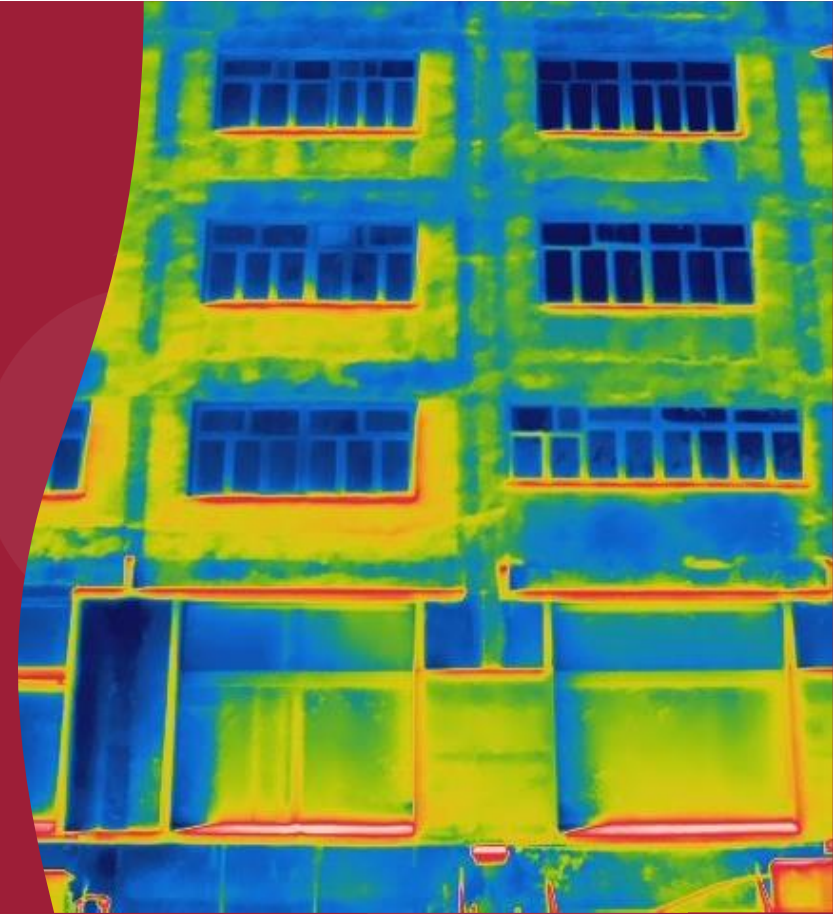


Diagnosing External Wall Debond via Infrared Thermography: the Old and New Approach

Ir Dr Wallace LAI, Lydia Chiu, Dr. Janet Sham
Department of Land Surveying and Geo-informatics
The Hong Kong Polytechnic University

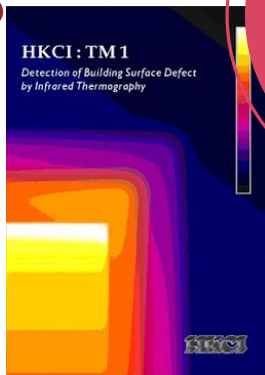


2005

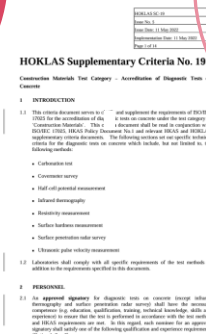


Buildings aged 30 years or above require to carry regular inspection

HKCI TM2 (Issue 1): Detection of **Building Surface Defect** by Infrared Thermography

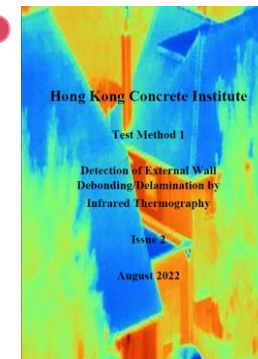


2009



HOKLAS SC19

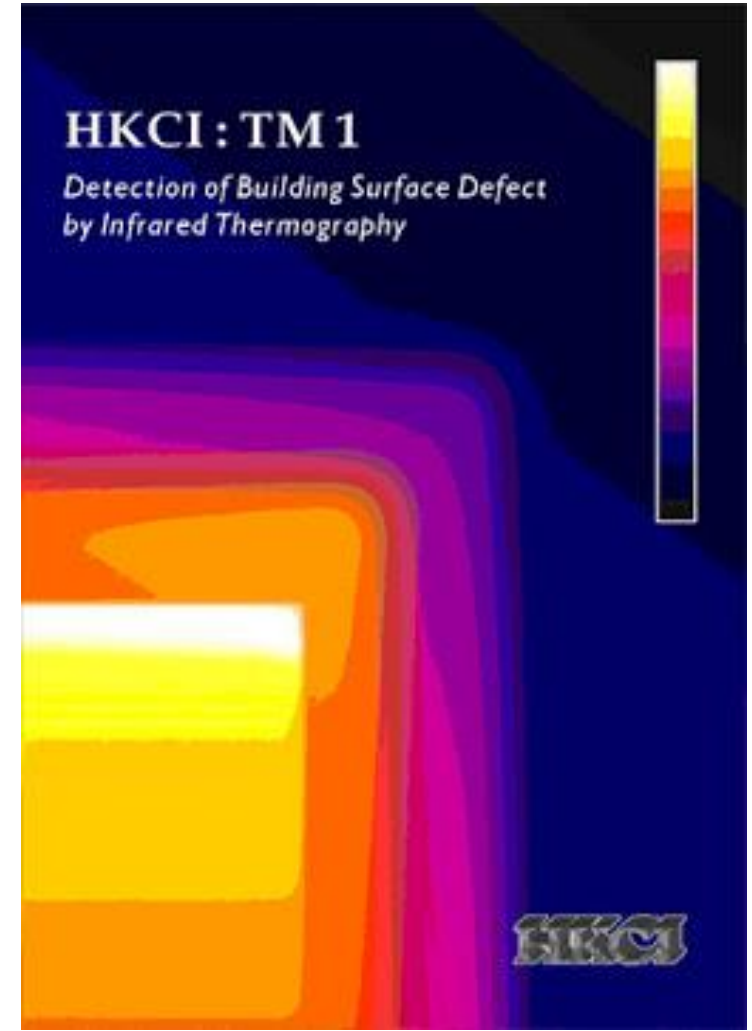
2012



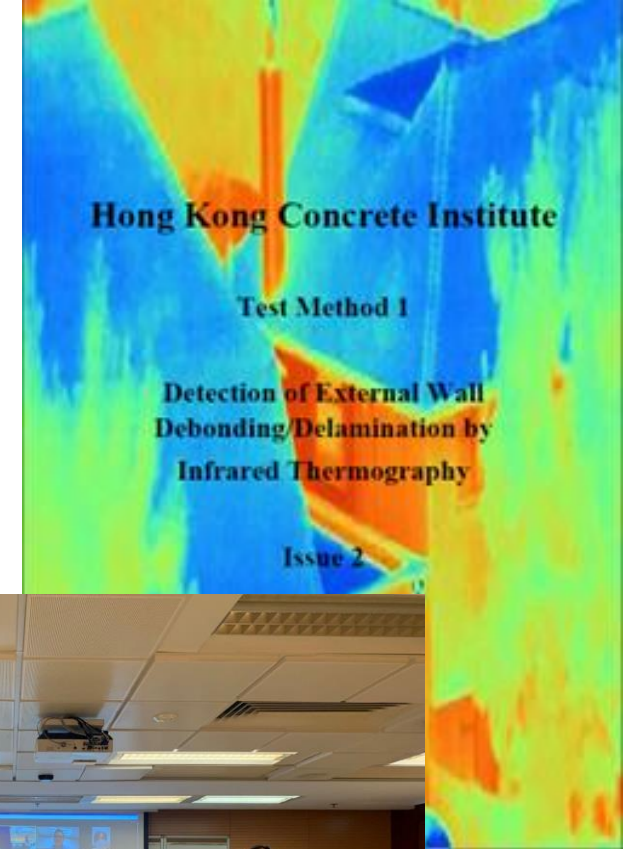
HKCI TM1 (Issue 2): Detection of **External Wall Debonding/Delamination** by Infrared Thermography

2022

- Published in 2009
- Determining constructional quality of exterior wall finishes such as rendering tiles and stones
- VTC training course:
 - Infrared Thermography for Building Diagnosis (Intermediate Level)

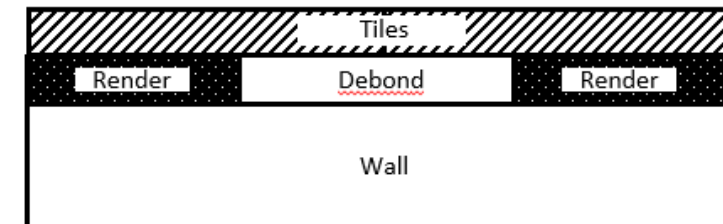
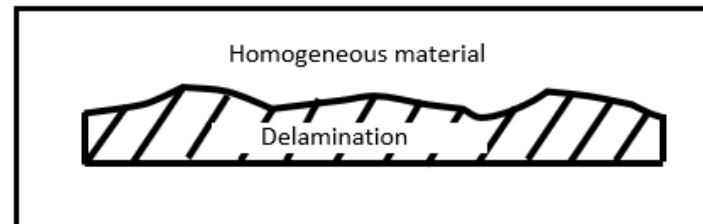
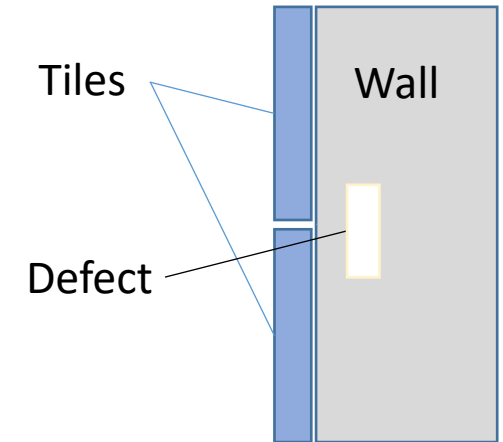
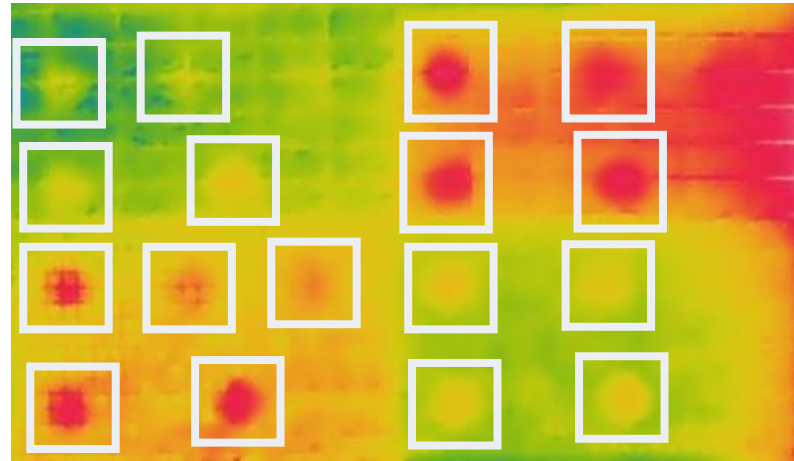


- Published in 2022
- Determining constructional quality of exterior wall finishes such as rendering, tiles and fair faced concrete
- Not suitable for low emissivity materials, e.g. metal



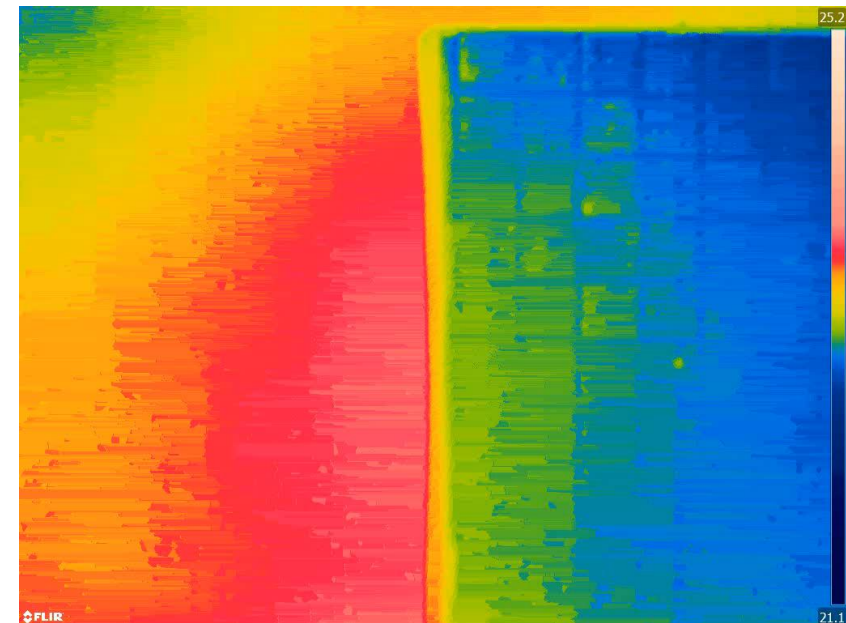
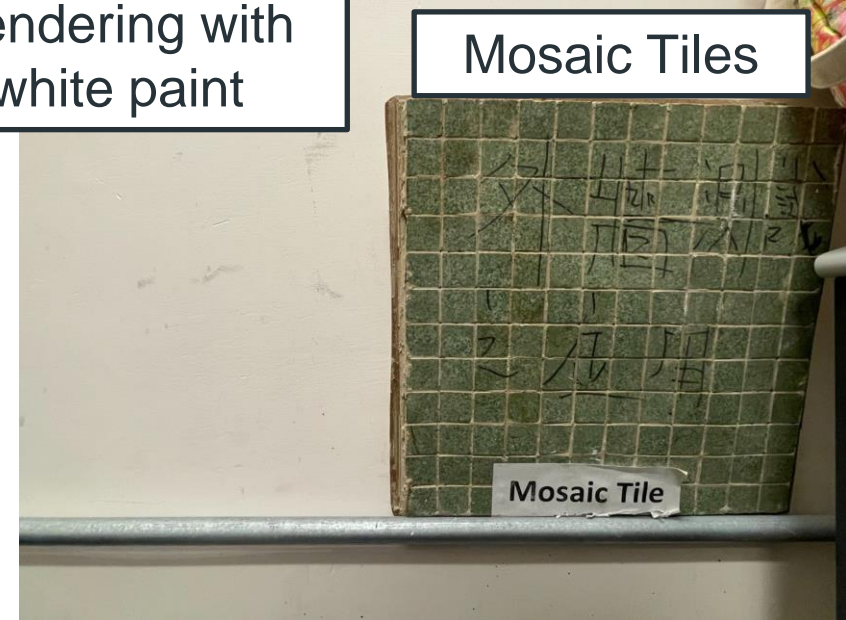
IRT Inspection

