STUDY REPORT

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Using Infrared Thermal Imaging to Audit Retrofitted Wall Insulation in Houses

Ian Cox-Smith

Funded by BRANZ from the Building Research Levy

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Preface

This is the first of two reports prepared during research into the potential use of infrared thermal imaging for evaluating the retrofitting of wall insulation in houses.

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Abstract

As part of a project studying the retrofit of insulation into the walls of New Zealand houses, the potential for using thermal imaging with hand-held infrared cameras during the insulation retrofit process has been investigated.

Thermal imaging may be useful:

- for training installers
- as part of the actual installation process
- as a tool for auditing the installation quality
- as a method for assessing the on-going thermal performance of retrofitted insulation.

The conclusion from this study is that a thermal imaging camera ccan be useful for all four of those tasks but success requires not only the correct choice of camera capabilities and settings but also the temperature conditions must be right well. Even with the best equipment and conditions it is the knowledge and experience of the operator that is critical to understanding what is observed.

Guidance is given on camera requirements, temperature conditions, and suitable wall construction types along with some of the pitfalls that might be encountered.

Contents **Page**

FIGURES AND TABLES

1. BACKGROUND

As part of a project studying the retrofit of insulation into the walls of New Zealand houses, the potential for using thermal imaging with hand-held infrared cameras during the insulation retrofit process has been investigated.

Thermal imaging may be useful:

- for training installers
- as part of the actual installation process
- as a tool for auditing the installation quality
- as a method for assessing the on-going thermal performance of retrofitted insulation.

Using thermal imaging for building diagnostics is still relatively new and will continue to evolve as cameras become more sensitive and more affordable. Although there have been some attempts overseas to develop techniques for quantitatively assessing the thermal performance of building components, the vast majority of published information and guidance is of a qualitative nature. Most published information relating to the use of thermal imaging for assessing residential insulation is focused on winter use where there are temperature differences of at least 10K between the interior and exterior. New Zealand's temperature climate combined with relatively poorly insulated and poorly heated houses means that it would be often difficult to find periods when a difference of 10K is maintained for significant time periods.

1.1 Retrofitted wall insulation

A large proportion of the New Zealand housing stock was built prior to the 1977 New Zealand Building Code mandatory requirements for insulation, and these houses lack ceiling, floor and wall insulation. There have been community and government initiatives to retrofit insulation into the ceilings and suspended timber floors of these uninsulated houses, but retrofitting insulation into walls is more difficult, more expensive and less cost-effective.

Retrofitted wall insulation is also more difficult to audit, as once the insulation is installed, it is hidden from sight. Wall insulation retrofitted by removing interior wall linings or exterior cladding can be installed and audited in the same way as new houses, but when insulation is installed into walls without removing the linings, entirely different techniques need to be employed. This report focuses on the use of thermal imaging to audit this method of installation.

A recent UK thermal imaging survey[1] of 84 houses retrofitted with loose-fill insulation has highlighted some shortcomings in the installation techniques and processes used

[1] Kingspan Insulation Solutions, *Injected Mineral Fibre Full Fill Cavity Wall Insulation, Workmanship, Voids and Heat Loss,* A White Paper www.insulateonline.com/pdf/White%20Paper-Injected.pdf

for controlling the installation quality. The report also demonstrates the potential for using thermal imaging as part of the insulation retrofit process

2. INFRARED INSPECTION OF BUILDING ENVELOPES – GUIDES, HANDBOOKS AND STANDARDS

2.1 Guides and handbooks

Manufacturers and distributors of infrared cameras have published a number of guides and handbooks relating to the use of thermal infrared cameras

These include:

- *Infrared Thermography Handbook: Volume 1, Principles and Practice*, Norman Walker, ISBN 0903132338, British Institute of Non-Destructive Testing (BINDT), 2005, www.bindt.org

- *Infrared Thermography Handbook: Volume 2, Applications*, AN Nowicki, ISBN 090313232X, BINDT, 2005, www.bindt.org

- *Thermography Code of Practice: Number 1, Building Thermography*, UK Thermography Association, BINDT, Northampton, UK, 2007, www.ukta.org.

- *Thermography Code of Practice: Number 2, Assessing Thermal Bridging and Insulation Continuity*, UK Thermography Association, BINDT, Northampton, UK, 2007, www.ukta.org.

Many of these publications are focused on the use of the cameras for building inspection – in particular, defects in the thermal envelope. Some have also formed the basis of course material for the training and certification of the professionals who undertake the infrared surveys.

Thermography Code of Practice: Number 1 is the first in what is intended to be a series of 11 technical notes relating to thermographic inspection and analysis methods in building assessment.

Thermography Code of Practice: Number 2 recommends the following as a minimum requirement for reliable thermography:

- Temperature difference across the building fabric to be greater than 10K.

- Internal air to ambient air temperature difference to be greater than 5K for the last 24 hours before survey.

- External air temperature to be within ± 3K for the duration of survey and for the previous hour.

- External air temperature to be within ± 10K for the preceding 24 hours.

In addition, external surveys should also comply with the following:

- Necessary surfaces free from direct solar radiation for at least 1 hour.
- No precipitation either just prior to or during the survey.
- Ensure all building surfaces to be inspected are dry.
- Wind speed to be less than 10 m/s.

2.2 Standards

Most publications relating to infrared inspection of buildings reference either ASTM C1060-90[2] or ISO 6781:1983.[3] Since the ISO standard dates back to 1983 when the cameras were considerably less capable than today, the standard is currently being updated to better match the industry's needs and the capabilities of the latest cameras. Most principles are still relevant but the more quantitative specifications and requirements are likely to be less meaningful. There is also an EN standard (13187:1999[4]) but it is simply a minor update to the ISO standard.

The standard practice outlined in ASTM C1060-90 offers reliable means for detecting suspected missing insulation and the possibility of detecting partial-thickness insulation, improperly installed insulation or insulation damaged in service. Proof of missing insulation or a malfunctioning envelope requires independent validation (such as visual inspection or an in situ R-value measurement).

3. CRITERIA FOR THERMAL IMAGING

3.1 Exterior versus interior thermal imaging

Northern hemisphere infrared surveys of exterior walls can often be undertaken from the exterior of houses, but New Zealand's temperate climate and therefore smaller difference in temperature across walls means that the infrared imaging will generally need to be made of interior wall linings rather than exterior cladding. For example, with claddings such as brick veneer, the thermal resistance, thermal mass and vented cavity behind the bricks means that the thermal characteristics of the exterior face of the bricks is significantly isolated from the thermal behaviour of the insulated framing.

Advantages of performing thermal imaging from the exterior:

- Quicker and easier.

[2] ASTM C1060-90 (Reapproved 2003) *Standard Practice for Thermographic Inspection of Building Installations in Envelope Cavities of Frame Buildings*. ASTM International.
[3] ISO 6781:1983 *Thermal Insulation – Qualitative detection of thermal irregularities in building envelopes – Infrared method*. International Organization for Standardization.
[4] BS EN 13187:1999 *Thermal Performance of Buildings – Qualitative detection of thermal properties in building envelopes – Infrared method* (ISO 6781:1983 modified).

- Possible to image a larger area of wall.
- Direct knowledge of the exterior conditions including sun exposure.
- Better at detecting thermal anomalies within cladding.

Disadvantages include:

- Not possible to image walls exposed to sunlight so limits the survey to night–time.
- Insulated or high thermal mass cladding and sheathing moderates surface temperature.
- Thermal impact of drained/vented cavities behind cladding.
- Difficulty in isolating impact of internal features such as wall junctions, wardrobes and so on.
- Likely to involve a wider range of surface emittances.
- Radiant heat reflecting off nearby object
- Greater vertical variation in air temperature adjacent to the wall surface.
- Indoor temperatures may vary from room to room, and this is not immediately apparent from the outside of a building.
- The surface film coefficient changes with wind speed.
- High wind speed makes the differences in surface temperature smaller.
- Residual moisture from rain or fog.
- Transient moisture in cladding materials.

Advantages of performing thermal imaging from the interior:

- More uniform and predictable air temperature gradients adjacent to surface.
- Uniform radiant environment.
- Uniform surface emittance.
- Imaging can be done during daylight.
- Radiant impact of windows can be controlled using curtains and blinds.

- Easy to account for physical features on the exterior of the wall and surrounding the house.

- Image field of view more consistent and easier to focus accurately.

- Better at detecting thermal anomalies positioned towards the interior face of a wall.

Disadvantages:

- Need to keep checking the exterior conditions – in particular, sun exposure.

