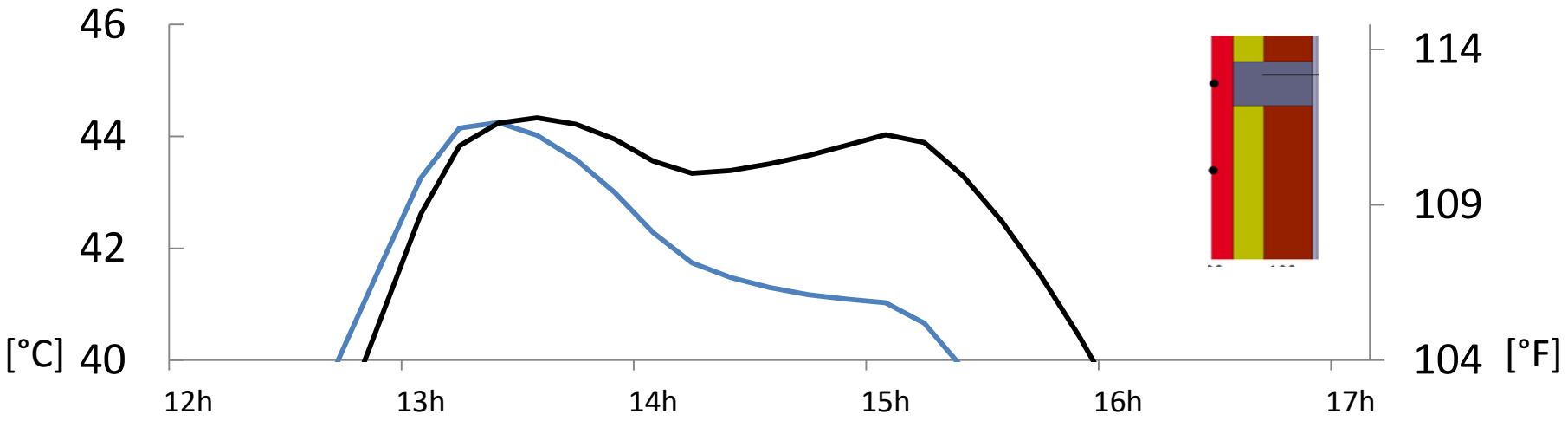
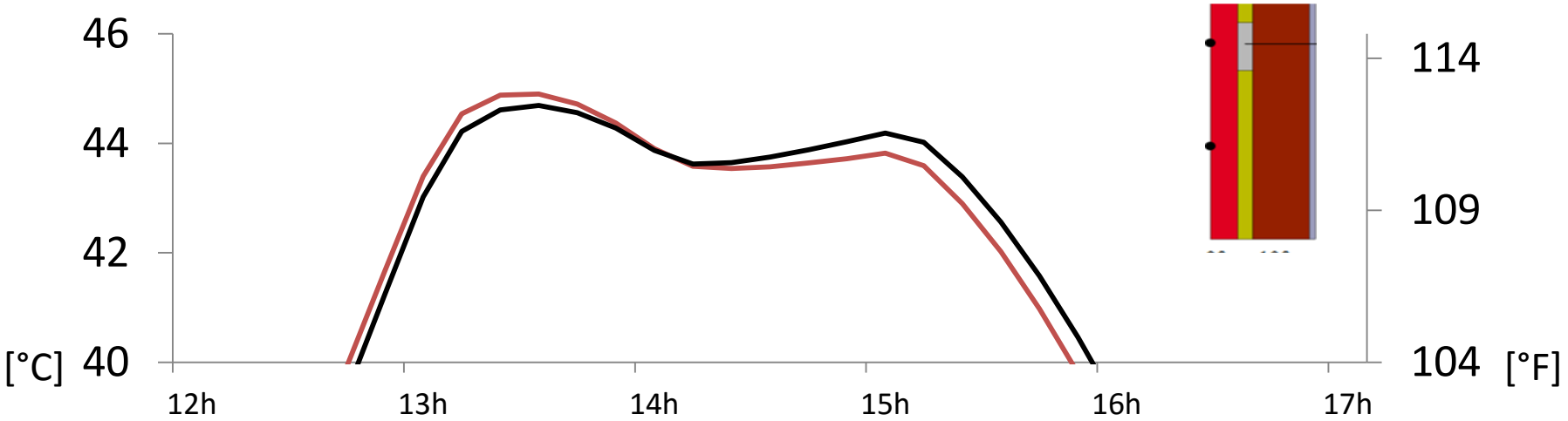