- Looks for defects
 - Delamination
 - Debond
- Defects appear in region of hot temperature



Rendering with
white paint

Mosaic Tiles



3-Dimensional Heat Conduction Equation

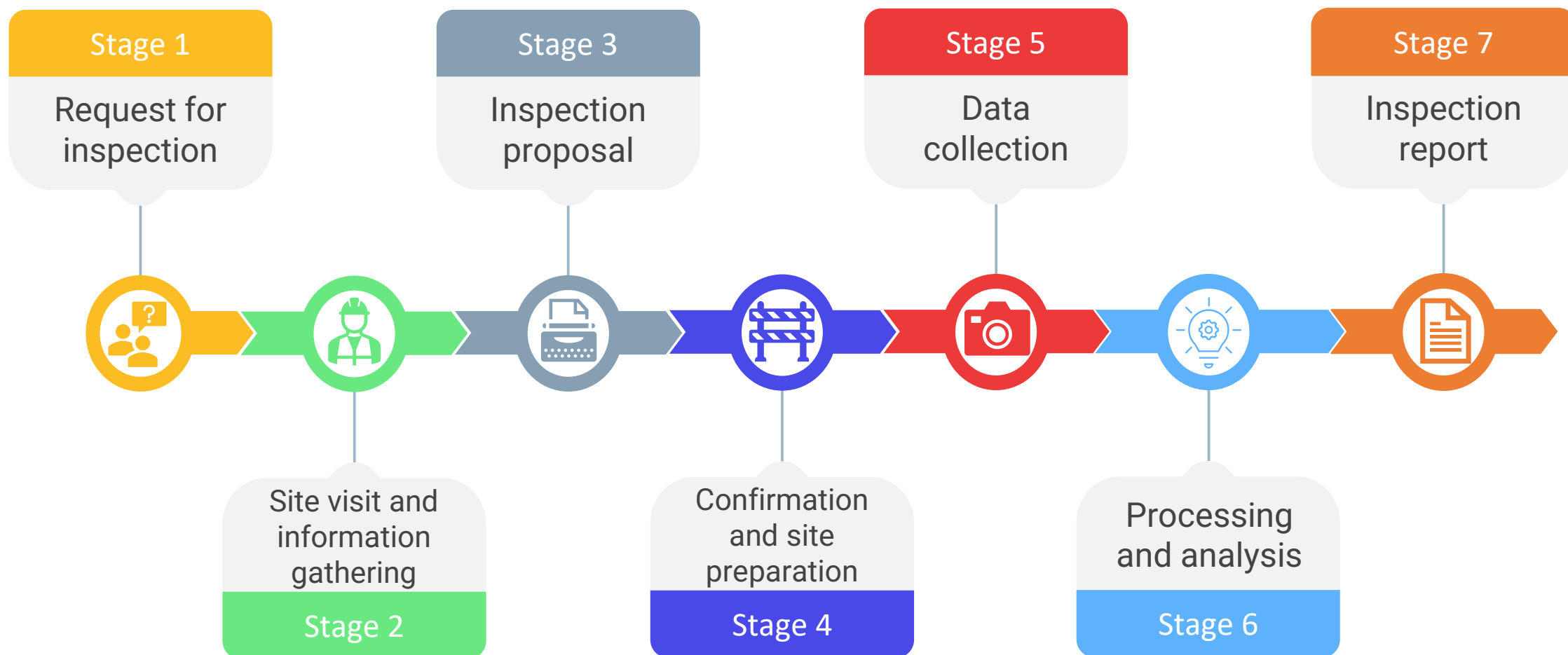
$$C\rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(k_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial T}{\partial z} \right)$$

C is specific heat (J kg⁻¹ K⁻¹)

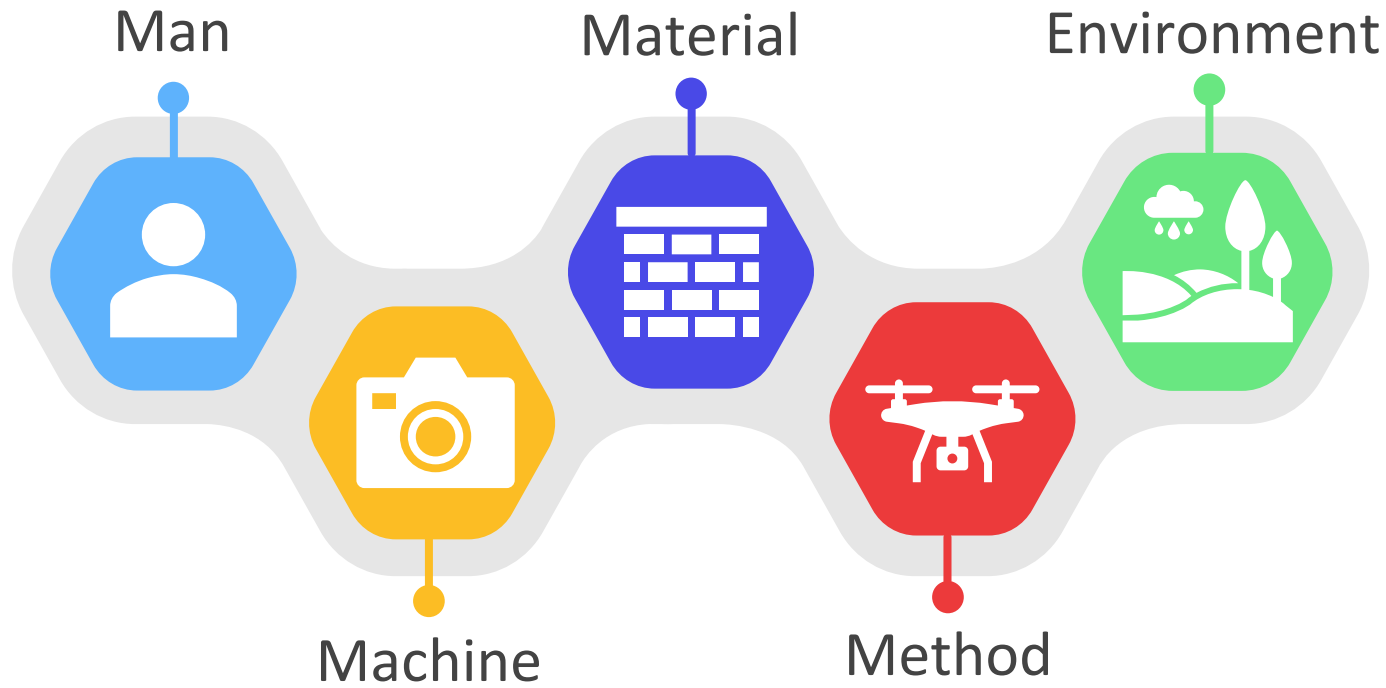
ρ is density (kg m⁻³)

k_x, k_y, k_z (W m⁻¹ K⁻¹) are the anisotropic thermal conductivities of heat transfer in the material in the x, y (lateral) and z (depth) directions

General Workflow



Factors affecting IRT Inspection

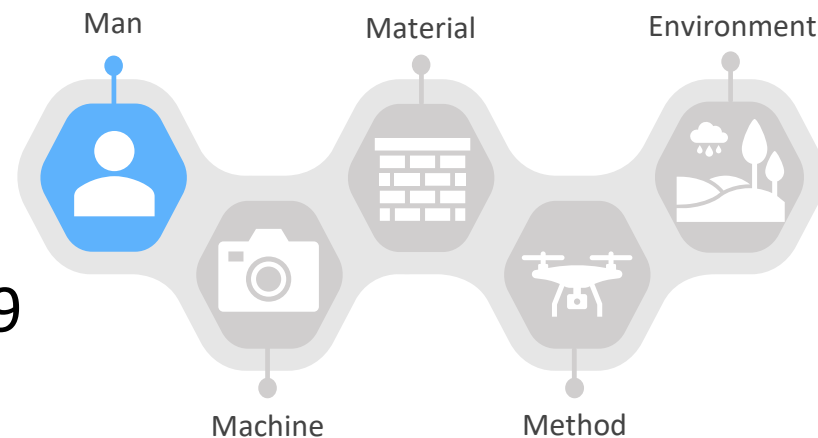


4M1E according to HKCI spec and
HOKLAS SC.19



Man – Personnel

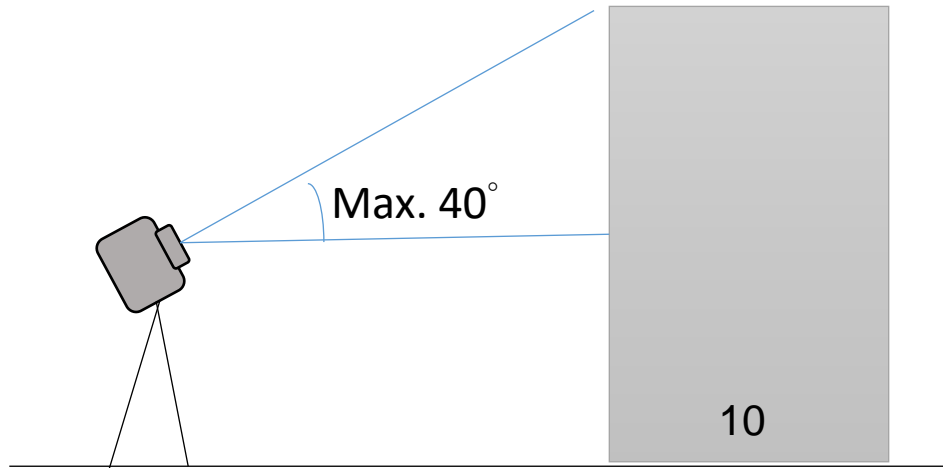
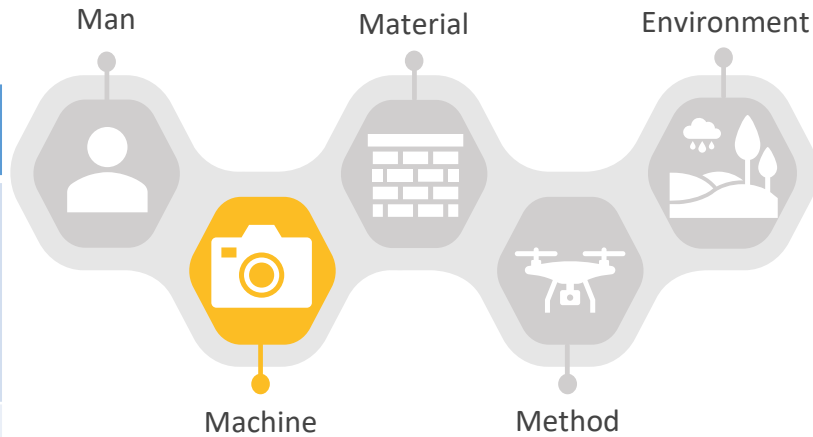
Personnel Qualifications of **signatories** and **testing personnel** are updated according to HOKLAS SC No.19



Issue 1 (2009)	Issue 2 (2022)	
Adequate training, qualifications and experience	Signatories	Testing personnel
	<ul style="list-style-type: none">• Level 2 Thermography or• Other equivalent qualifications	<ul style="list-style-type: none">• Level 1 Thermography or• Other equivalent qualifications

Machine – Instrument

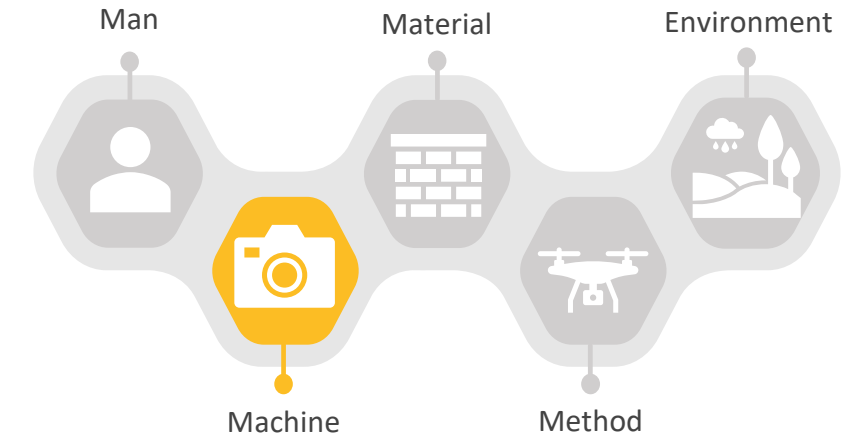
Issue 1 (2009)	Issue 2 (2022)
Spectral range: 2 – 14 μm (MWIR and LWIR) Spatial resolution (IFOV): at least 1.3 mrad	Spectral range: 7 – 14 μm (MWIR and LWIR) Spatial resolution (IFOV): at most 1.3 mrad
Angle of incidence should be $< 40^\circ$ <ul style="list-style-type: none">For high-rise buildings, robotic device (e.g. UAV) equipped with radiometric IR camera could be used	