- More intrusive to the occupants and the requirement to shift furniture and fittings.

- Slower.

3.2 Housing dimensions

The New Zealand housing stock with uninsulated walls includes quite a range of construction styles and practices, but a few gross generalisations are a useful way to start an analysis of what a typical retrofit wall insulation case might involve.

A typical uninsulated residential wall consists of:

- timber framing with a depth of 100 mm (4”) and width of 50 mm (2”)

- stud height 2440 mm (96”)

- studs at 450 mm (18”) centres

- three rows of dwangs at 560 mm (22”) centres

- either brick veneer or weatherboard cladding

- either plasterboard or scrim interior lining.

The criterion for satisfactory thermal conditions is the ability to distinguish framing members from cavities.

The critical minimum dimensions for discriminating missing insulation in frame construction is two framing spacings wide and one framing spacing high. Outdoors, it is typically convenient to view at least one floor-to-ceiling height across and one-half that distance high.

Independent verification may be needed for metal-framed buildings to establish typical patterns for insulated and uninsulated areas.

3.3 Preferred conditions for performing infrared inspections

A minimum temperature difference of 10K is required between interior and exterior surface or ambient air temperatures for a period of 4 hours prior to the test.

As ambient air temperature measurements cannot account for the strong radiative effects of the sun or for convective effects from wind, the following precautions should be taken when using air temperature measurements for temperature difference:

- No direct solar radiation on the inspected surfaces for approximately 3 hours previous to the inspection for light frame construction and approximately 8 hours for masonry veneer construction. Temperature differences greater than 10K reduce these times. Direct sunlight and other strong sources of thermal radiation make discrimination of uninsulated areas unreliable. Exterior surveys should be performed after sunset and before sunrise for best results. Interior surveys may be possible on veneer surfaces or ceilings under attics an hour or two after sunrise.

- For exterior surveys, the wind speed should be less than 6.7 m/s and the building surface should be dry.

4. INFRARED THERMAL IMAGING CAMERAS

Table 1 below lists typical characteristics of infrared (IR) cameras that are using for building envelope diagnostics. Apart from the obvious relationship between resolution/sensitivity and cost, the most significant feature is only the very expensive high-end cameras have the option for using a lens with a wider field of view. This is particular important in the New Zealand context where the majority of the imaging would need to be from the house interior.

One disadvantage of IR cameras is that, to maintain accuracy, they are required to internally recalibrate to compensate for things such as internal temperature. This occurs frequently, and each time it happens, the resulting output will subtly change. This can make it difficult to assess changes across a wall surface when multiple images are used. With ordinary camera images, it is possible to use software to ‘stitch’ separate images together into a single picture, but with thermal images it is much more difficult.

A wide-angle lens requires fewer images to be taken (see Figure 1), which makes a survey quicker. Focusing a thermal image is generally more difficult than a standard image, so taking fewer images allows more time for using a tripod, composing the shot and focusing the camera.

Table 1: Typical specifications[5] for thermal imaging cameras

Camera resolution (pixels)	Wide angle lens option	Thermal sensitivity (NETD)(K)	Resolution when area of wall 1.2m tall x 1.6m wide fills field of view (mm)	Approximate cost (US$000)
640 x 480	Some brands	0.03–0.065	2.5	25+ (33 wide angle)
320 x 240	A few cameras	0.05–0.07	5	15–25
240 x 180	None	0.07–0.08	7	10–13
200 x 150 180 x 180	None	0.07–0.08	13	7–8
140 x 140	None	0.08–0.09	17	5–6
120 x 120	None	0.1+	10	<5

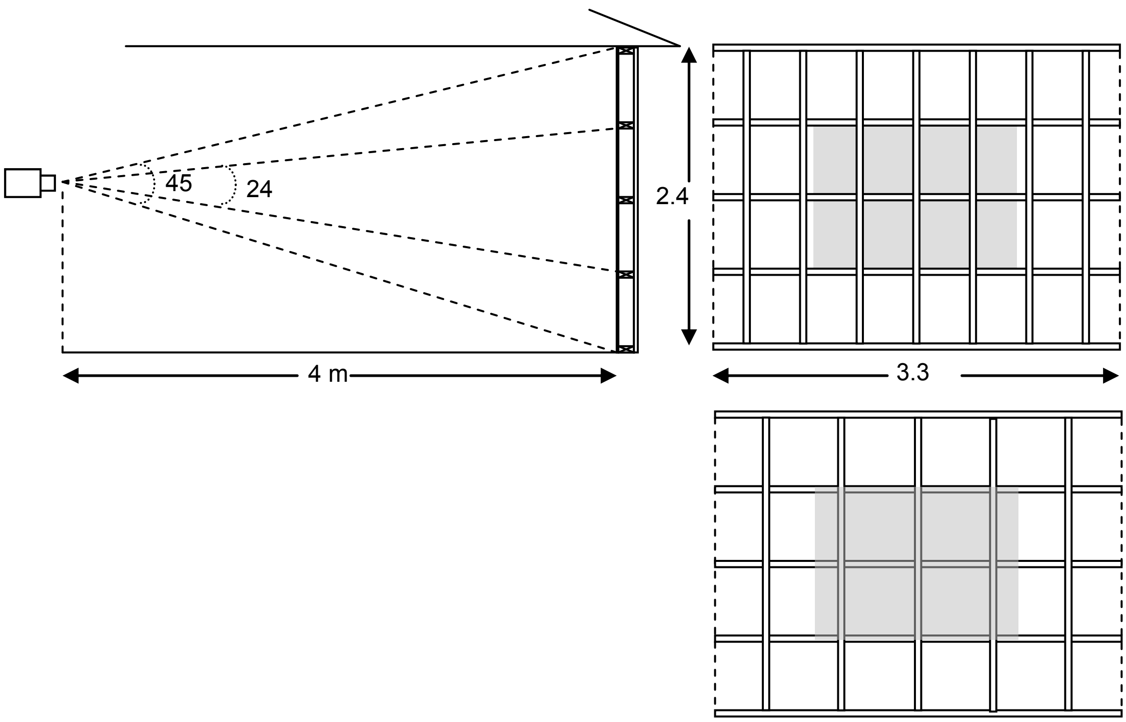

Figure 1: Advantage of changing from standard 24° field of view to standard wide-angle 45° field of view

5. R-VALUES

The majority of houses that have uninsulated timber-framed walls have been built with a frame depth of 100 mm, but more modern ones will have 90 mm framing. The frame depth of 90–100 mm puts restrictions on the possible R-value of any retrofitted insulation.

A practical (cost-effective) upper limit of performance for insulation materials is R3.0 at 100 mm. At the other extreme, it is probably not cost-effective to install anything less than an R2.2 material (at 100 mm). The mean value between R 3.0 and R 2.2 of

[5] Useful background information on understanding thermal imaging camera specifications can be found in Electrophysics Resource Center infrared imaging white paper Understanding Infrared Camera Thermal Imaging Quality www.electrophysics.com/tiq

R2.6 is readily achievable with insulation materials that are available for wall retrofit, so the following analysis is based on a typical retrofitted wall insulation material as being R2.6.

When a loose-fill insulation material is installed into a wall, the target R-value will only be maintained if the quality of the raw material and the installed density and fibre homogeneity are also maintained. A poorly installed R2.6 material can be as low as R1.3 if the density is only 60% of the target value.

If thermal imaging is to be an effective tool for assessing installation quality, it needs to be able to detect that type of anomaly where the R-value is half the R-value elsewhere. The anomalous region may only cover part of a frame cavity or it may extend to an entire frame cavity or even a section of wall. If thermal imaging is reliant on comparative measurements, the latter will be much harder to detect as it might require more than one image to be taken and compared.

Table 2 demonstrates the impact that the range of expected insulation material R-value will have on the wall component R-value. Obviously given the 18% difference in overall performance, it would be desirable to be able to use thermal imaging to detect the differences between R2.2 and R3.0 material.

Table 2: Impact of insulation R-value on clear-wall R-value for typical retrofit situation of studs on 450 mm (18”) centres and with dwangs at 550 mm centres (22” 3-rows)

Insulation	Clear-wall thermal resistance (m^2K/W)	Difference from wall with R2.6
R2.6	2.1	–
R3.0	2.3	+8.5%
R2.2	1.9	-9.5%
R1.3	1.4	-33%

Computer modelling can be use to determine the likely impact of uninsulated gaps between the retrofitted insulation material and the framing. Gaps can arise because of insulation segments being cut undersize, because of settlement of loose material, or because of drying/age shrinkage of foam type materials.