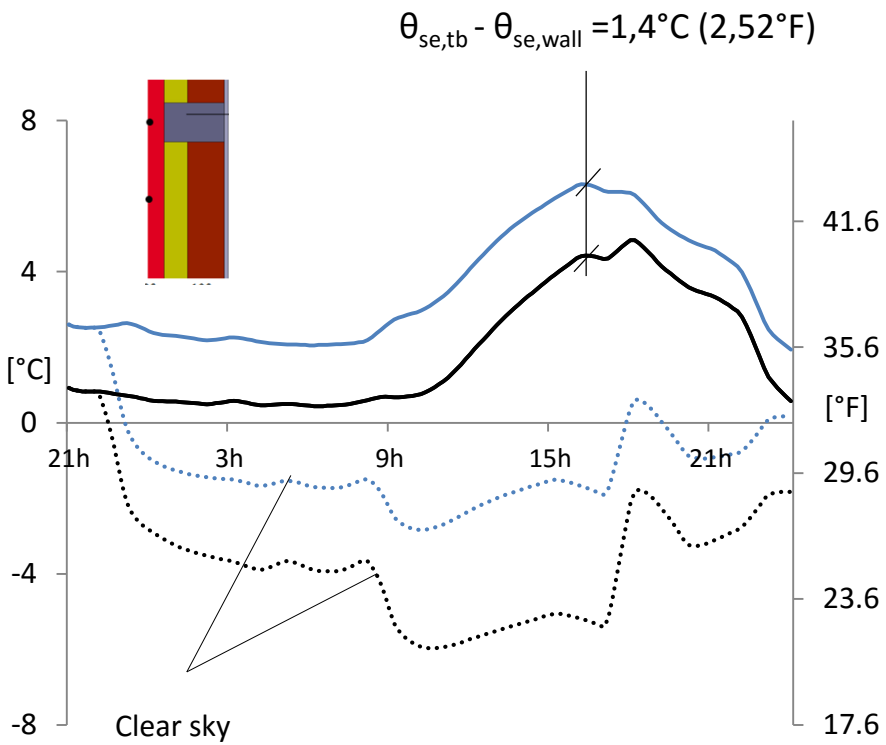
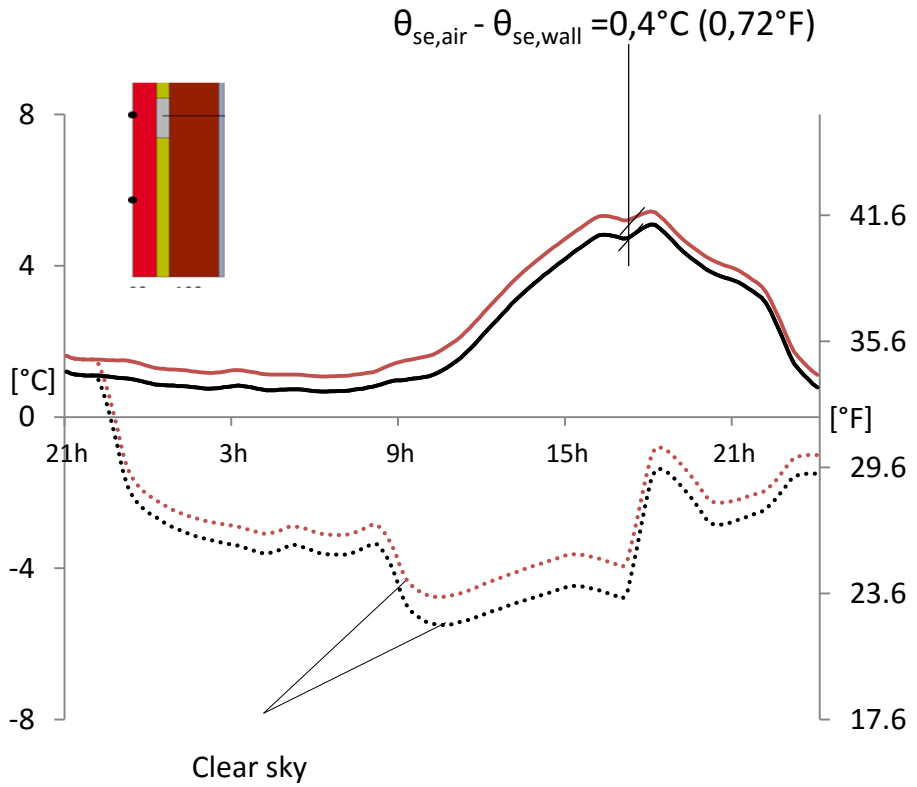