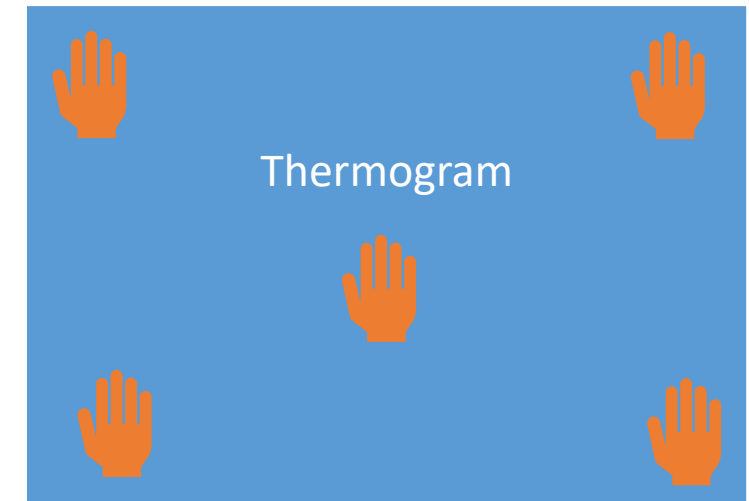
Machine – Instrument

HKCI TM1 – Issue 2 (2022)

On-site functionality test



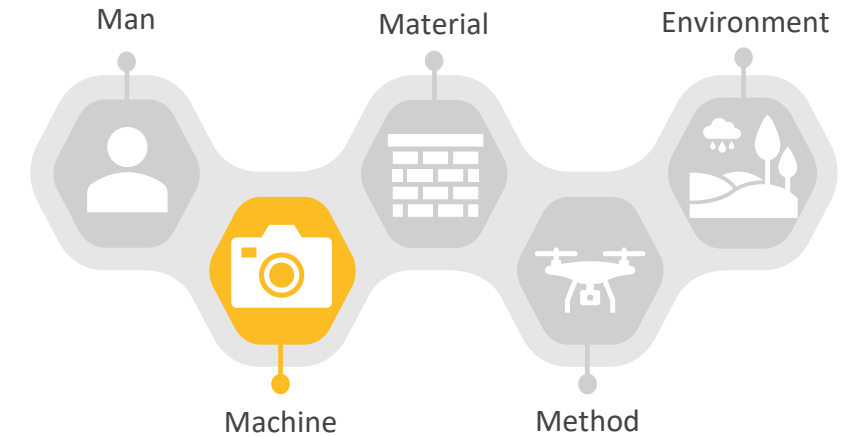
Issue 1 (2009)	Issue 2 (2022)
3-point test (if temp. diff. $\leq 2^{\circ}\text{C}$, test can be carried out; if temp. diff. $> 2^{\circ}\text{C}$, test shall not be conducted)	Recognizing a distinct object (e.g. fingers) clearly at five locations



Machine – Instrument

HKCI TM1 – Issue 2 (2022)

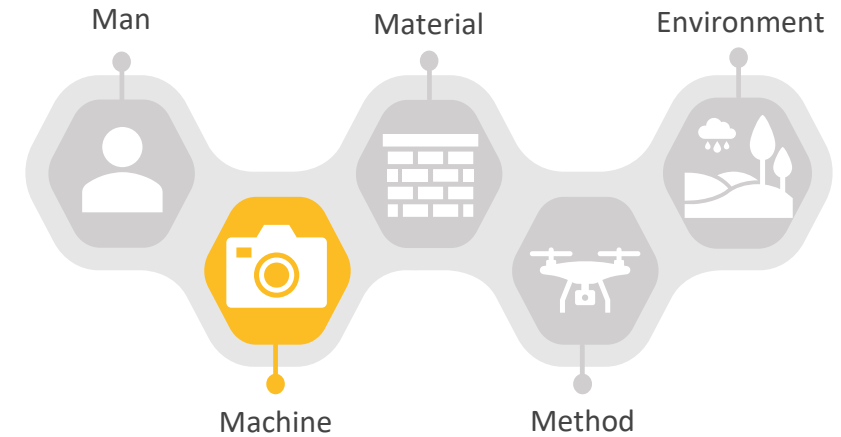
Calibration



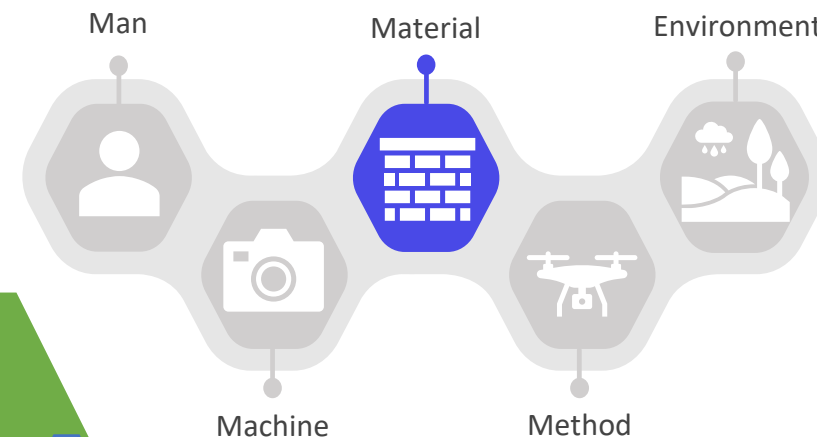
Issue 1 (2009)	Issue 2 (2022)		
Calibration of the equipment shall be performed by a recognized calibration authority.	Type of equipment	Recommended maximum period between successive calibration/verification	Recommended calibration/verification procedure
	Infrared imaging device	5 years	• Calibrate using reference black bodies
		1 year	• Carry out the uniformity check on a flat target with a high emissivity (at least 0.9)
		Before each test	• Check the working performance, e.g. fingerprint test

Machine – Instrument

Issue 1 (2009)	Issue 2 (2022)
<p>Accuracy requirement for these equipment:</p> <ul style="list-style-type: none">• Angle measuring device: N/A• Temperature measuring device: $\pm 0.5^{\circ}\text{C}$• Wind speed measuring device: $\pm 1.2\text{m/s}$• Relative humidity measuring device: $\pm 3\%$	<p>Calibration for these equipment are <u>optional</u>:</p> <ul style="list-style-type: none">• Angle measuring device• Temperature measuring device• Wind speed measuring device• Relative humidity measuring device



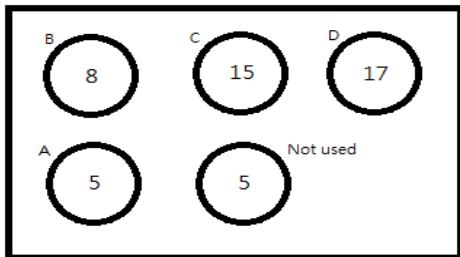
Material – Target



Depends on the emissivity of the material

Factors affecting IRT Inspection

Material – Target

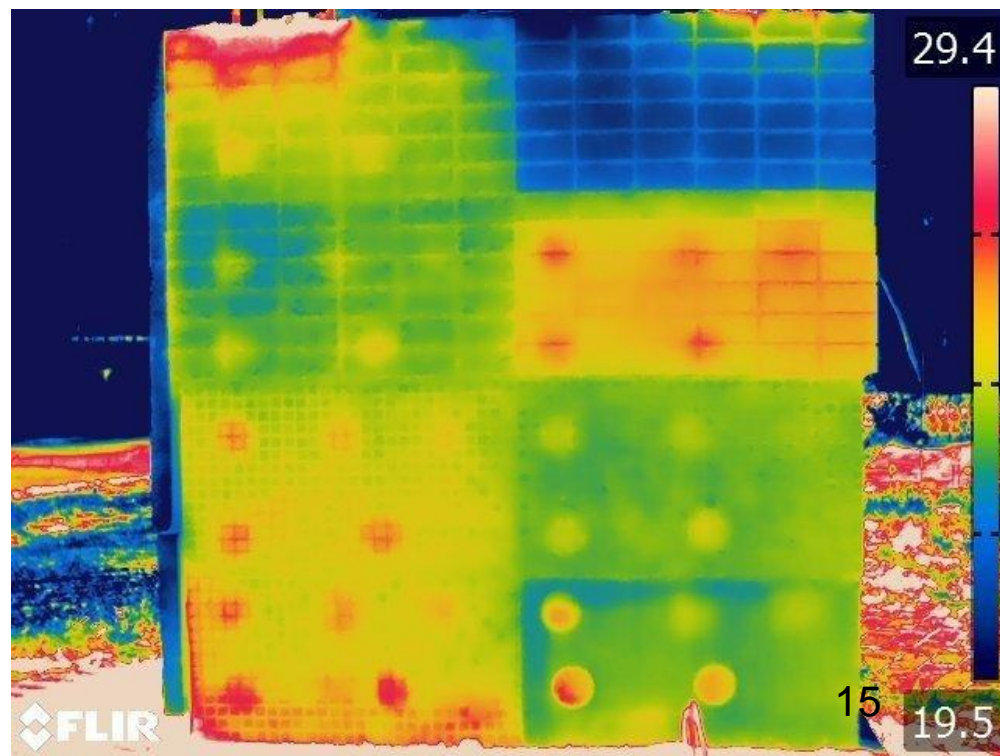
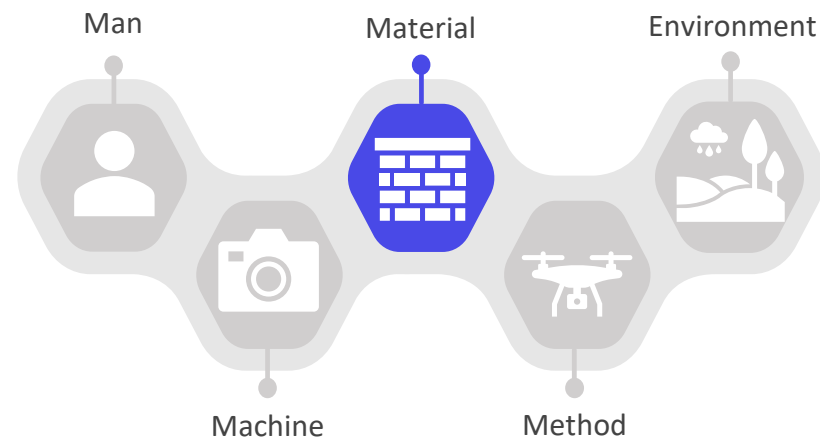


8 demonstrates the depth of debond (in mm)

- Tile: Matt Black
Size: 95mm x 45mm
- Tile: Grey Ceramic
Size: 95mm x 45mm
- Tile: Blue Mosaic
Size: 19mm x 19mm
- Tile: Mixed-color Mosaic
Size: 19mm x 19mm



- Tile: Reflective White
Size: 95mm x 45 mm
- Tile: Smooth Black
Size: 95mm x 45 mm
- Tile: White Mosaic
Size: 19mm x 19 mm
- Tile: Fair-face Concrete
Size: N/A

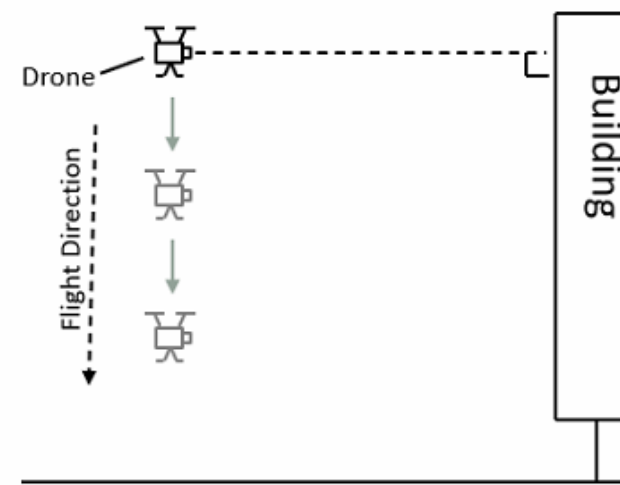
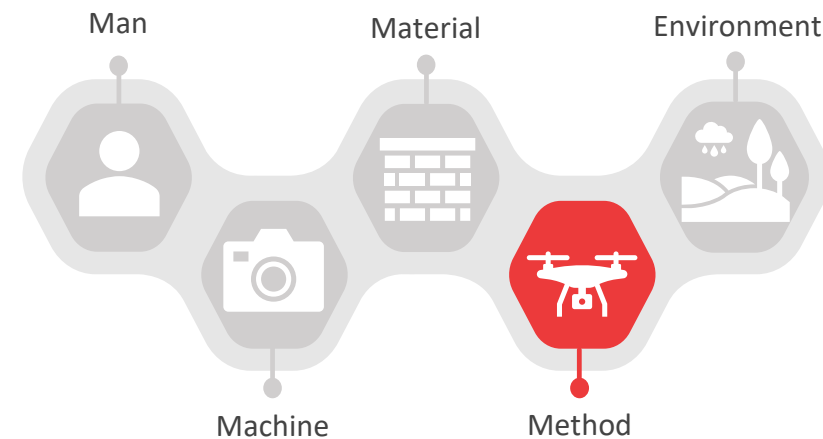
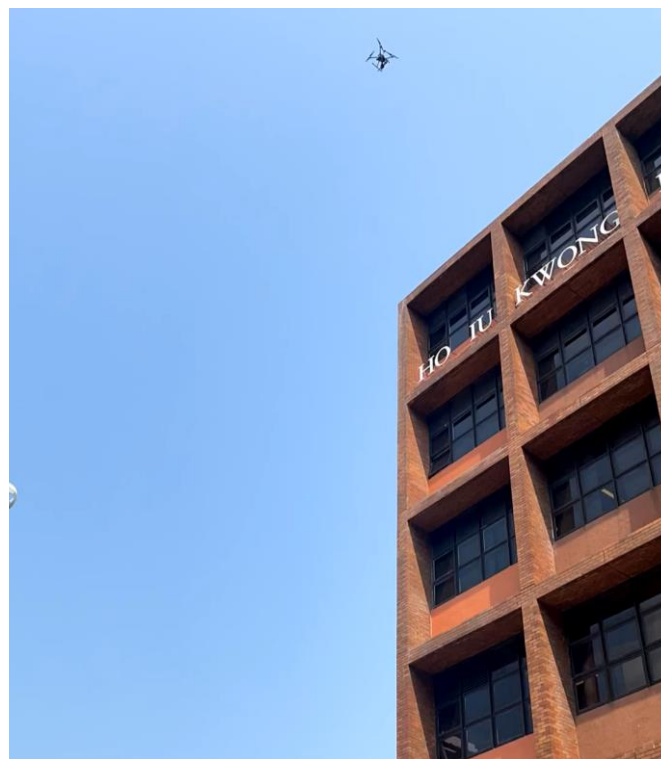