Table 3 represents the impact of a gap on one edge only between the top of the insulation and the underside of a dwang or top plate. It can be seen that even gaps as small as 10 mm are likely to have a significant impact on the overall performance of the insulation.

Computer modelling can also be used to estimate the temperatures likely to be experienced on the surface of the interior lining of a typical wall for a range of overall temperature difference between interior and exterior. (See the appendix for output images from the computer model.)

Table 3: Impact on clear-wall R-value from having an uninsulated gap (shrinkage/settlement) between the top edge of insulation and the underside of the dwang above, assuming R2.6 insulation and framing as above

Gap (mm)	Gaps size relative to 550 mm frame cavity height	Clear-wall thermal resistance (m^2K/W)	Difference from wall with R2.6
0	–	2.1	–
5	1%	2.0	-5%
10	2%	1.9	-8%
20	4%	1.8	-14%
30	6%	1.7	-19%
40	7%	1.6	-23%
50	9%	1.5	-27%
Uninsulated cavity	100%	0.45	-80%

Whilst the actual appearance is quite different from what is actually displayed by a thermal image, comparisons between the computer images enables an assessment of the likely detection ability of a thermal imaging camera. The computer modelling combined with the practical experience to date of BRANZ staff suggests that a surface temperature difference of at least 0.3K is needed to reliably ascertain that there might be a thermal defect present in the insulation.

Tables 4 and 5 summarise the results from the computer model. Table 4 compares the effect of changing the R-value of the insulation materials, and Table 5 shows the effects of gaps between the insulation and framing.

Table 4: Effects of changing the R-value of the insulation materials

Temperature difference across wall	Insulation	Surface temperature difference between area insulated with R2.2/3.0 and area insulated with R1.3	Surface temperature difference between insulated and non-insulated areas
2.5K	R2.2	0.1	0.5
	R3.0	0.2	0.6
5K	R2.2	0.2	0.9
	R3.0	0.3	1.0
10K	R2.2	0.3	1.8
	R3.0	0.4	1.9
15K	R2.2	0.4	2.0
	R3.0	0.5	2.1

The most obvious conclusion from the computer modelling is that, unless there is a significant temperature difference between interior and exterior (15K), it is unlikely that thermal imaging will be able to reliably detect the difference between R2.2 and R3.0 insulation. Even detecting areas with R1.3 insulation material would required considerable care and would probably need the use of actual air and surface temperature measurements to confirm the thermal images.

Table 5: Temperature difference between surface adjacent to frame and surface adjacent to gap at top edge of insulation

Temperature difference across wall	Height of gap between top edge of insulation and underside of dwang					
	5 mm	10 mm	20 mm	30 mm	40 mm	50 mm
2.5K	–	–	–	0.3	0.3	0.3
5K	–	–	0.3	0.3	0.4	0.5
10K	–	0.3	0.6	0.9	1.2	
15K	0.4	0.6	0.8	1.2		

6. THERMAL IMAGING

6.1 What can thermal imaging show?

Irregular variation of the thermal pattern in the spaces between framing members may indicate a combination of possible causes, including varying density of insulation, convection or air leakage, moisture or thermal bridges. Variable density insulation often allows air leakage and convection and thereby creates intruding areas of surface temperature variation.

Air leakage, usually at joints and junctions in the building envelope, typically produces irregular shapes with uneven boundaries and large temperature variations. Air leakage can be detected thermographically when air of a different temperature than the surface viewed comes from the side of the envelope opposite the observer.

Areas where insulation contains significant moisture conduct heat much more readily than dry insulation or no insulation. Within the moist region, there may be a mottled and diffused thermal pattern. Temperature variations within the pattern are not extreme.

Users can expect to obtain anomalous thermal images from phenomena that are about the size of a framing member or larger.

6.2 Thermal images from laboratory tests

Figure 2 shows two images from a laboratory test wall with deliberate defects and outward heat flow. The image on the left represents a larger overall temperature difference between interior and exterior than that for the image on the right.

The frame cavity on the left side of the left-hand image shows evidence of convective air movement around a gap at the bottom edge of the insulation. The insulation is thinner than the depth of the wall cavity, and there are gaps against both faces of the insulation. The frame cavity on the right side of the left hand image shows evidence of an electrical flush box size area of missing insulation.

In the image on the right, the small area of missing insulation has resulted in a warmer surface temperature than in the insulated area because of a transient increase in solar gain on the exterior of the wall.

Despite the dwangs towards the bottom of the images having different sized gaps between the insulation and the framing, the impact is not detectable because either there is insufficient temperature difference between interior and exterior or the camera has insufficient temperature difference resolution. An alternative reason could be that the field of view is too large to resolve temperature differences in the area of interest.

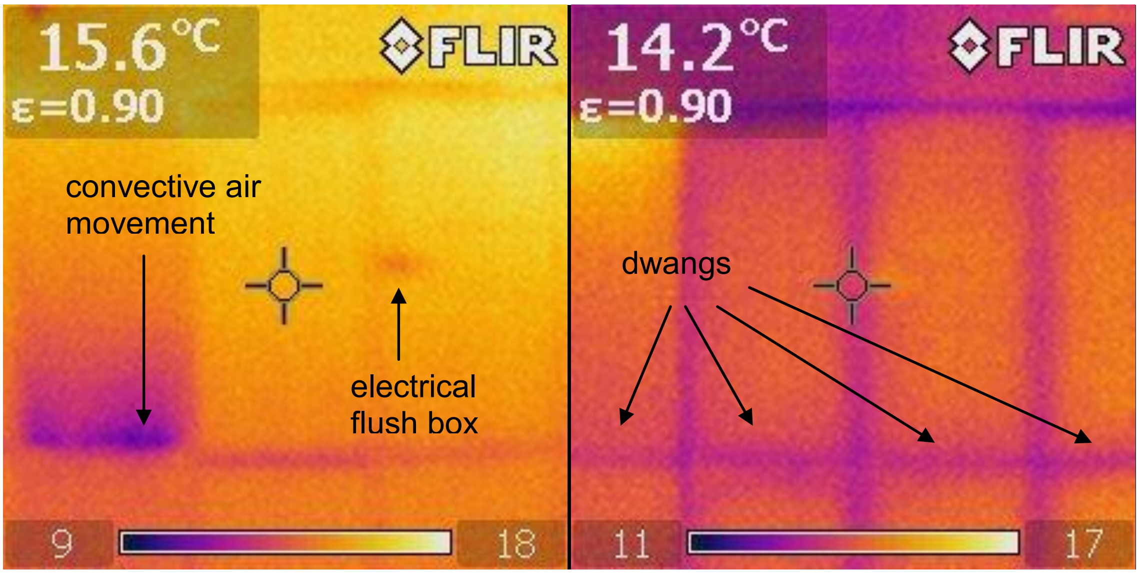

Figure 2: Thermal images of laboratory-based test walls using 250 x 250 pixel camera equipped with a standard lens.

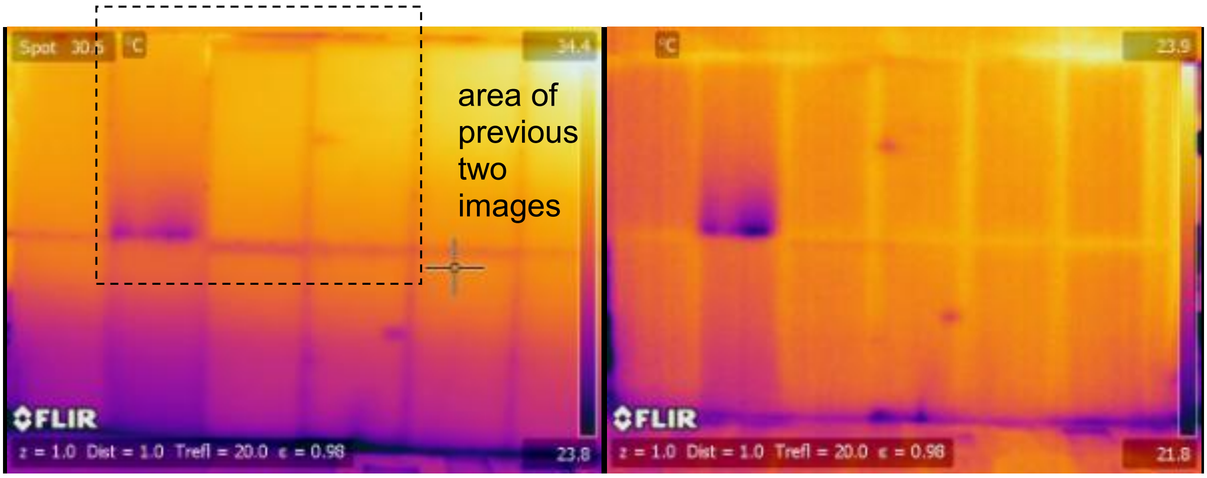

Figure 3: Thermal images of laboratory-based test walls using 640 x 480 pixel camera equipped with a wide-angle lens

Figure 3 shows the same laboratory test wall but with images taken with a 640 x 480 pixel camera and using a wide-angle lens. Because the full wall height is visible, it is possible to compare the upper wall cavities with the lower ones and to simultaneously observe surface temperatures in the vicinity of both the top and the bottom plates. It is also much easier to associate where the image was taken.