Dynamic simulations

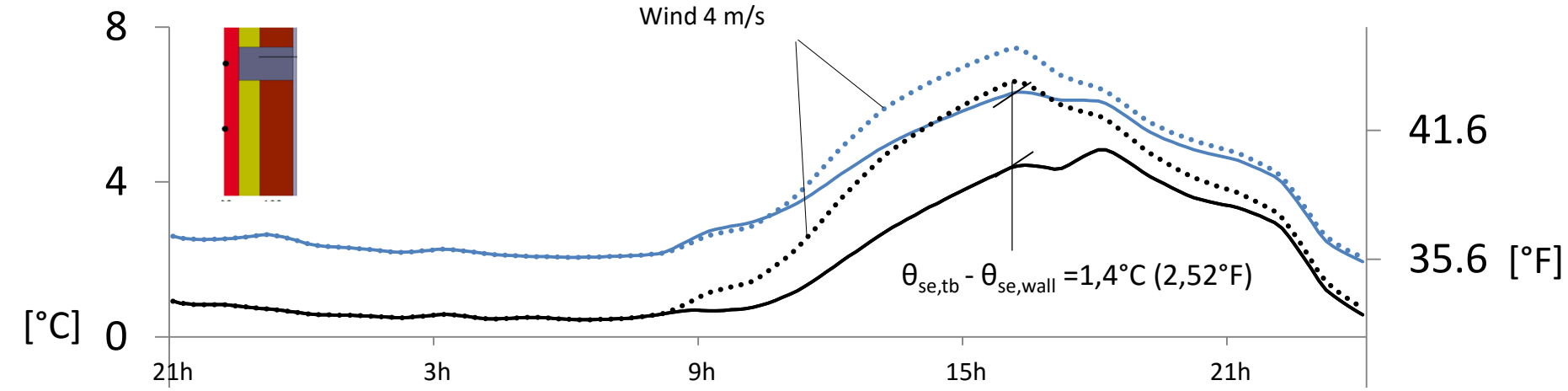
No sun, **Clear sky vs. fully clouded**, No wind