Factors affecting IRT Inspection

Method

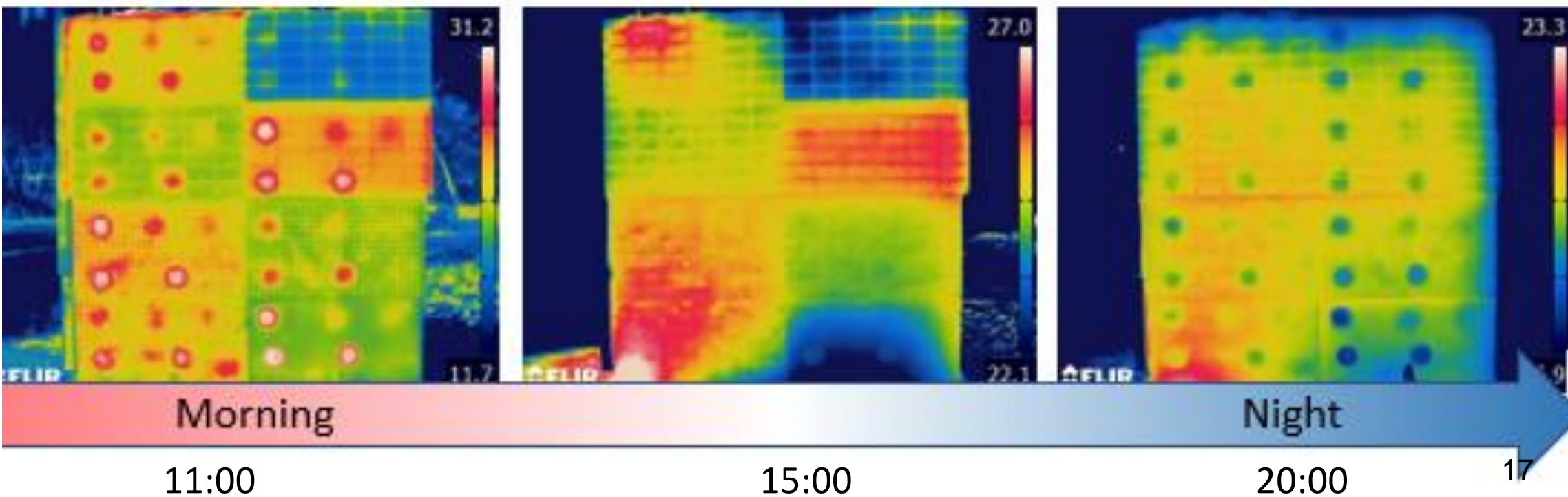
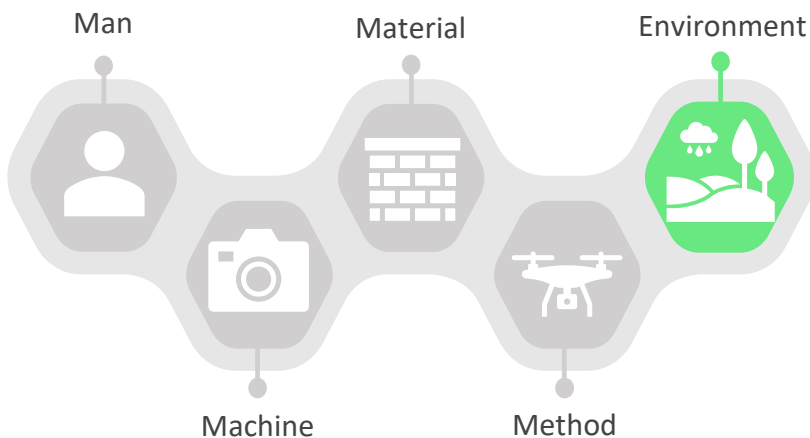
Issue 1 (2009)	Issue 2 (2022)
Ground-based	Ground-based or UAV

Normal case – ground-based High-rise buildings – with UAV



Environment

Time Factor



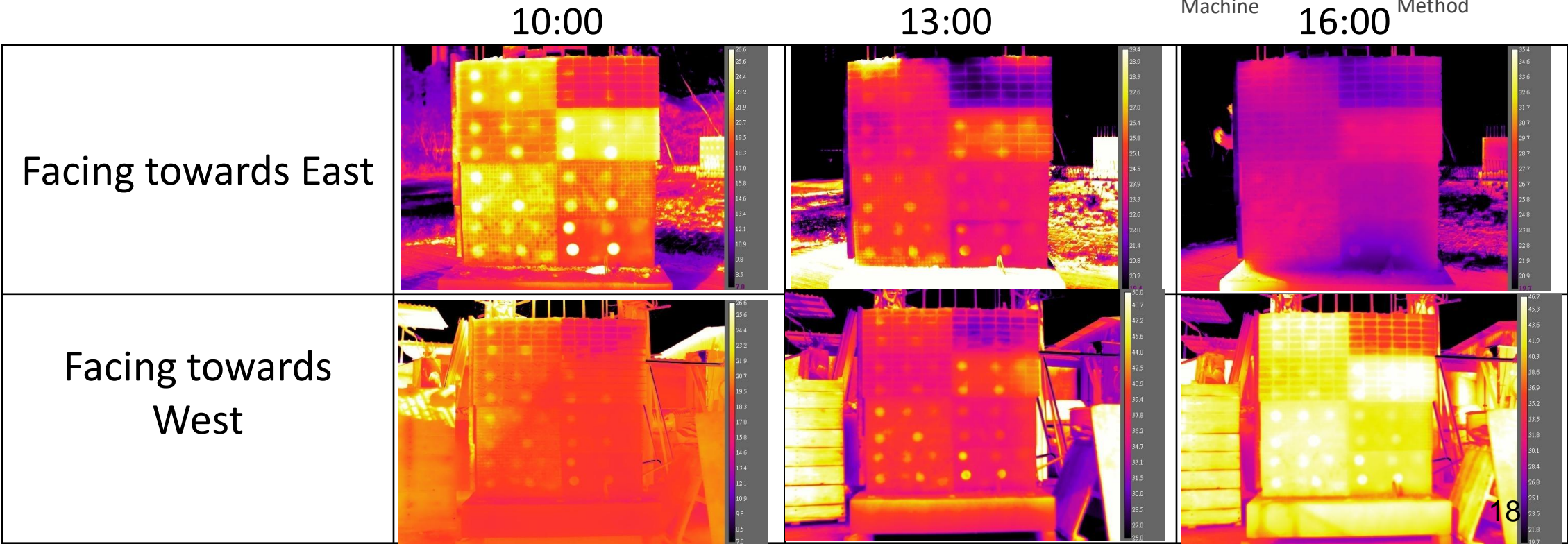
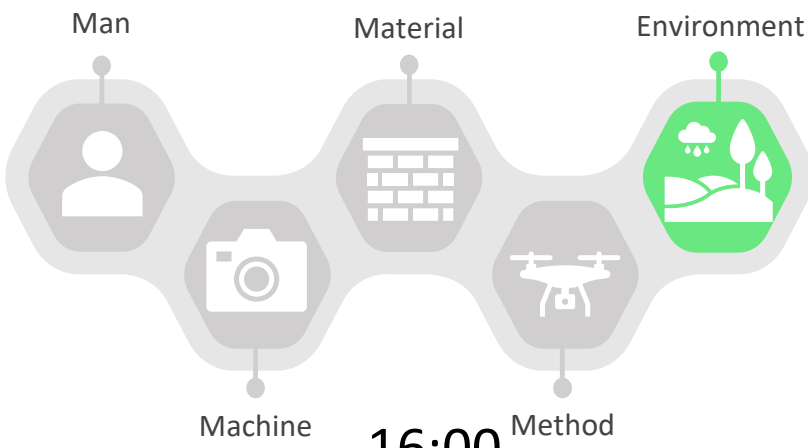
Factors affecting IRT Inspection



Environment

Orientational Factor

Issue 1 (2009)	Issue 2 (2022)
Orientation shall be considered in qualitative evaluation.	



Factors affecting IRT Inspection

Environment

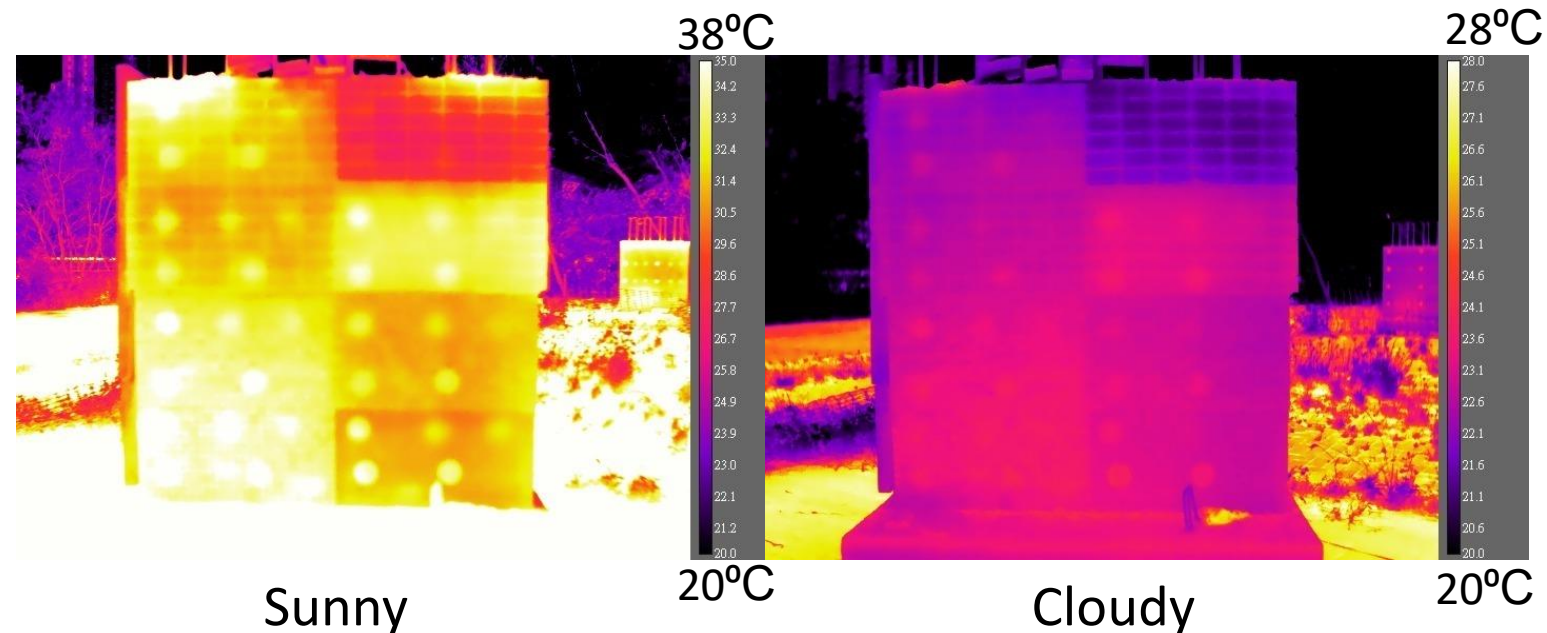
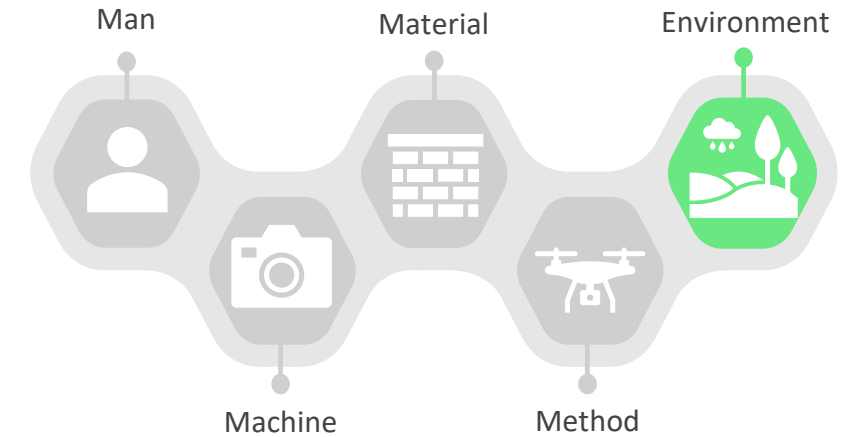
HKCI TM1 – Issue 2 (2022)

Fine Weather

- Cloud coverage: $< 6/8$
 - Wind speed: $< 6.5 \text{ m/s}$
 - 2-3 days prior to survey
- **at least 12 hours** prior to survey

Bad Weather (i.e. cloudy)