As previously, the overall temperature between interior and exterior is larger in the case of the image on the left than the one on the right. Artificially raising the interior air temperature in the image on the left has resulted in a detectable surface temperature gradient from the bottom to the top of the wall.

The image on the left of Figure 3 represents outward heat flow (artificially elevated interior air temperature during summer) whereas the one on the right represents inward heat flow.

For the inward heat flow case (right-hand image), the surface temperature adjacent to the framing is warmer than the surface adjacent to the insulation. In both cases, the two electrical flush box-sized areas of missing insulation results in colder surface temperature than for the insulated areas. For the image on the right, this is because the image was taken in the late afternoon immediately after the disappearance of solar gain on the exterior surface of the wall. Thermal mass has kept the framing warm whereas the relatively low thermal mass cladding has immediately dropped in temperature. In the areas, where the insulation is missing, radiant heat flow from the exterior cladding has transferred heat rapidly to the interior lining.

Because of the high sensitivity of the camera, most of the salient features of the image on the right are still visible despite the range in temperature represented in the image being only 2K. The camera sensitivity combined with the large temperature difference between interior and exterior has resulted in the thermal impact of the screws holding the interior lining being visible in the image on the left. The impact of gaps in the insulation where it touches the dwangs is still not resolvable despite using a more sensitive camera. The impact of the gaps might have become detectable if either the temperature difference between interior and exterior had been increased or the field of view had been decreased by moving the camera closer to the wall.

Whilst the image on the right shows evidence of air leakage along the bottom plate, the appearance of the air leakage is similar to the area in the centre left of both images where there is convective bridging around the gap at the bottom of the insulation. The impact of air leakage at the bottom plate can be made visible for the image on the left by changing the temperature midpoint and span for the image.

Figure 4 shows a laboratory test wall with two rows of five-frame cavities separated by a central row of dwangs. From left to right, the gap between the insulation and the underside of the dwangs increases from nothing to 60 mm in steps of 15 mm. For the image on the left, the difference between the air temperatures on the two faces was only 5K, whereas the difference was increased to 10K for the right-hand image. In the left-hand image, the 15mm gap is only just detectable, as the surface temperature difference between the insulated areas and the areas with insulation missing is only 0.3K. For the right-hand image, the gaps are significantly more obvious because of the increase in surface temperature difference to 0.6K. These results are consistent with the predictions of surface temperature difference using 3D modelling of the test specimen.

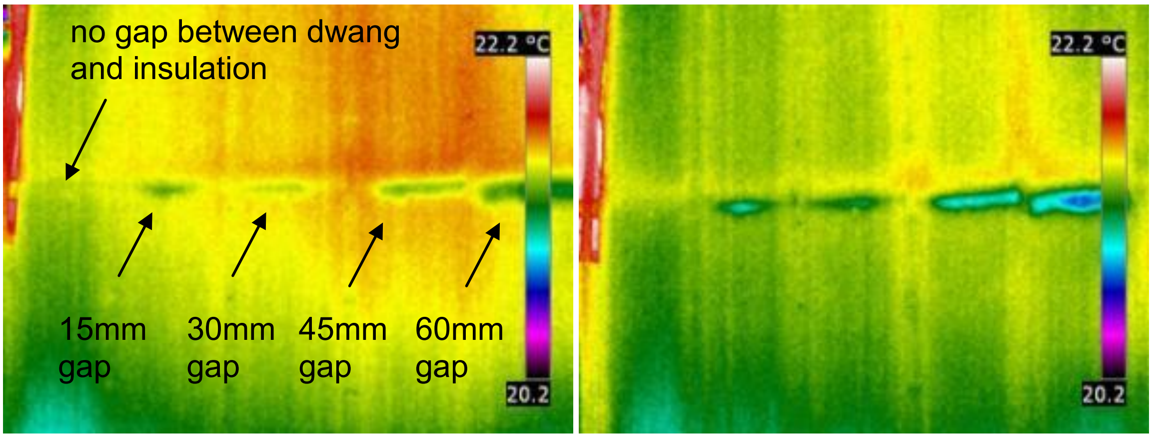

Figure 4: Test wall with two rows of five-frame cavities separated by a central row of dwangs.

6.3 Thermal images from houses retrofitted with wall insulation

What follows is a series of images taken during the summer months from the interior of houses using a thermal imaging camera with 640 x 480 pixel resolution and equipped with a wide-angle lens. Conditions in general were not favourable for thermal imaging – in particular, the air temperature difference between exterior and interior was usually less than 5K. Because most of the imaging was done during the early morning or early evening, it was usually the case that heat flow through the wall was from interior to exterior. Many of the images represent instances when there was transient solar gain on some of the exterior face of the wall being imaged.

In Figure 5, the small bright areas towards the top of some of the frame cavities are a result of transient radiant heat transfer from solar gain on the exterior of the wall transferring heat through areas of either missing insulation or areas of insulation with significantly lower density. Because the image was taken during a period when there was a relatively small temperature difference between interior and exterior, the insulation defects were not visible without the benefit of solar gain.

Figure 5: Wall with bright sunlight on exterior cladding

In Figure 6, whilst the diagonal bracing is only detectable in the image taken from the exterior, the missing insulation in the area immediately above the door is only detectable in the image taken from the interior. The diagonal bracing is highlighted in the exterior image because it is both narrower than the depth of the wall cavity and located against the weatherboards rather than against the interior lining. In the top left-hand image, the bright area in the middle of the image represents a gap between the insulation and the diagonal bracing that has been highlighted because of solar gain on the exterior surface of the wall. Since diagonal bracing that is narrower than frame cavity is more likely to have been installed against the back of the cladding than against the back of the lining, it is more easily detected in thermal images taken from the exterior than those taken from the interior.

In principle, although diagonal bracing that is narrower than the frame cavity has a gap that allows retrofitted loose fill insulation to flow past, the presence of the bracing is sometimes difficult to detect (with thermal images, electronic stud finders, tapping on the surface or feeler wire) and not all material or installation methods will necessarily result in the insulation flowing through the gap.