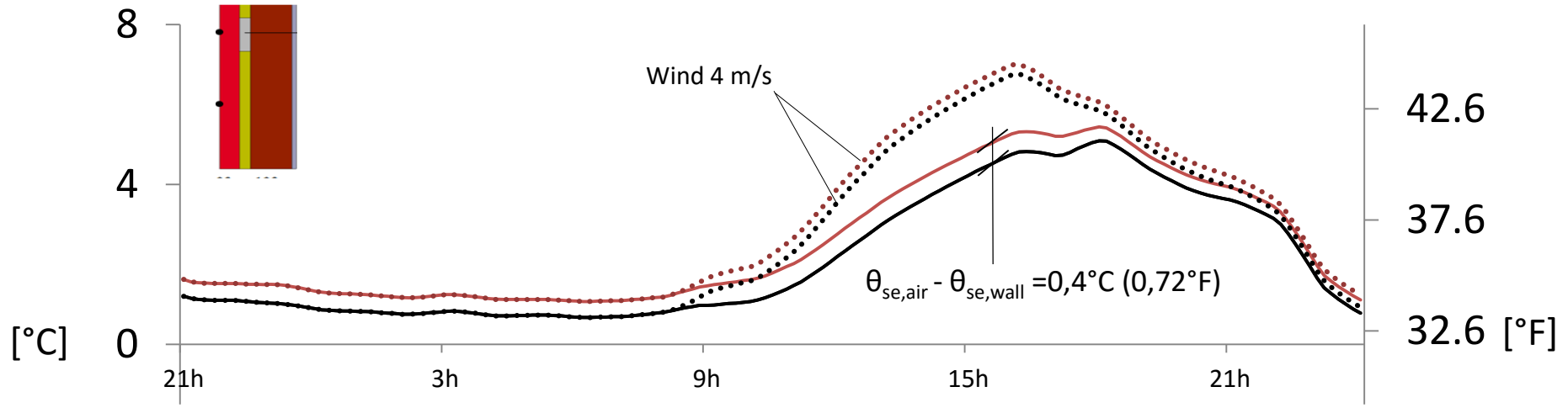




Dynamic simulations

No sun, Fully clouded and **Wind (4 m/s) vs. No Wind**





Dynamic simulations

Only waiting times after sun radiation necessary

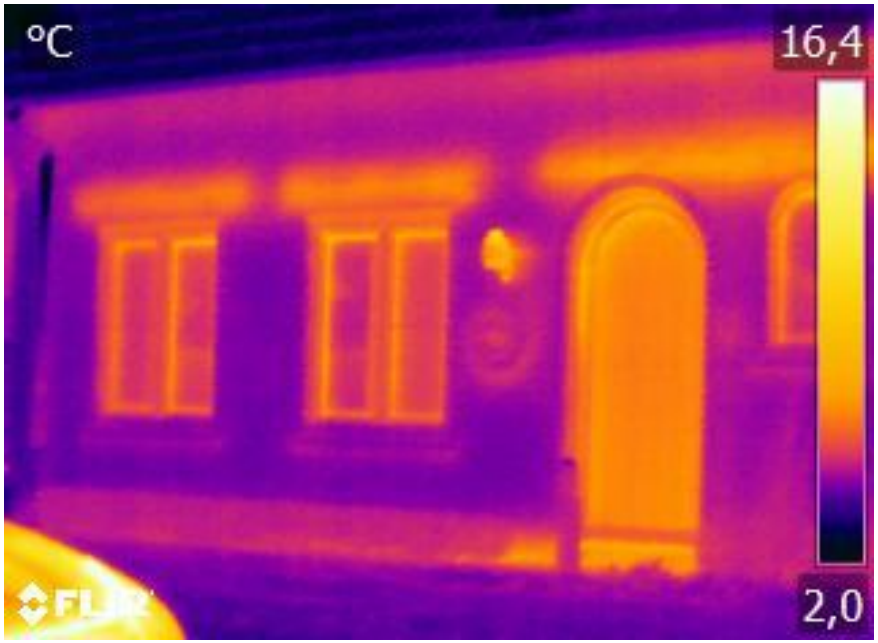
	Timber frame	**Filled cavity wall**	**Non-filled cavity wall**	**Partially filled cavity wall**
11400 kJ/m²	0 – 1,5h	3,5 – 7h	2 – 6,5h	3,5 – 7h
8400 kJ/m²	0 – 1h	2 – 6h	0,2 –5h	2 – 6h
5600 kJ/m²	0h	0 – 4,5h	0 – 3,5h	0 – 4,5h
2750 kJ/m²	0h	0 – 2h	0 – 0,5h	0 – 2h
0 kJ/m²	0 – 0,2h	0 – 1h	0 – 0,2h	0 – 1h

+ Temperature difference > 10°C (18°F) across the wall

Dynamic simulations

In practice:

Go measure in wintertime, before sunrise



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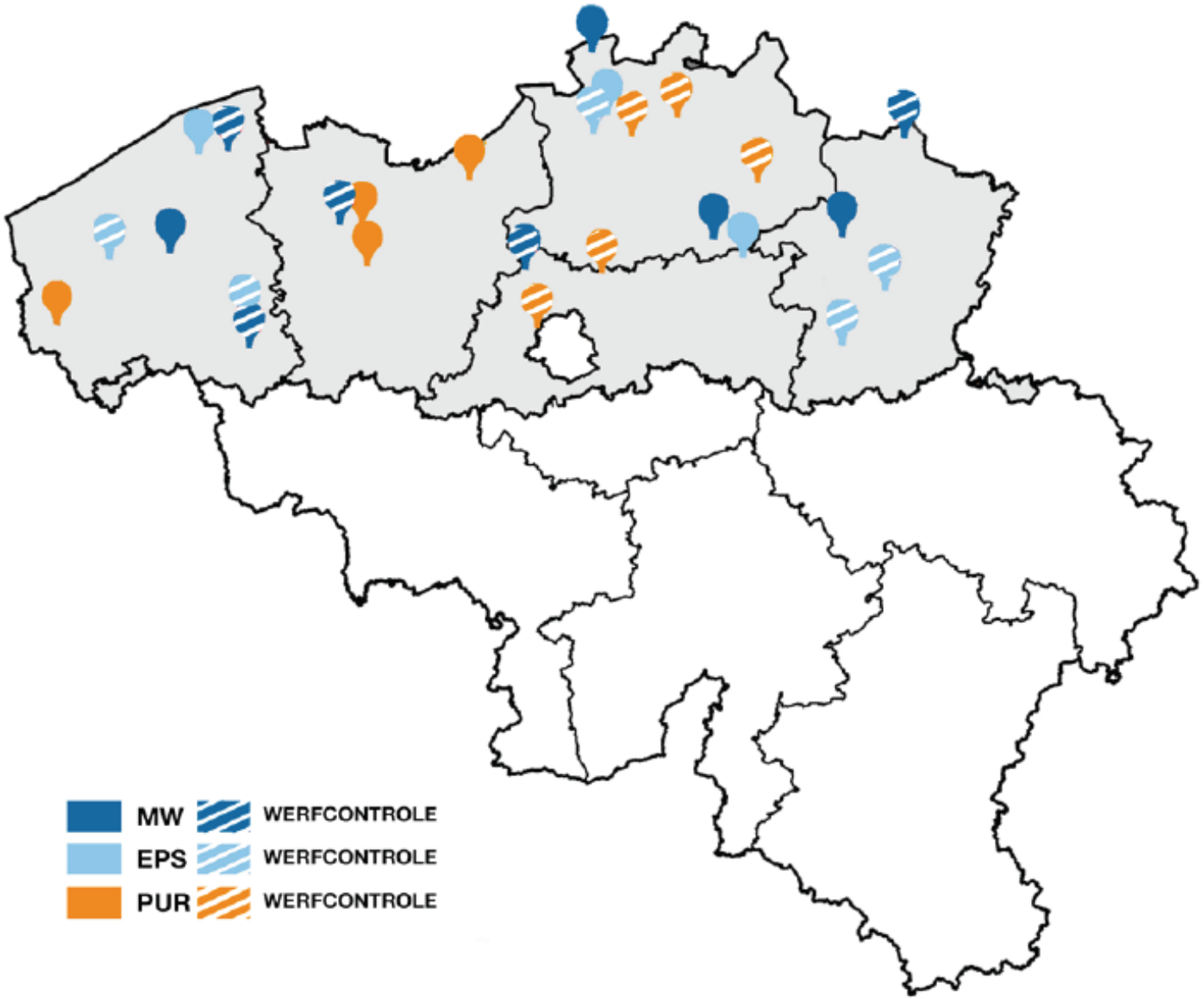


(Beulque, 2014)