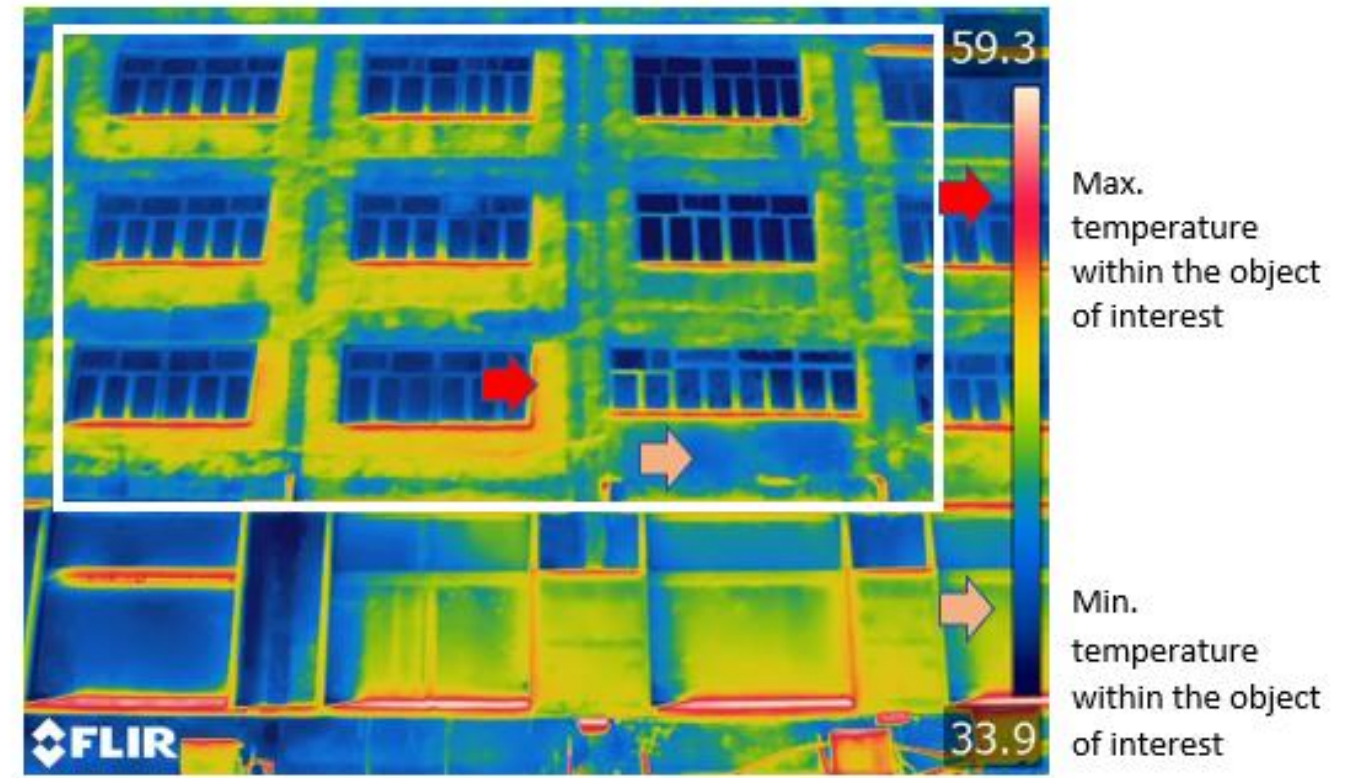
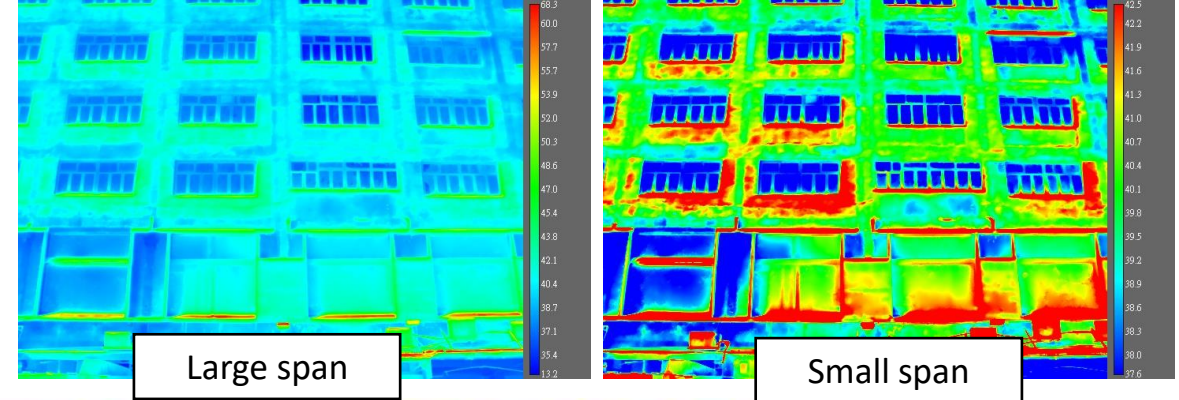
- Haphazard adjustment of temperature bar



Infrared Image Interpretation

HKCI TM1 – Issue 2 (2022)

- Temperature span: max. and min. temperature within objects of interest
- Evenly/linearly distributed colour palette



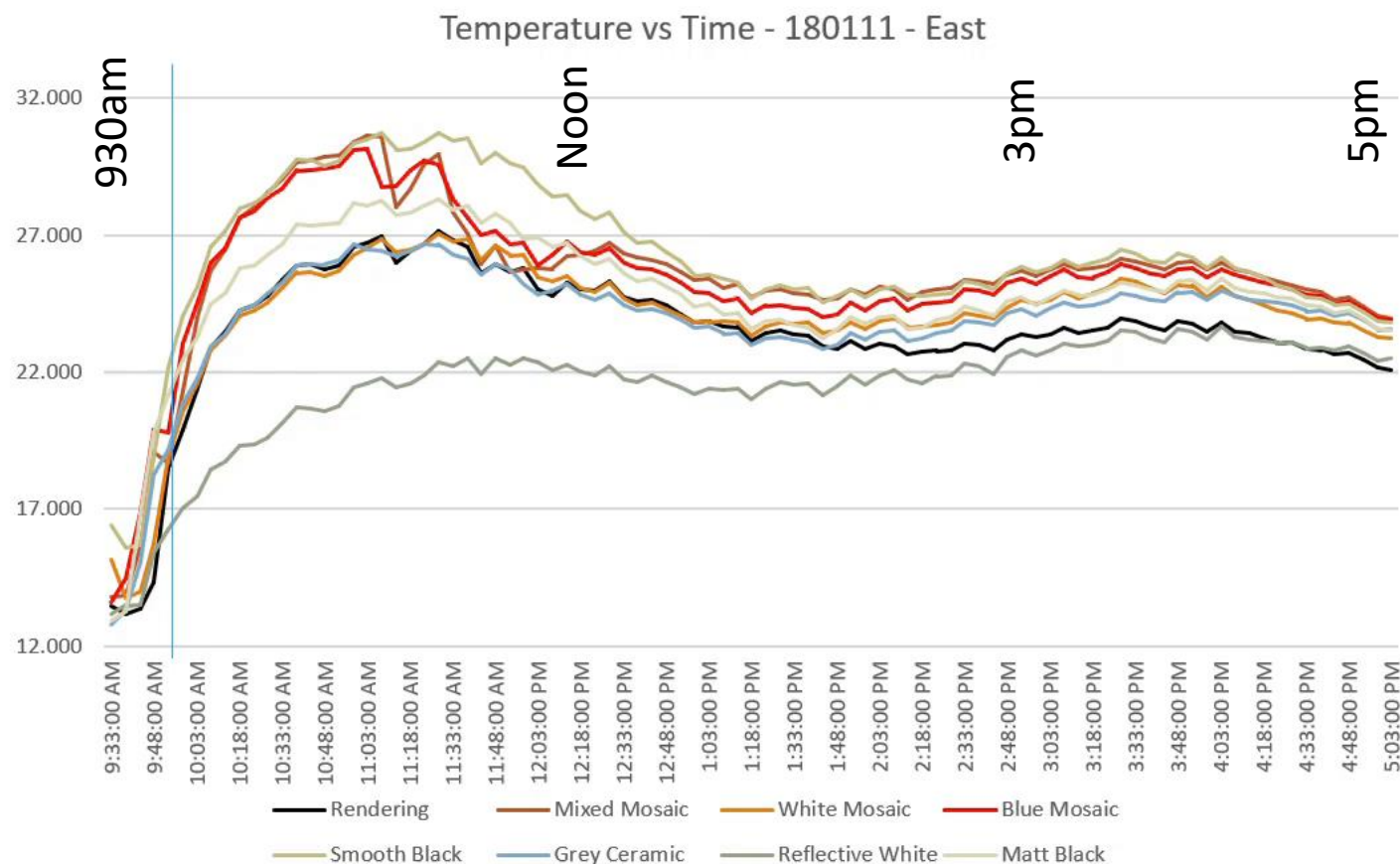
HKCI TM1 – Issue 2 (2022)

Commonly found limitations: only in Issue 2

Limitations	Reasons of declaring 'Survey Unreliable'	Reasons of declaring 'Survey not successful'
A. Reflections from other sources	Applicable	Applicable
B. Insufficient thermal contrast	Applicable	Applicable
C. Unable to gain access	Not Applicable	Applicable
D. Angle of inclination	Not Applicable	Applicable

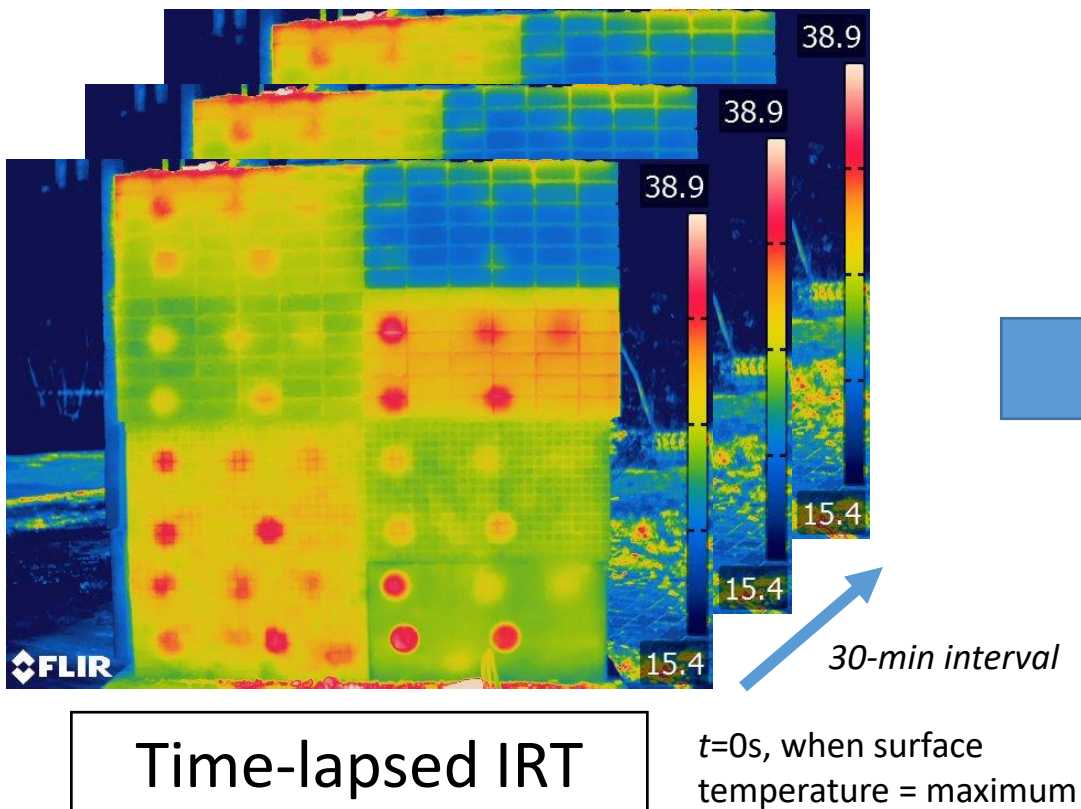
Future Approach – Time-lapse Analysis

Different material → Difference in cooling rate

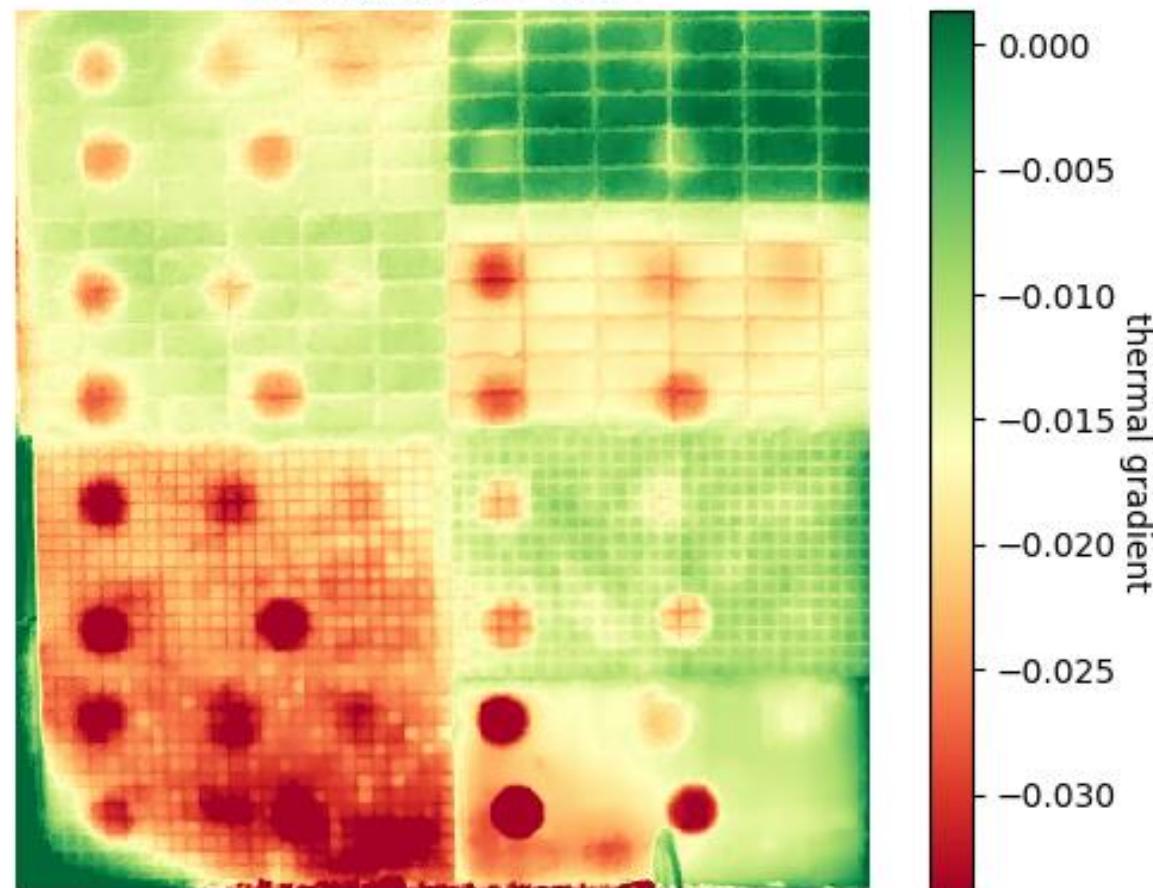


Thermograms taken in every 5 mins

Future Approach – Time-lapse Analysis



Thermal Gradient Map
with Normalized Natural Logarithmic Base -
Cooling Phase - 2SD