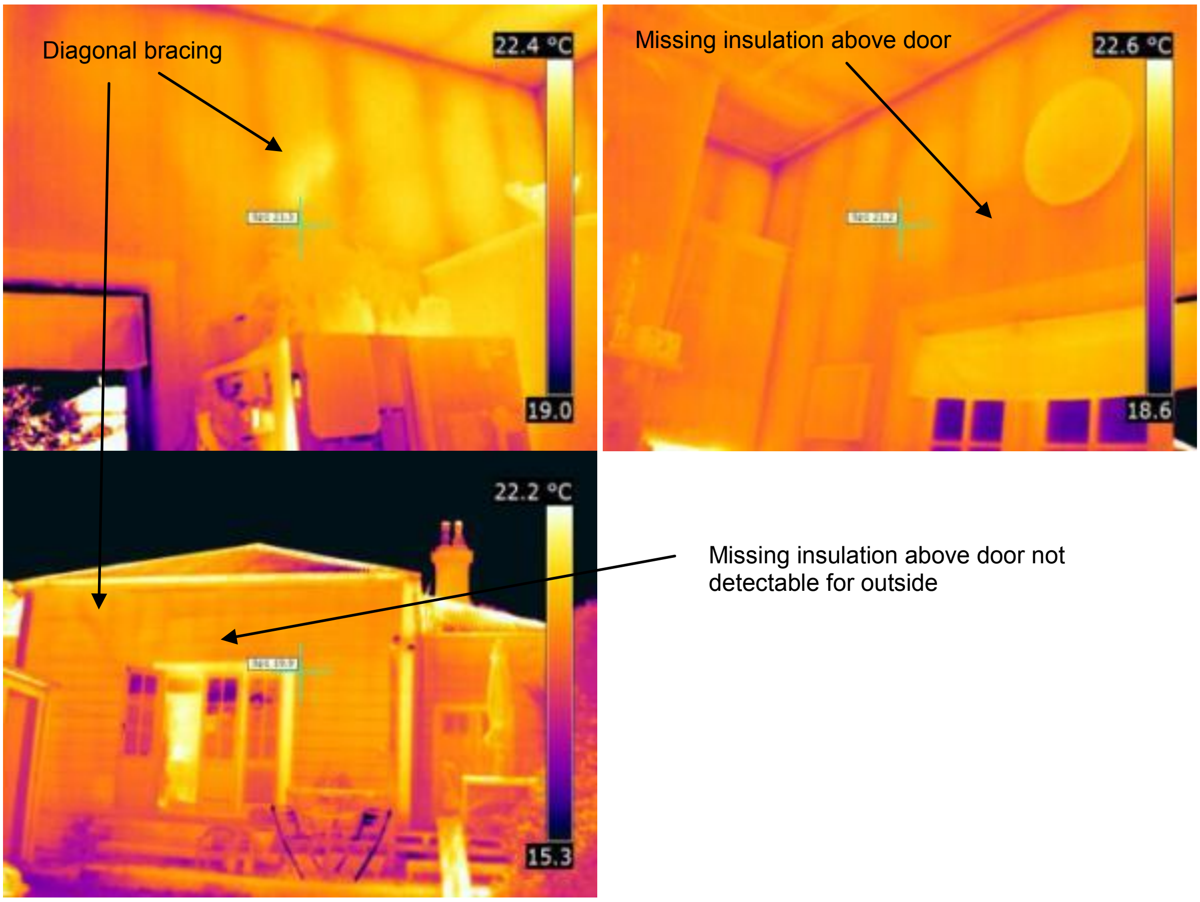

Figure 6: Bevel-backed weatherboard-clad wall imaged from both the interior and exterior of a house.

Figure 7 demonstrates how the physical shape of wall cladding – in this case, shiplap weatherboards – can make it more difficult to detect the thermal impact from any defects in frame cavity insulation.

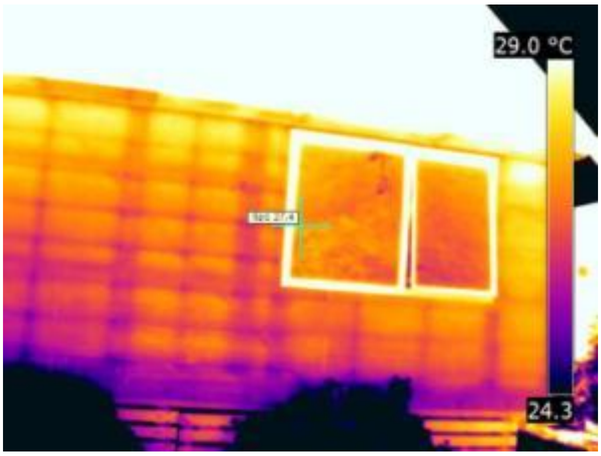

Figure 7: exterior of wall with shiplap weatherboards.

Figure 8 shows a situation where the thermal mass of the bricks has made the image taken from the exterior relatively featureless. The images taken from the interior highlight missing insulation but require careful analysis to fully understand the heat transfer processes occurring within the wall.

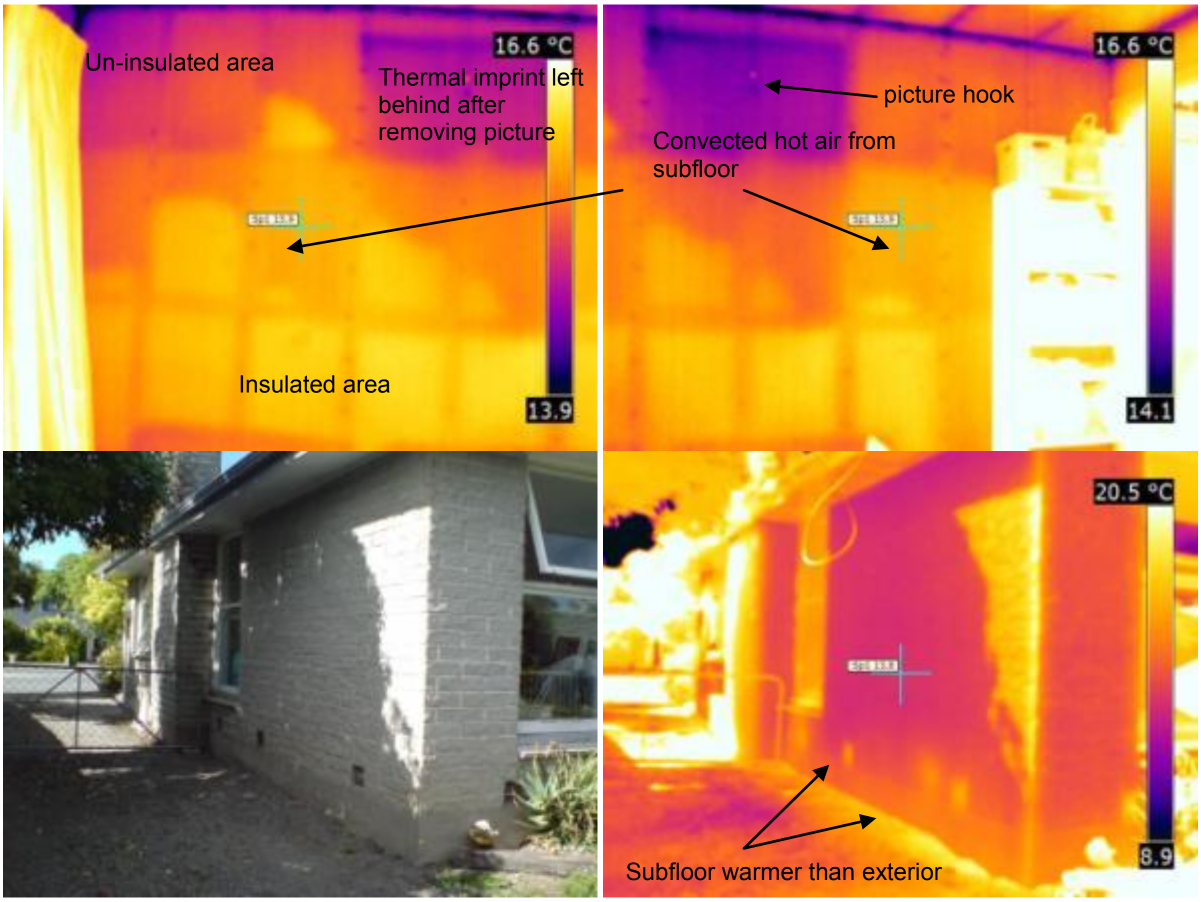

Figure 8: Both interior and exterior views of a wall with brick veneer cladding.

The brightest areas on the interior surface represent insulated areas, the slightly cooler areas are where hot air from the subfloor has penetrated into a few of the empty or partially filled frame cavities in the lower two-thirds of the wall – note the warm subfloor vents in the exterior image.

Convective mixing makes the air temperature in those frame cavities relatively uniform. The cooler area at the top of the wall that is visible in the images taken from the interior is the result of removing a picture that was hanging on the wall immediately before taking the shot. The bright spot in the middle of the dark area is the picture hook.

The image is made slightly more confusing by the coincidence that the picture just happened to have exactly spanned the distance between the studs.

Figure 9 illustrates how interior lining materials with either significant thermal mass or significant thermal resistance can make detection of framing and insulation defects more difficult because the difference in surface temperature is reduced.

This is also an issue where walls are lined with tongue-and-groove timber or double layers of plasterboard.

Figure 9: Wall lined with lathes and plaster.

The image on the left of Figure 10 shows a wall insulated with a material that has shrunk with age, hence the relatively fuzzy thermal outline of the framing.

The image on the right is of a wall insulated with the same type of material but where shrinkage is not as severe, either because the material is less susceptible to shrinkage or it is at an age where the shrinkage is small enough that it not yet having a significant impact. In this case, the thermal signature of the framing is relatively sharply defined, and areas of partial insulation fill are still easy to spot.

This highlights the difficulty of detecting insulation shrinkage or settlement if it is occurring at a slow rate. The thermal impact of gaps between the top of the insulation and the underside of the dwangs is detectable in the left-hand images.