Case studies

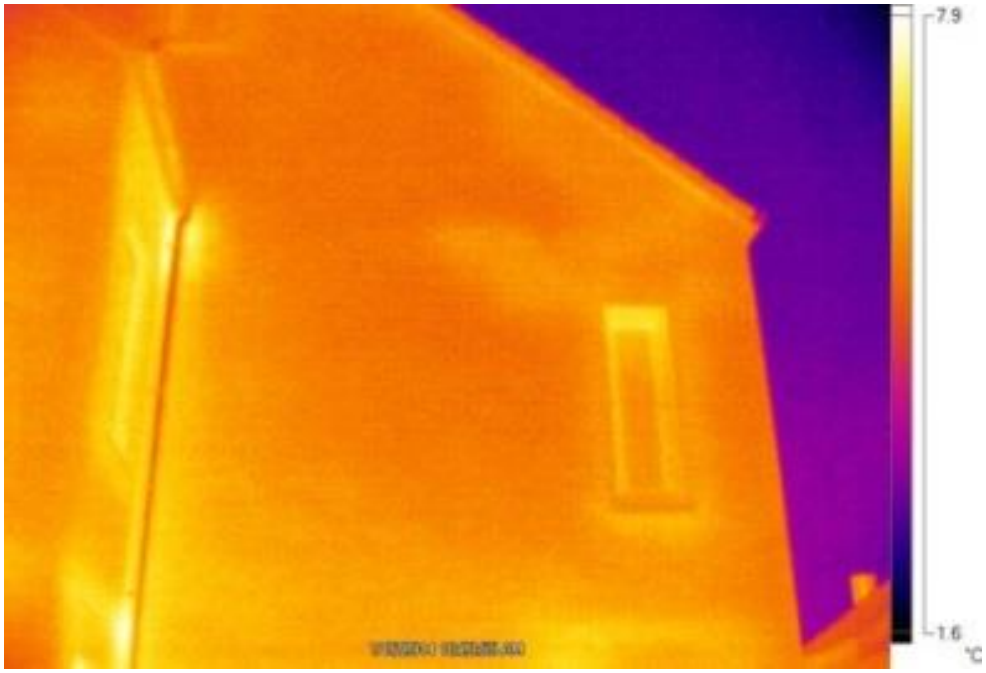
Common flaws

- Poor or lacking measurement data of the cavity width
- Ignorance towards the minimum cavity width (< 5 cm or 1,96”)
- Insufficient number of bore holes
- Incorrect glue flow rate of the EPS pearls
- Incomplete filling at corners and cavity interruptions
- Missing bore holes due to vegetation or cables
- Open parpens at the top
- Parpens and openings in the inner cavity leaf during cavity filling

Which of these flaws are detectable with thermography?

Case studies

Know what you can expect → Execution report



Vegetation during cavity filling work
→ no bore holes
→ insufficient filling locally

Case studies

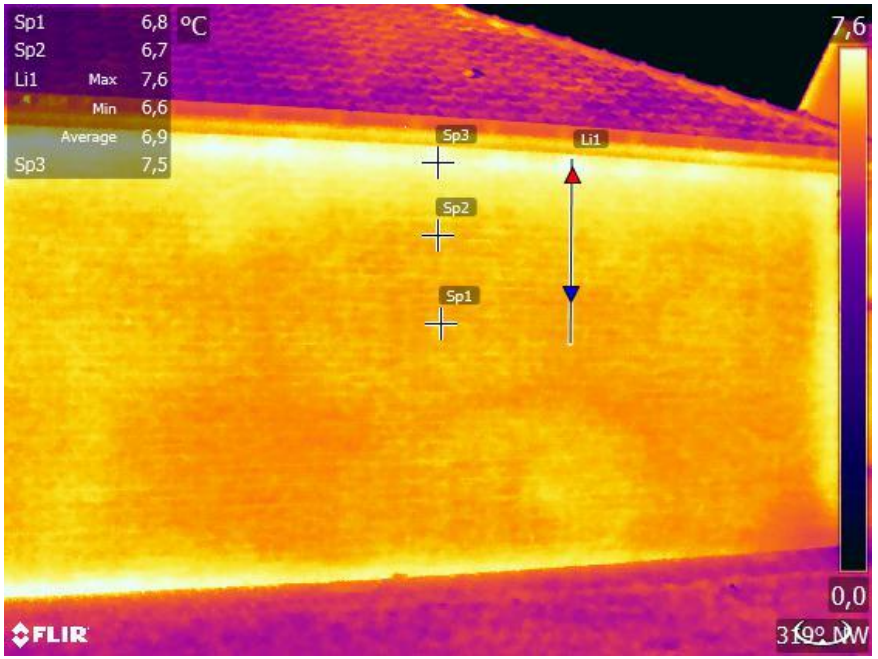
Know what you can expect → Execution report

Filling with EPS-pearls
Glue stacked at the corners

Case studies

Know what you can expect → Execution report

Chimney effect?



EPS pearls escaped through openings in the inner cavity wall

$U_{measured}$ = 0,476 W/m²K (+26%)

U_{calc} = 0,377 W/m²K

Conclusion

Yes, thermography has potential

General overview

Thermal bridges are clearly visible

- Avoid sun and $\theta_i - \theta_e > 10°C$ (18°F)
- Predictable locations and shape (above windows, at floors,…)

However, do not draw direct conclusions

The ease by which thermal deficiencies are recognized depends on:

Type, shape, geometry of the building, condition of the surface, location of the pattern, prior weather conditions…….

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Yes, thermography has potential

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Thermal bridges are clearly visible

- Avoid sun and $\theta_i - \theta_e > 10°C$ (18°F)
- Predictable locations and shape (above windows, at floors,…)

To indicate the location for further research with

- An endoscopy
- Destructive research

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