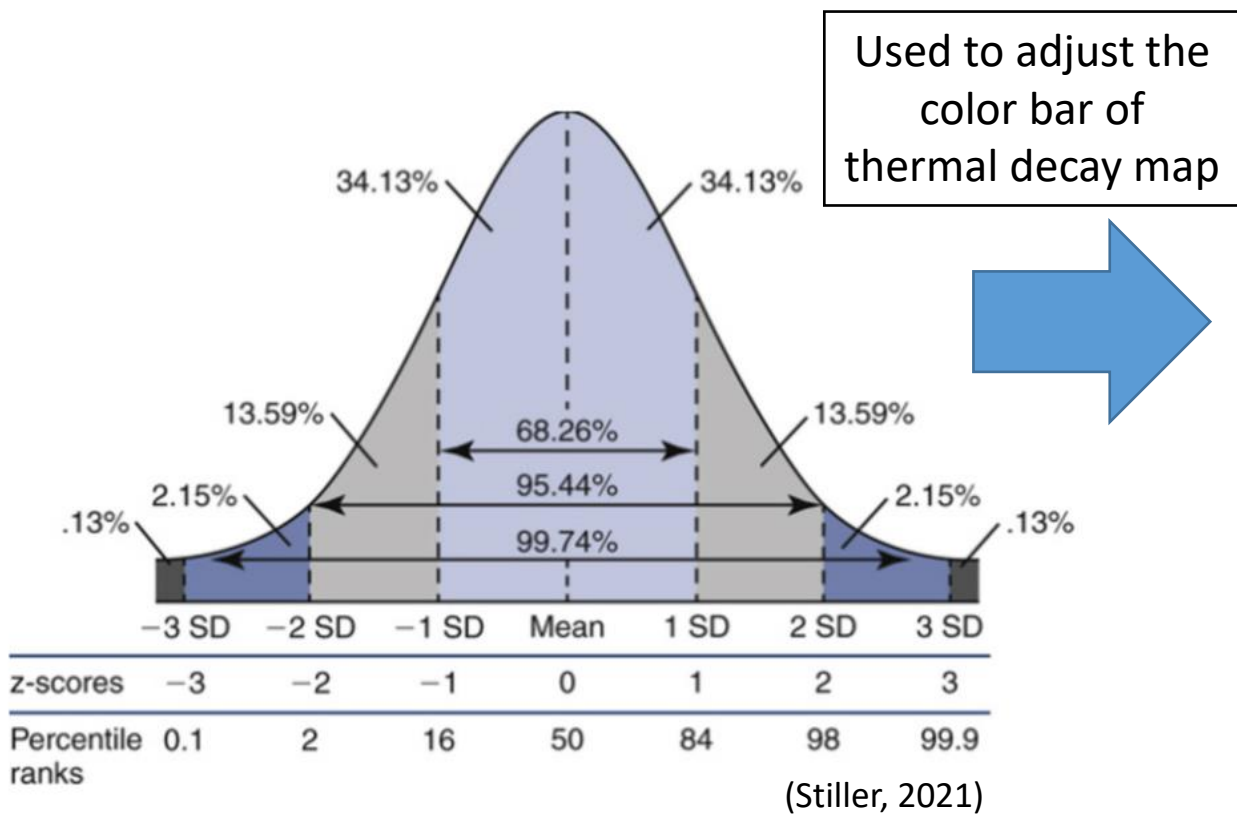


Thermal Decay Mapping

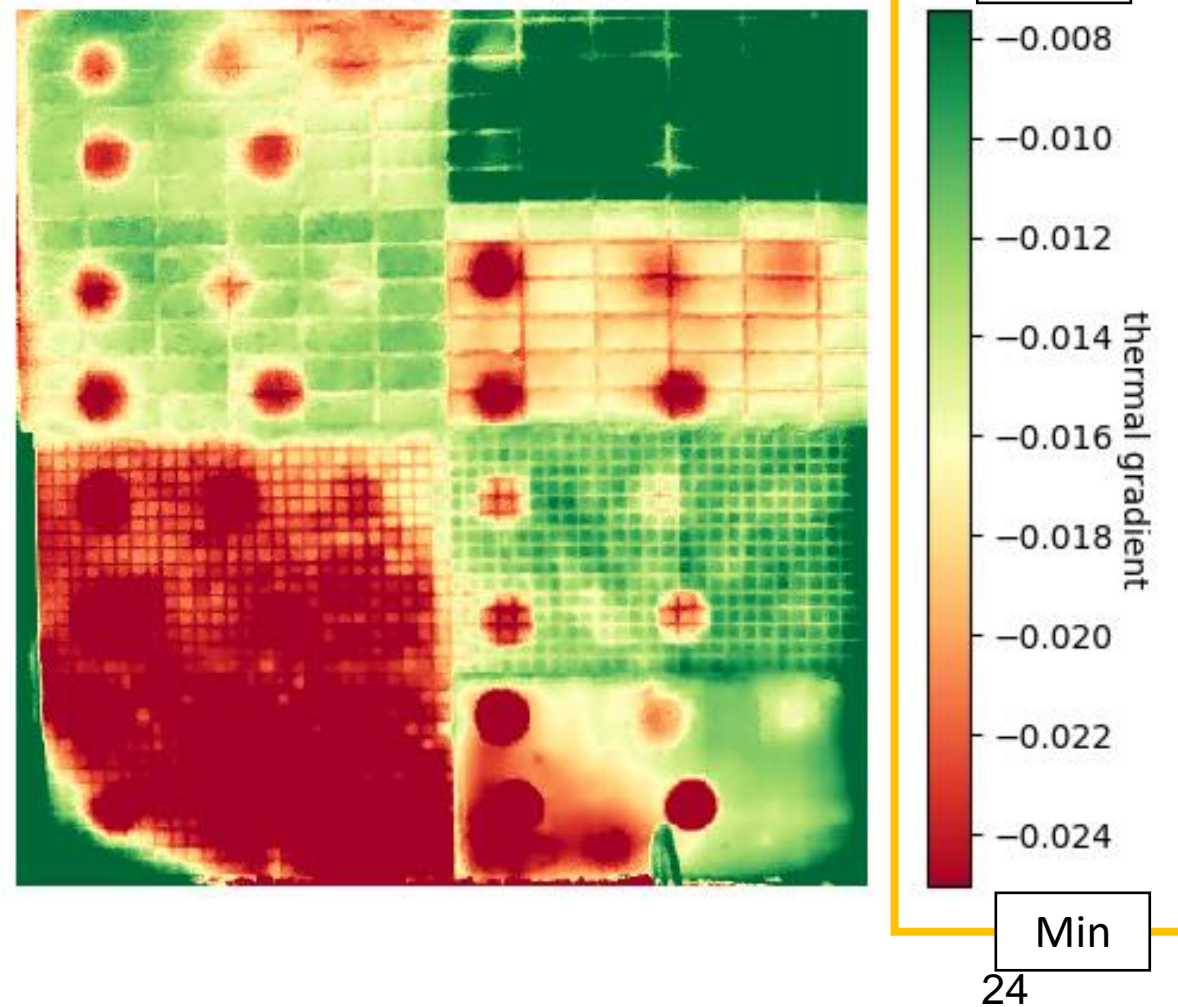
Future Approach – Time-lapse Analysis

SD

$$\begin{aligned} \max &= \text{Mean}_G + n \times \text{SD}_G \\ \min &= \text{Mean}_G - n \times \text{SD}_G \end{aligned}$$



Thermal Gradient Map
with Normalized Natural Logarithmic Base -
Cooling Phase - 1SD



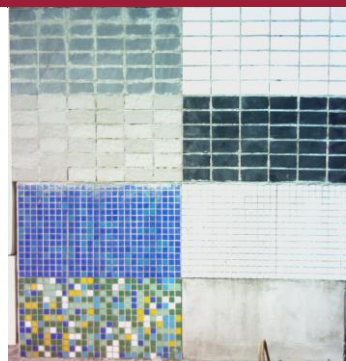
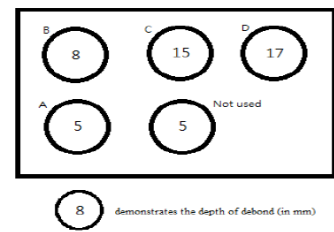
Future Approach – Time-lapse Analysis



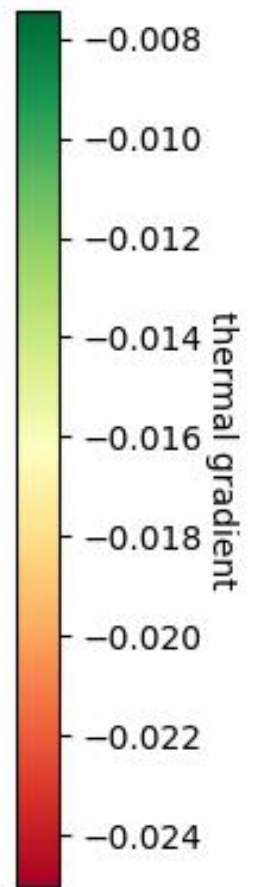
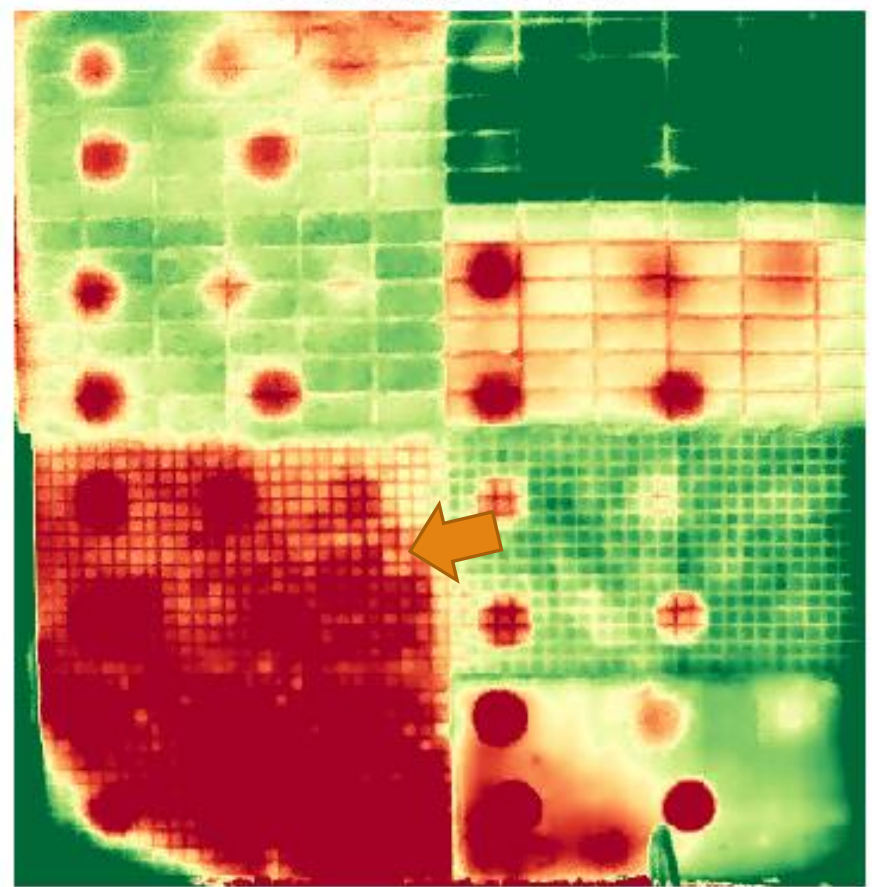
Date: 2018/01/11
Orientation: East
Average Temperature:
12.1 – 16.1°C

Material: Overall
Time: 11:28 – 13:33
No. of images: 26

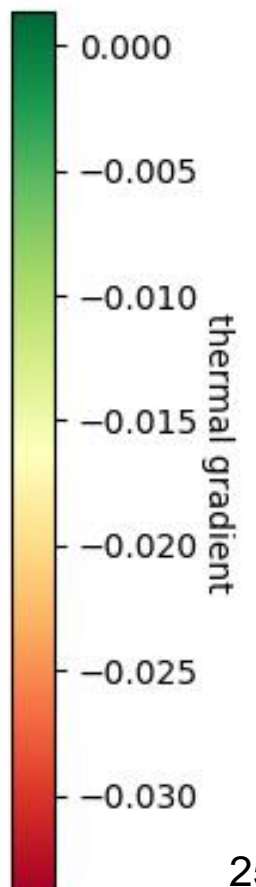
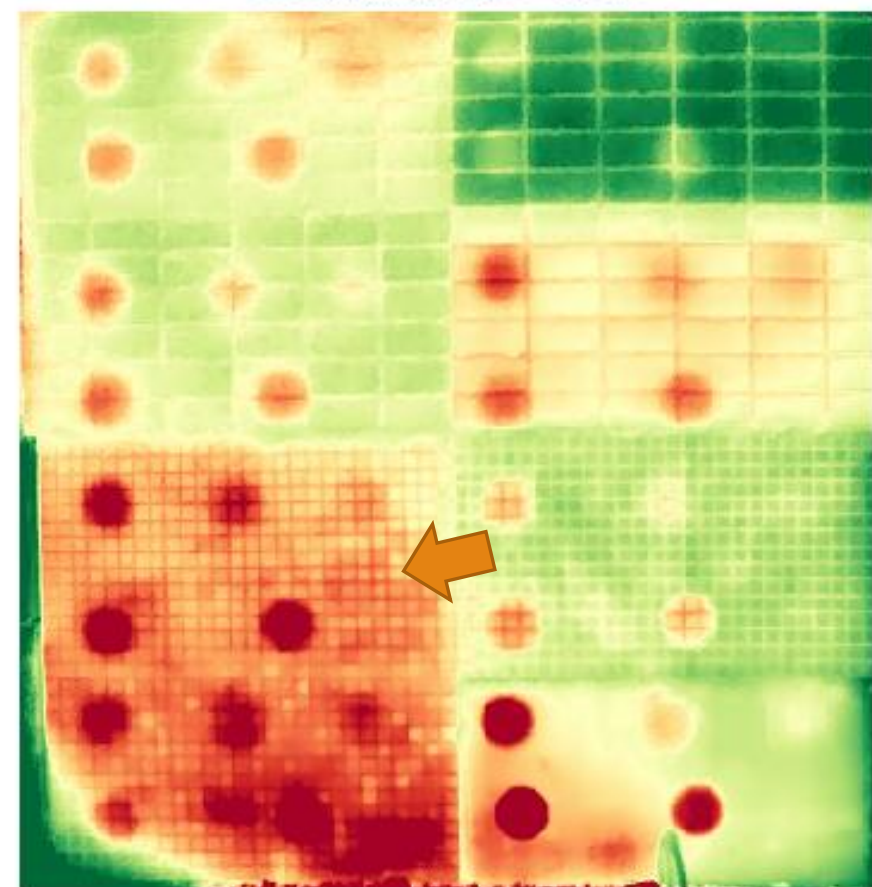
More defects shown
when number of SD
increases.