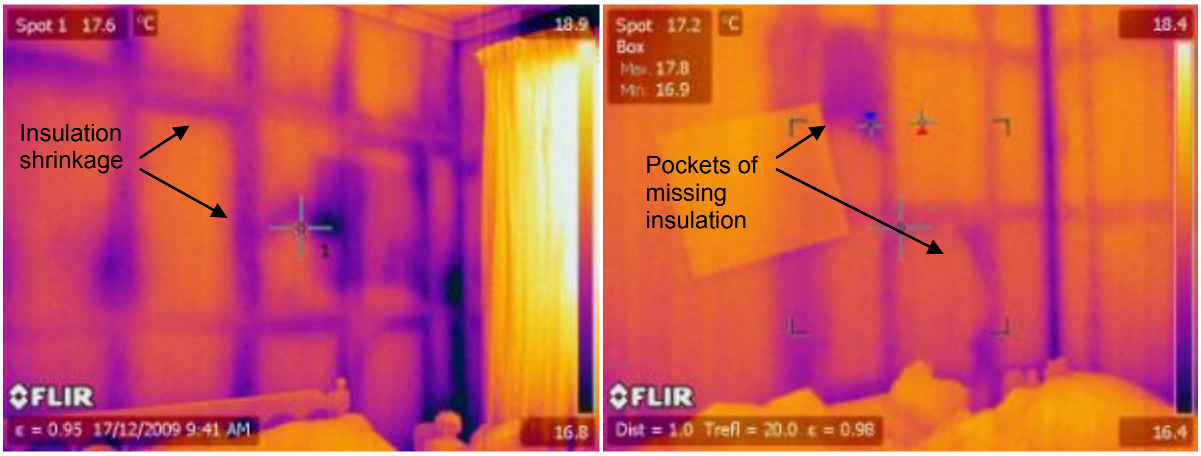

Figure 10: An example (left image) of insulation shrinkage creating gaps against framing and an example (right image) with little to no shrinkage but with missing pockets of insulation.

In comparison, Figure 11 shows a wall and ceiling with well fitted bulk insulation with a relatively high thermal resistance. The wall and ceiling framing is sharply defined.

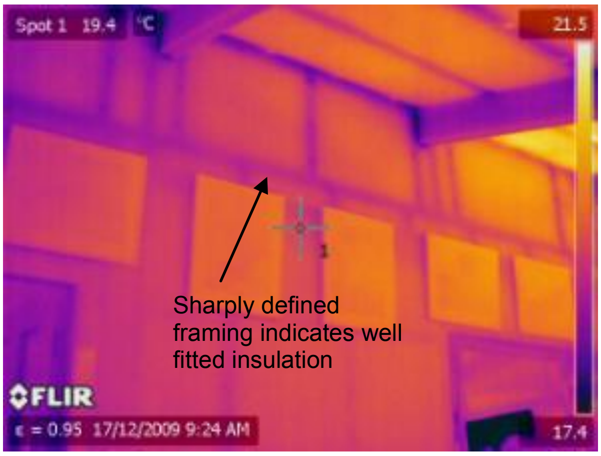

Figure 11: Wall and ceiling with well fitted bulk insulation.

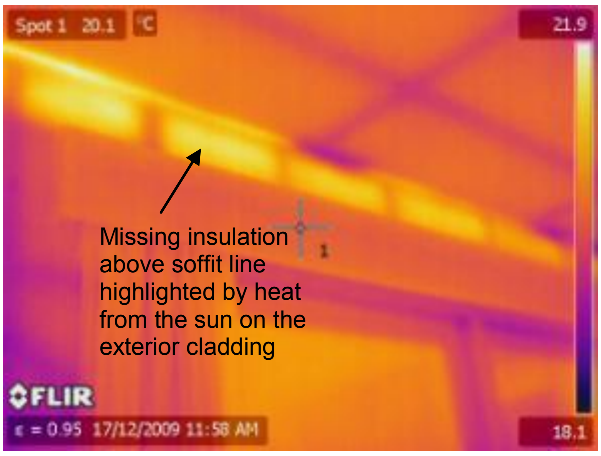

Figure 12: An example of the sometimes difficult to insulate area above soffit line.

Figure 12 shows a bright area above the curtain pelmet where there is no insulation because the soffit line is below the top of the wall. The thermal impact of missing insulation has been heightened by the radiant heat from transient solar gain on the roof. This is an area of a wall that is often either difficult to insulate or that is missed when retrofitting wall insulation.

Figure 13 shows two uninsulated walls in the same house, taken on the same day, but with the exterior surfaces of the walls exposed to solar gain only on the upper part of the wall in the left-hand image and only on the lower part of the wall in the right-hand image.

Because of convective air mixing in the empty frame cavities, the row of dwangs through the midpoint of the walls causes the discrete temperature boundary on the surface. The natural boyancy of warm air results in a larger overvall vertical gradient in surface temperature in the left-hand image compared with the right-hand image.

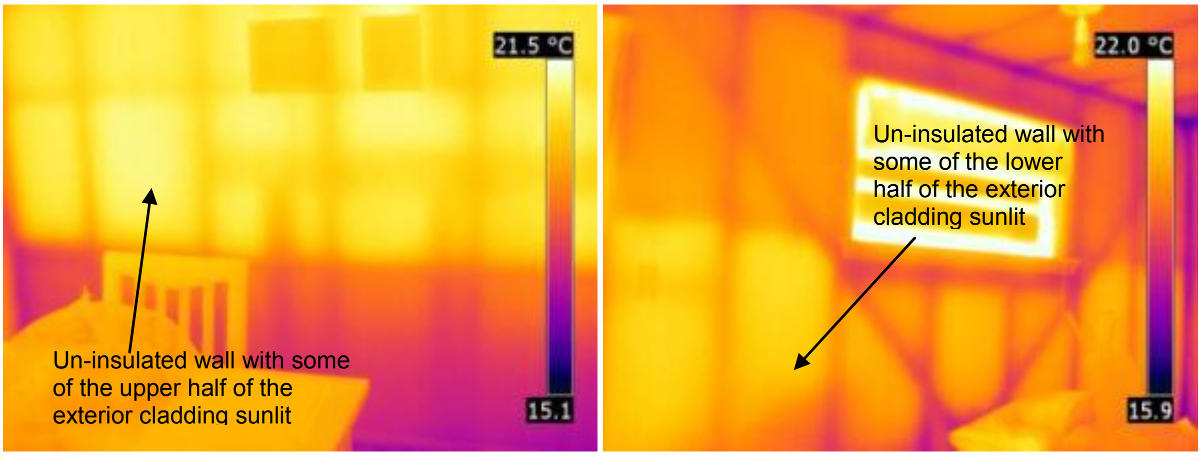

Figure 13: Two uninsulated walls, the left one with sunlight incident on the top half of the wall and the right one with sunlight incident on the bottom half of the wall. Taken in same house on the same day.

Figure 14 shows two images are of the same area of a wall before and after the retrofit of a loose fill insulation material. The images were taken on different days, and there is a significant difference in both the mean and range in surface temperature. This highlights how difficult it can be sometimes to distinguish between the images from insulated and uninsulated walls. In this case, the cavity with missing insulation in the image on the right is a clear indicator that the wall has insulation. One of the triangular cavities formed by the diagonal bracing shows the effect of either incomplete fill or settlement of the insulation material.

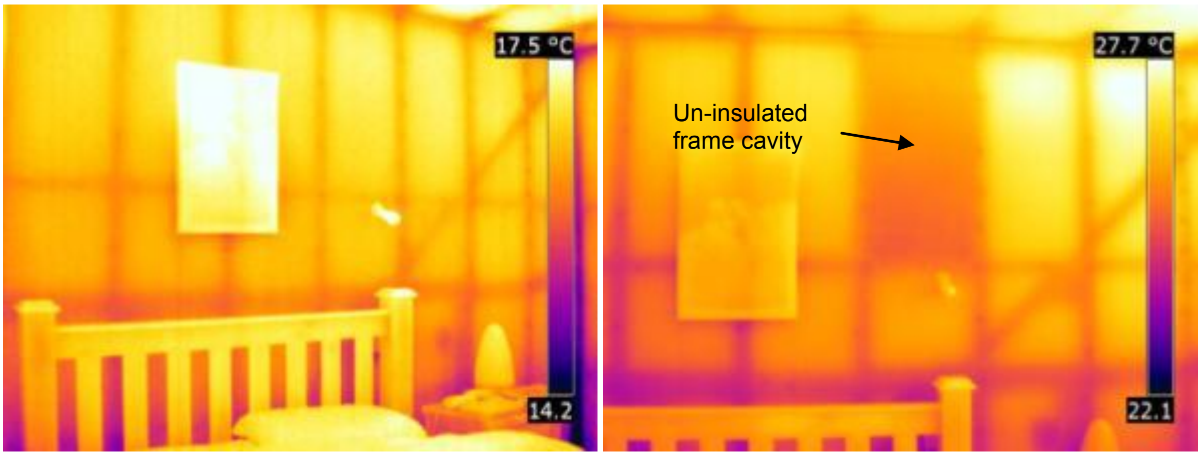

Figure 14: The same wall both before (left image) and after (right image) the retrofit of insulation.