Thermal Gradient Map
with Normalized Natural Logarithmic Base -
Cooling Phase - 1SD



Thermal Gradient Map
with Normalized Natural Logarithmic Base -
Cooling Phase - 2SD



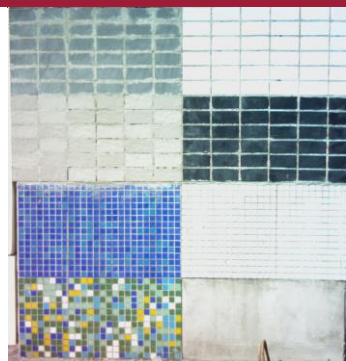
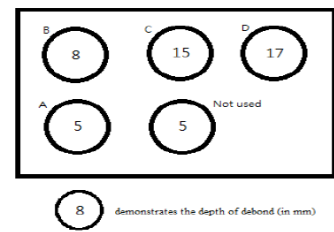
Future Approach – Time-lapse Analysis



Date: 2018/01/11
Orientation: East
Average Temperature:
12.1 – 16.1°C

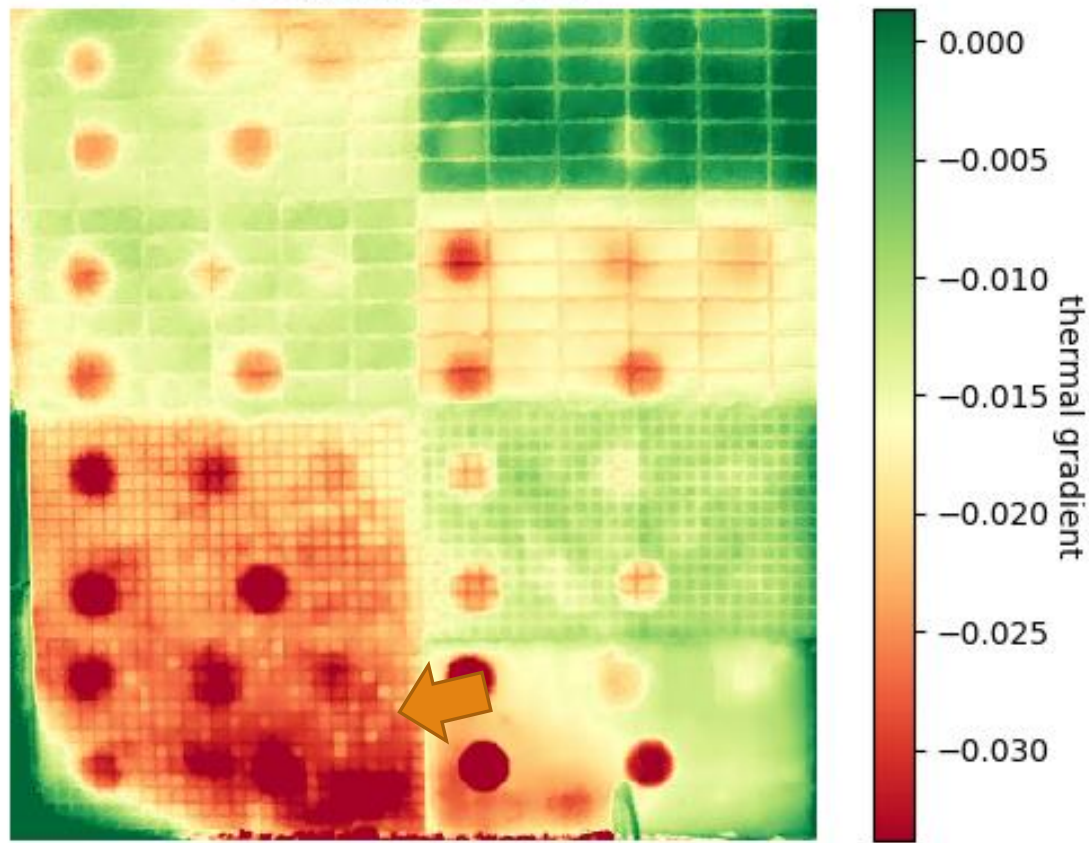
Material: Overall
Time: 11:28 – 13:33
No. of images: 26

More defects shown
when number of SD
increases.



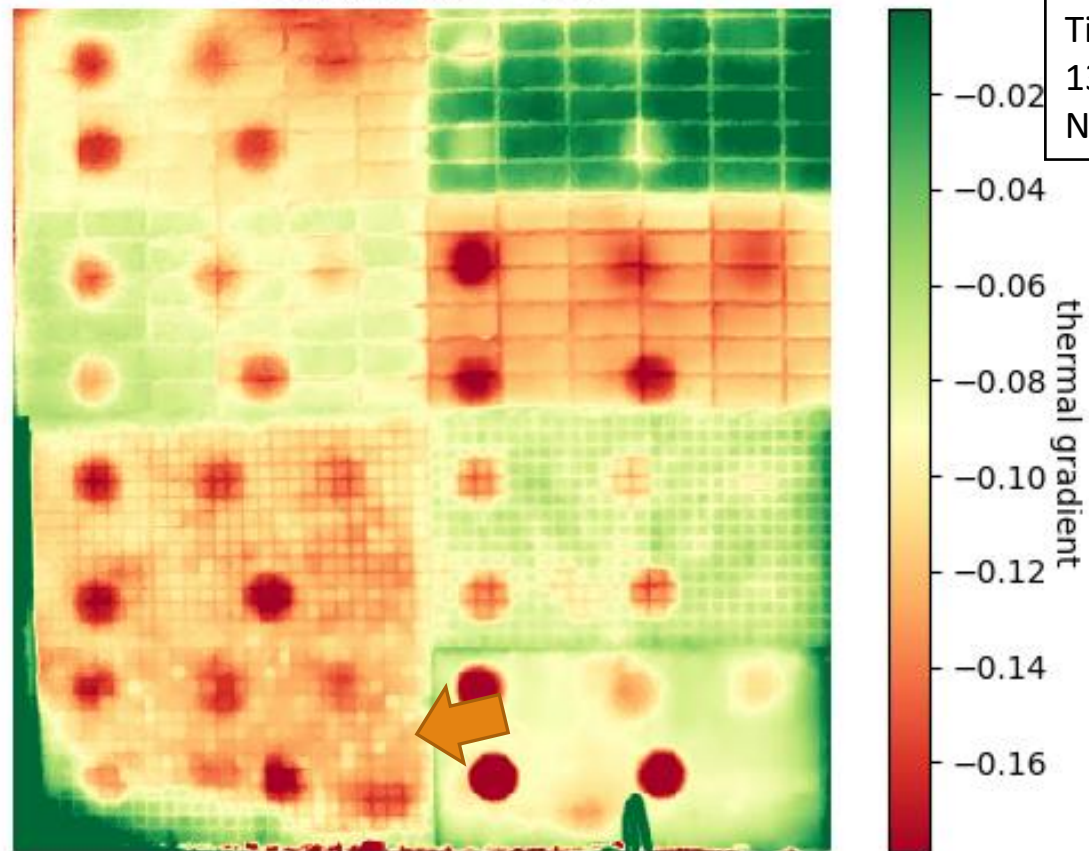
Thermal Gradient Map
with Normalized Natural Logarithmic Base -
Cooling Phase - 2SD

Time: 11:28 – 13:33
No. of images: 26

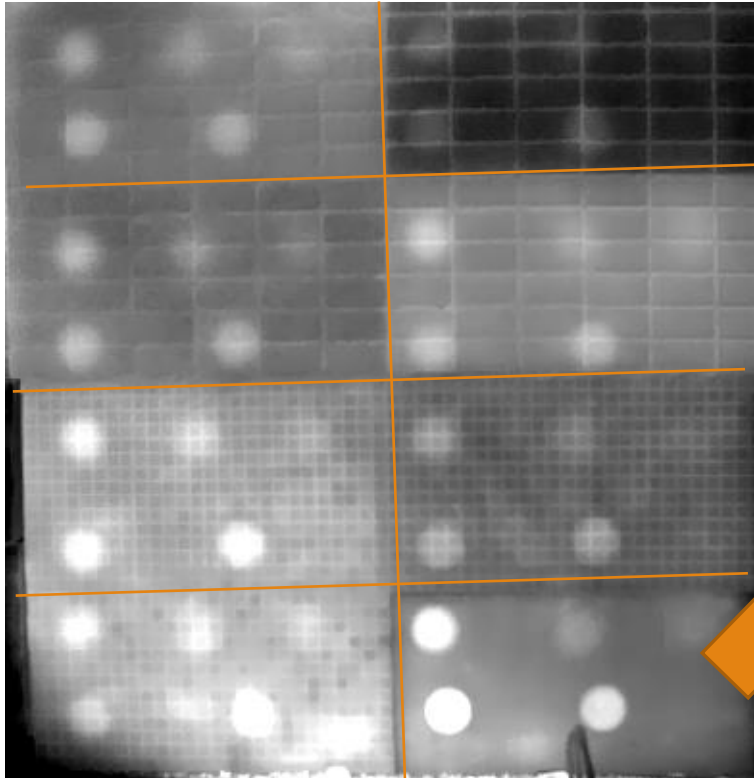


Thermal Gradient Map
with Normalized Natural Logarithmic Base -
Cooling Phase - 2SD