Figure 15 is another example of before and after images for retrofit insulation. The absence of insulation in the left-hand image is indicated by the solar gain induced temperature change at mid-height on the wall. The presence of insulation in the right-hand image is indicated by the small defect in the insulation on the left-hand side of the image.

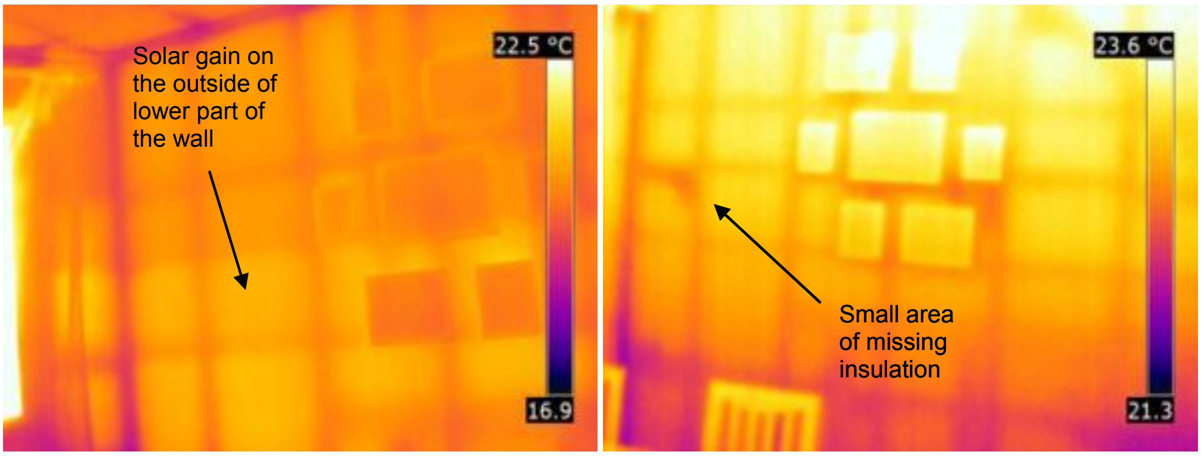

Figure 15: Same wall before insulation (Left) and after (Right)

In Figure 16, the image on the left shows a wall that was retrofitted with a loose fill insulation material 3 years prior to the image being taken. The image on the right is the same as the one on the left but with the temperature span reduced (using software) from 4K to 2K to highlight the area (marked with a box) where there had been a large picture hanging just prior to the image being taken. The installer of the insulation has failed to detect the two diagonal braces (90 degrees to each other), so the insulation has not been installed below the bracing timber.

The residual thermal footprint from the picture frame has confused the thermal impact from the insulation defects to some extent, but the small area at the top of the wall above the middle cavity suggests that the cavity was only half filled above the diagonal bracing. The area of that cavity that is below the diagonal bracing probably has no insulation.

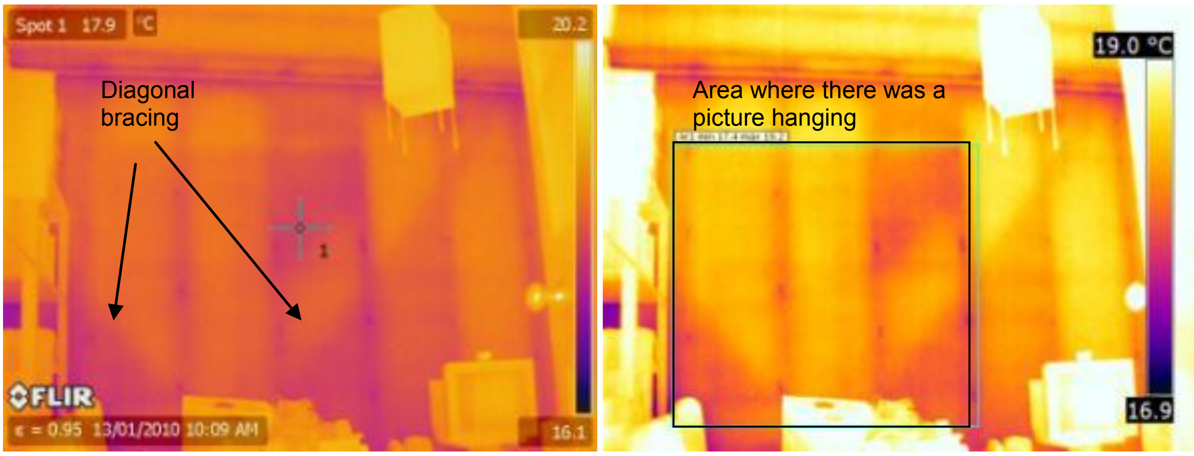

Figure 16: Insulation not installed completely around diagonal brace

Figure 17 shows a wall from the same house as shown in Figure 16. Because there is only a small air temperature difference between exterior and interior, the thermal bridging from the framing is not particularly well defined. Since it is known that the ceiling insulation has a high R-value and has been well fitted, the inclusion of a section of ceiling in the image acts as reference point to enable an assessment that there are probably no significant gaps between the wall insulation and the framing.

The survey conditions are sufficient to determine that insulation has been missed out of some of the wall cavities, and one of the cavities above the window has a small corner of missing insulation.

Figure 17: Area of insulated ceiling included in the image as a reference for the wall insulation

The images in Figure 18 show a wall retrofitted with a loose fill insulation material using holes drilled through the interior lining.

The top left image is the wall before installing any insulation. The top right image was taken immediately after installing insulation into the six frame cavities underneath the window. The heat associated with the insulation blowing process has made it clear which frame cavities have been insulated, but the dramatic change in temperature has swamped any ability to use the thermal image to assess if each of cavities is completely full or to assess the quality of the insulation. Some of the heat has transferred into adjacent empty frame cavities and has more clearly defined where the framing is located. The bottom left image was taken the day after the first two and immediately after installing insulation into three further frame cavities to the left of the earlier ones. The frame cavities that were insulated the day before are now clearly visible, including the framing. The bottom right image was taken after the temperatures in the wall had come to equilibrium. It was only then, three days after the insulation was installed, that it was possible to detect that one of the frame cavities (to the left of the window) is only two-thirds full.