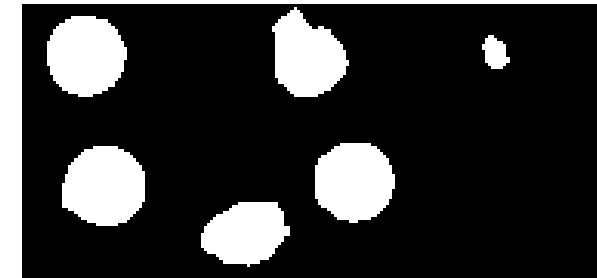
Time: 11:28 &
13:33
No. of images: 2



Future Approach – Time-lapse Analysis



Thermal decay map are separated into 8 sections according to materials

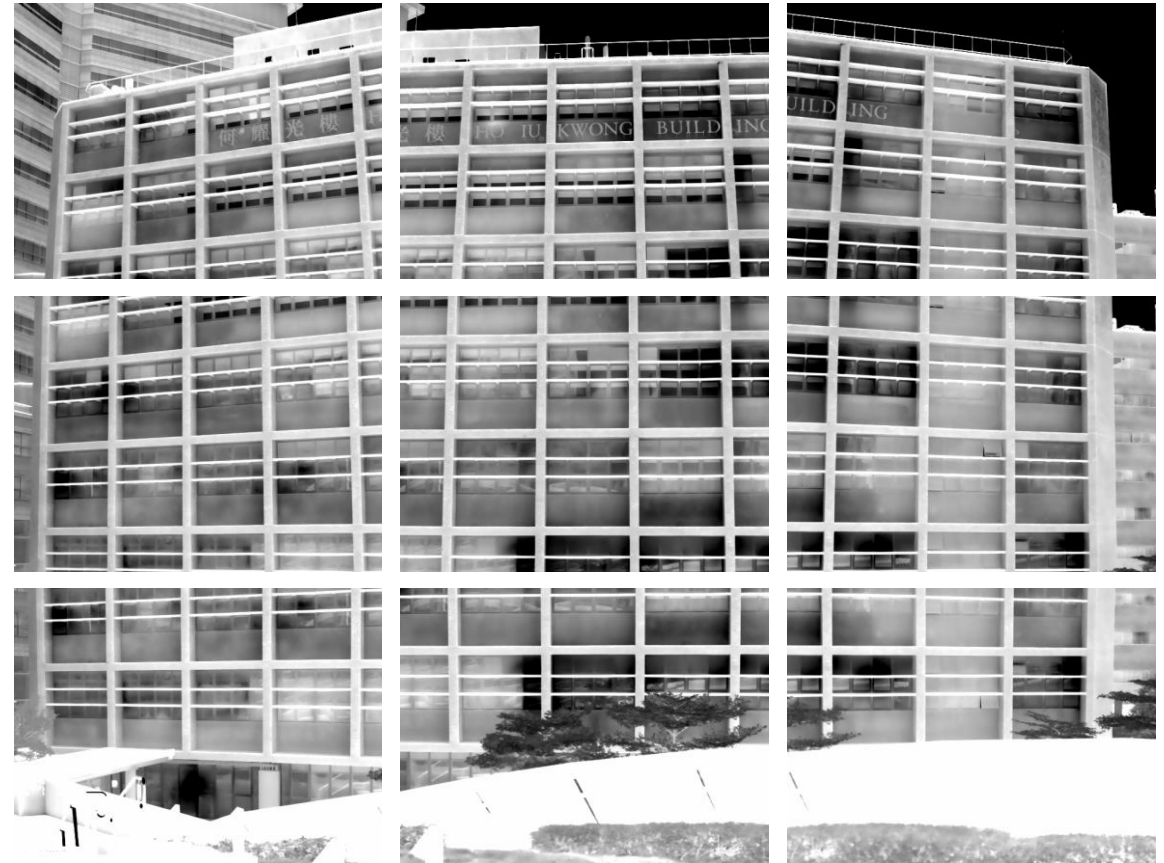


Threshold binary image for size estimation

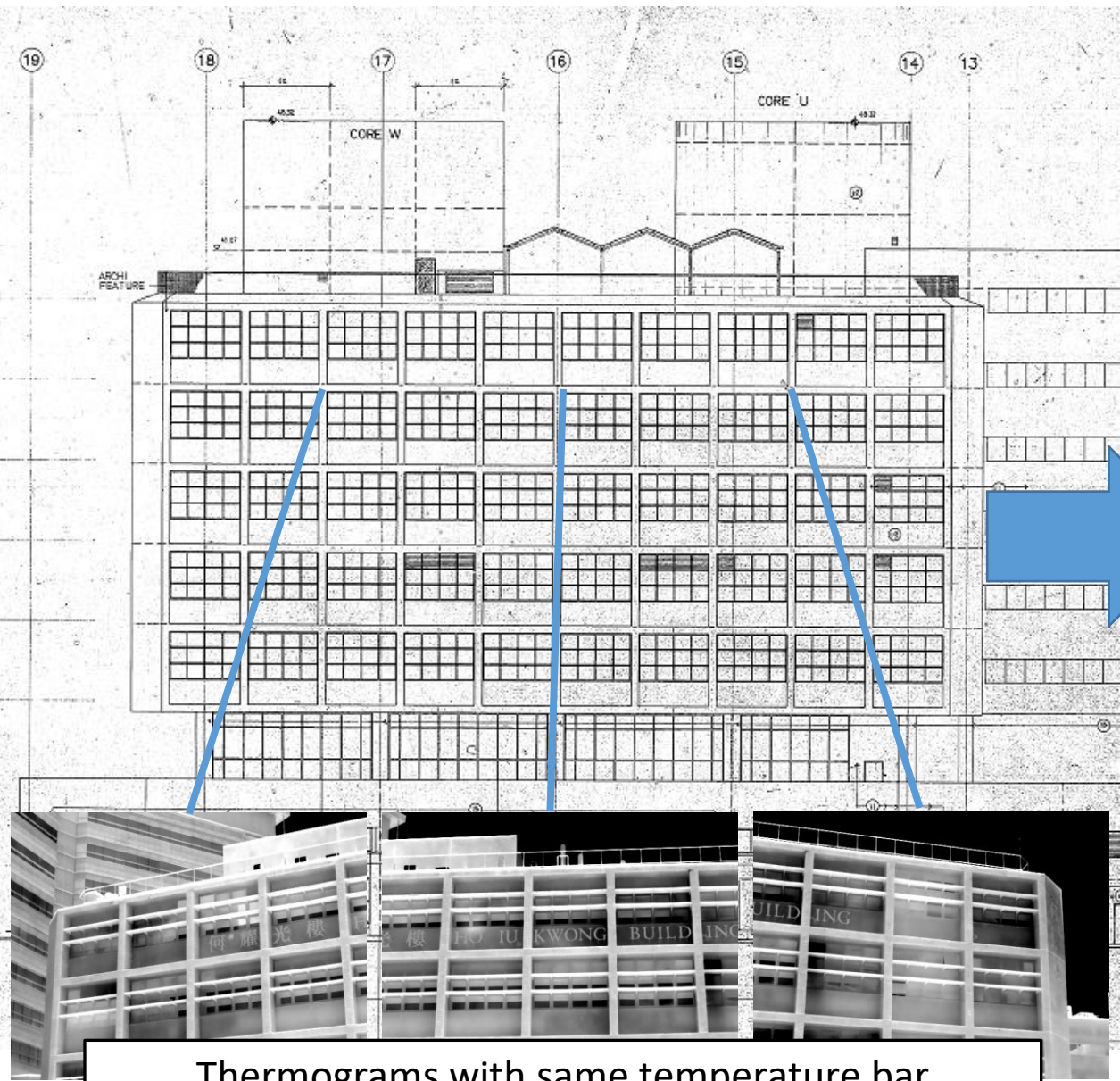
HKCI TM1 – Issue 2 (2022)

Max. no. of storeys to be covered = 4-5 storeys

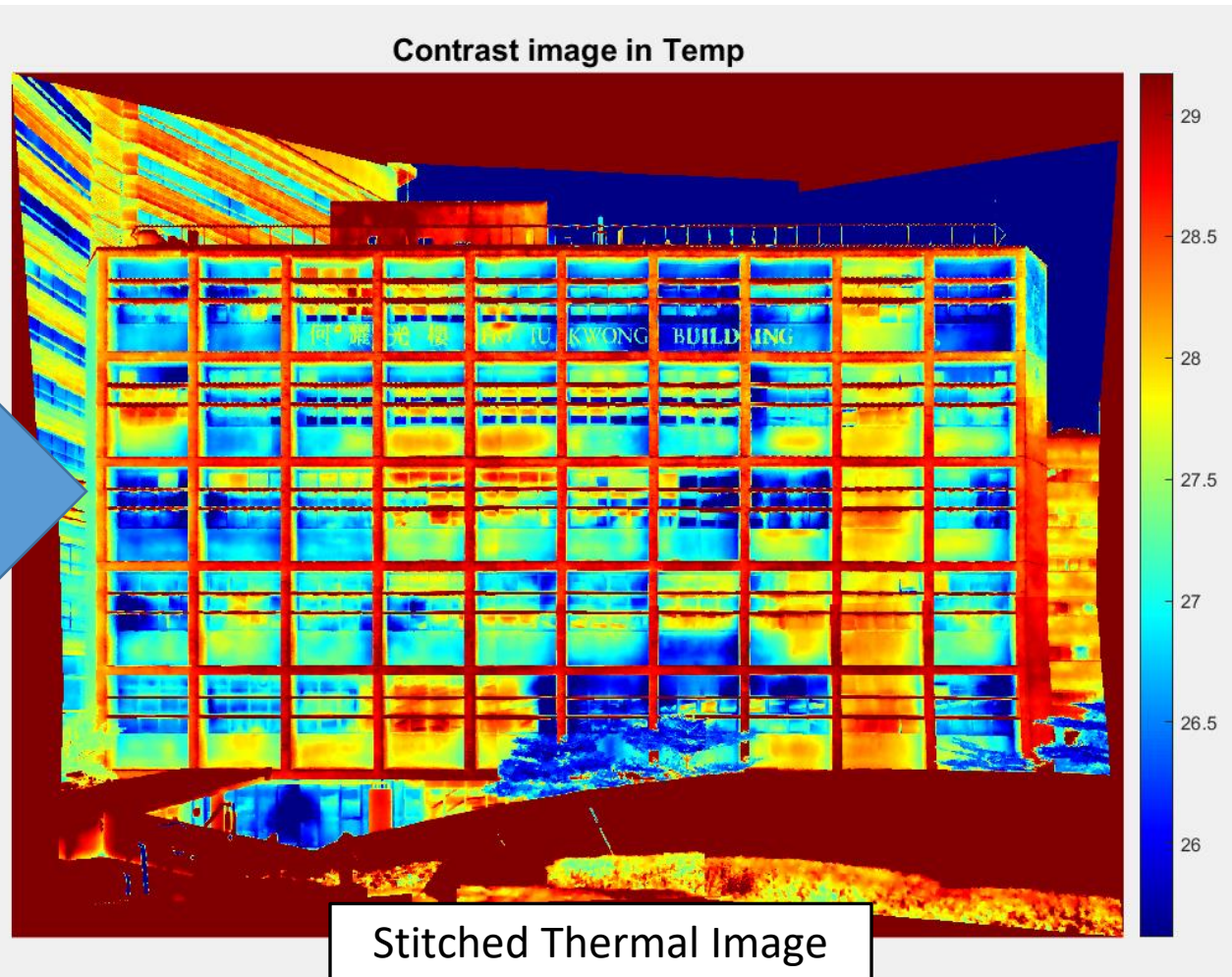
→ Needs to be separated into different sections to cover the whole wall



Future Approach – Thermal Image Stitching



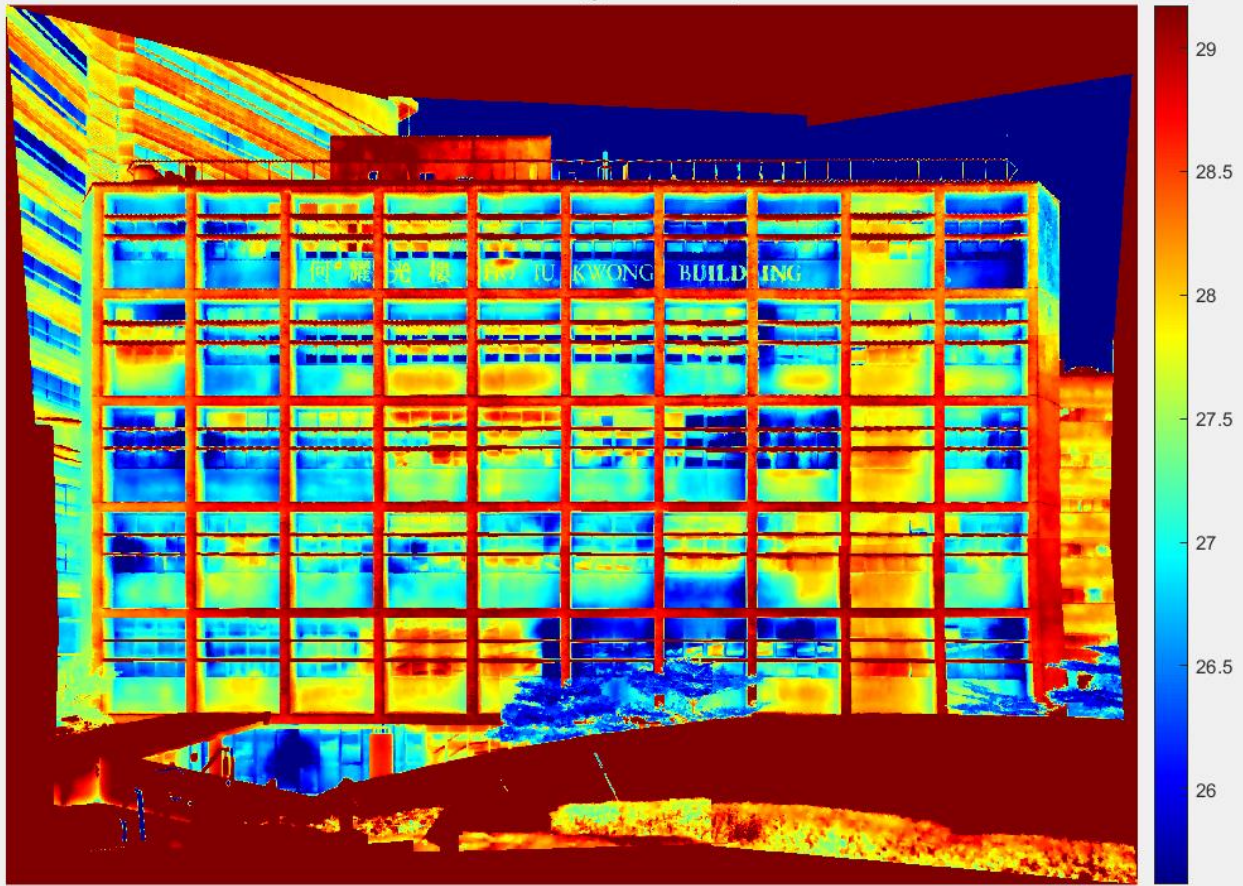
Thermograms with same temperature bar



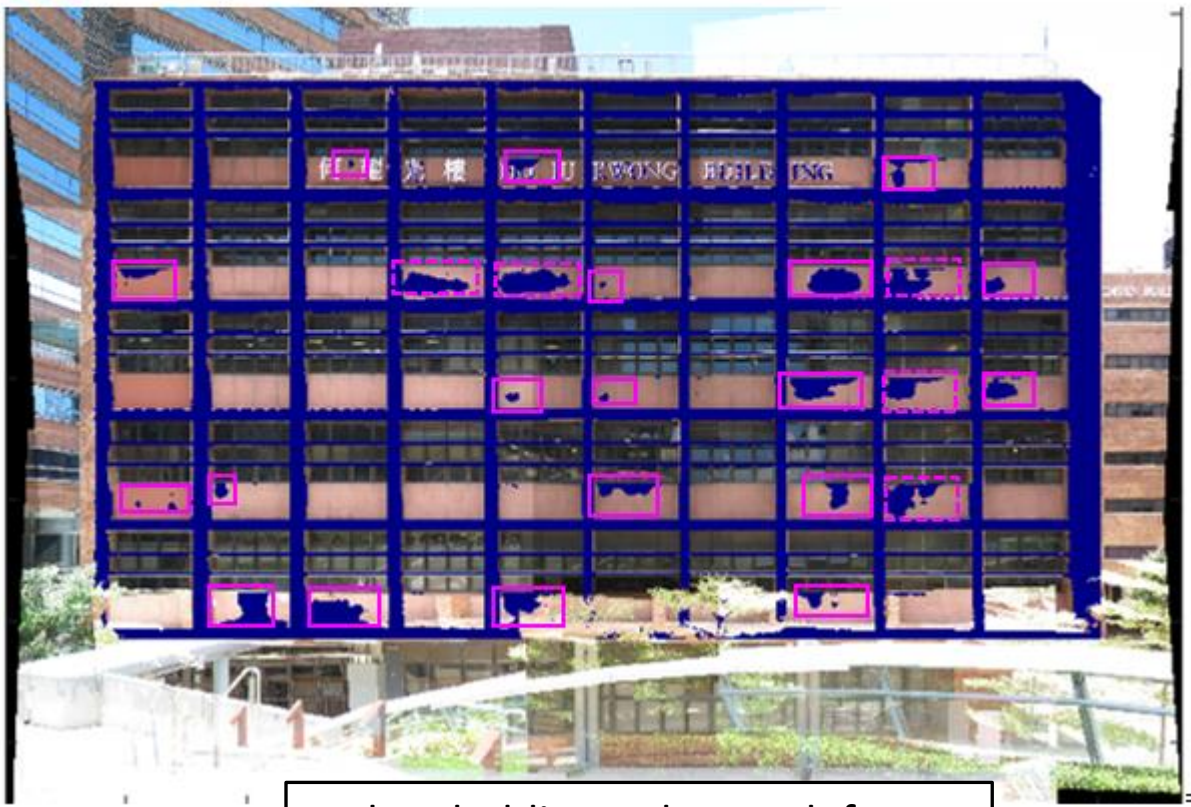
Future Approach – Thermal Image Stitching



Contrast image in Temp



- Suspected delaminated area
- Check suspected heat source behind the wall/outdoor reflection



Thresholding to locate defects



THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

Questions?

Thank you!

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啟迪思維 • 成就未來