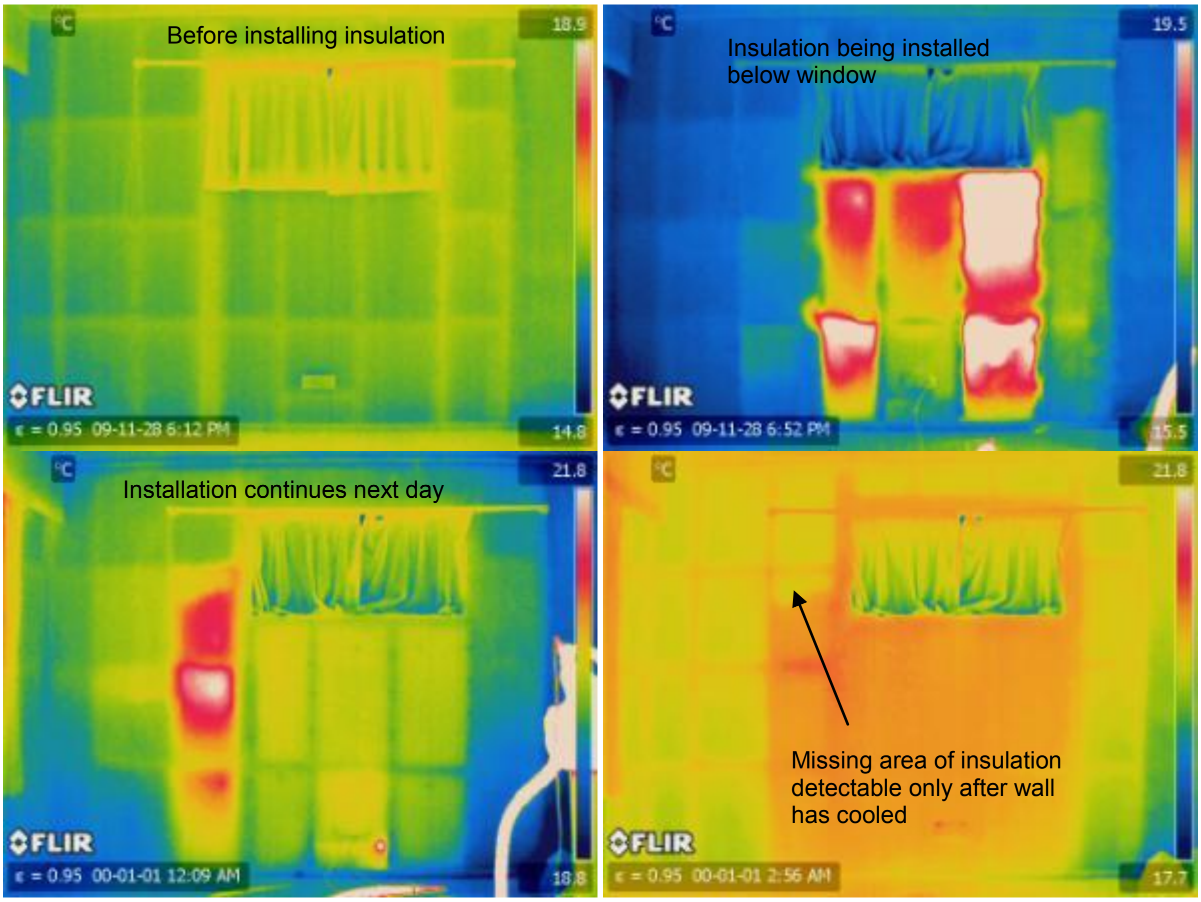

Figure 18: Impact of heat from the blower during installation of a blown insulation

7. CONCLUSION

Provided the wall construction, camera, settings, and operator knowledge are up to the task, it is possible to use a handheld thermal imaging camera for the four principle objectives:

- for training installers
- as part of the actual installation process
- as a tool for auditing the installation quality
- as a method for assessing the on-going thermal performance of retrofitted insulation.

Although it has been demonstrated that it possible to use a camera for these tasks during typical summer conditions, it requires a level of equipment and experience that may not be practical for many of the operators intending to retrofit wall insulation.

Restricting camera use to the winter months when there is more likely to be temperature conditions which are suitable for reliable thermal imaging will also simply the analysis process by having the heat flow direction restricted to being from the interior to the exterior.

Success requires thorough knowledge of the heat flow processes involved, a reasonable understanding of the wall construction being imaged, and lots of experience with the use of the particular camera, including its limitations.

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APPENDIX – RESULTS FROM 3D FINITE ELEMENT MODELLING OF HEAT FLOW THROUGH A SECTION OF WALL FRAMING

2.5K temperature difference across wall

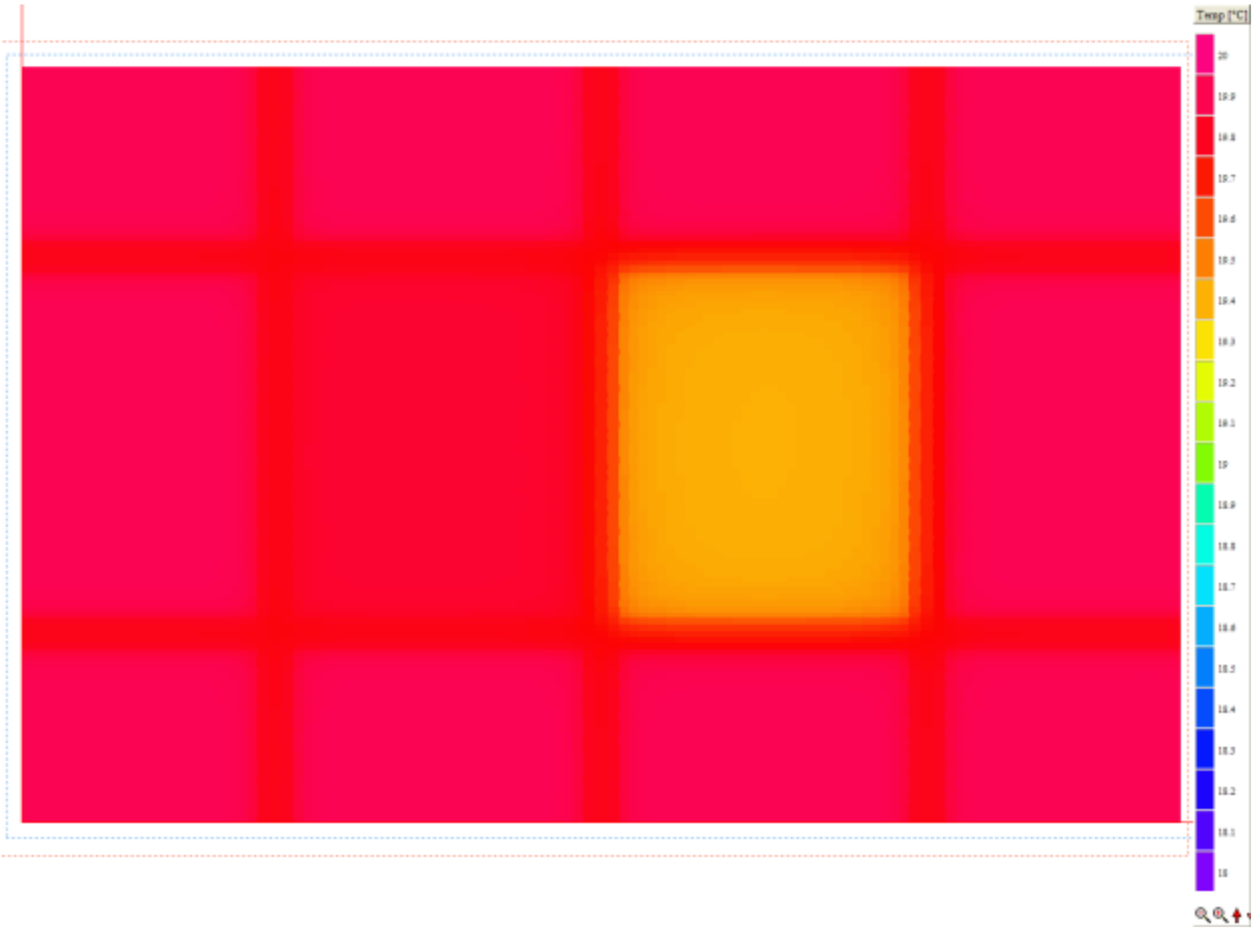

Figure 19: R2.6 insulation except R1.3 in centre left cavity and no insulation in centre right.

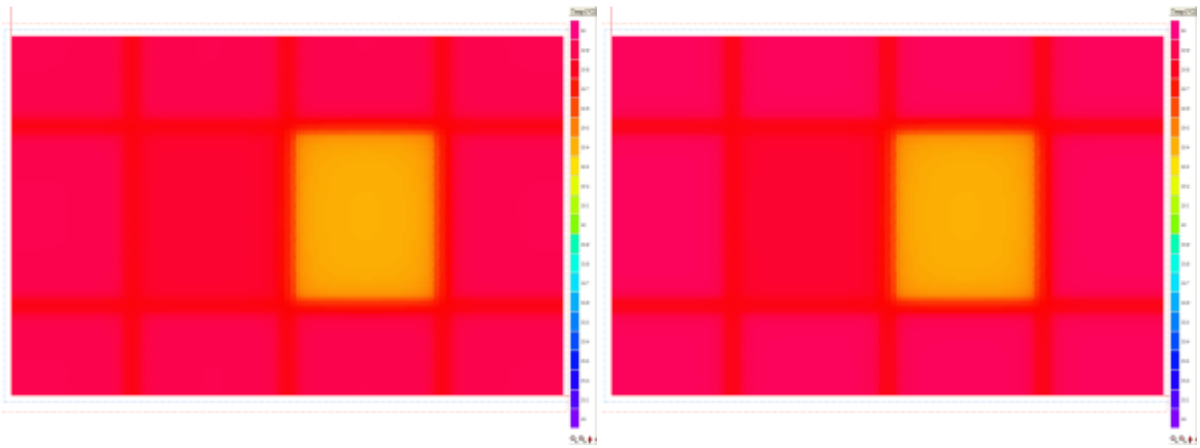

Figure 20: Same as above but using R2.2 insulation instead of R2.6 in left-hand example and using R3.0 in right-hand example.

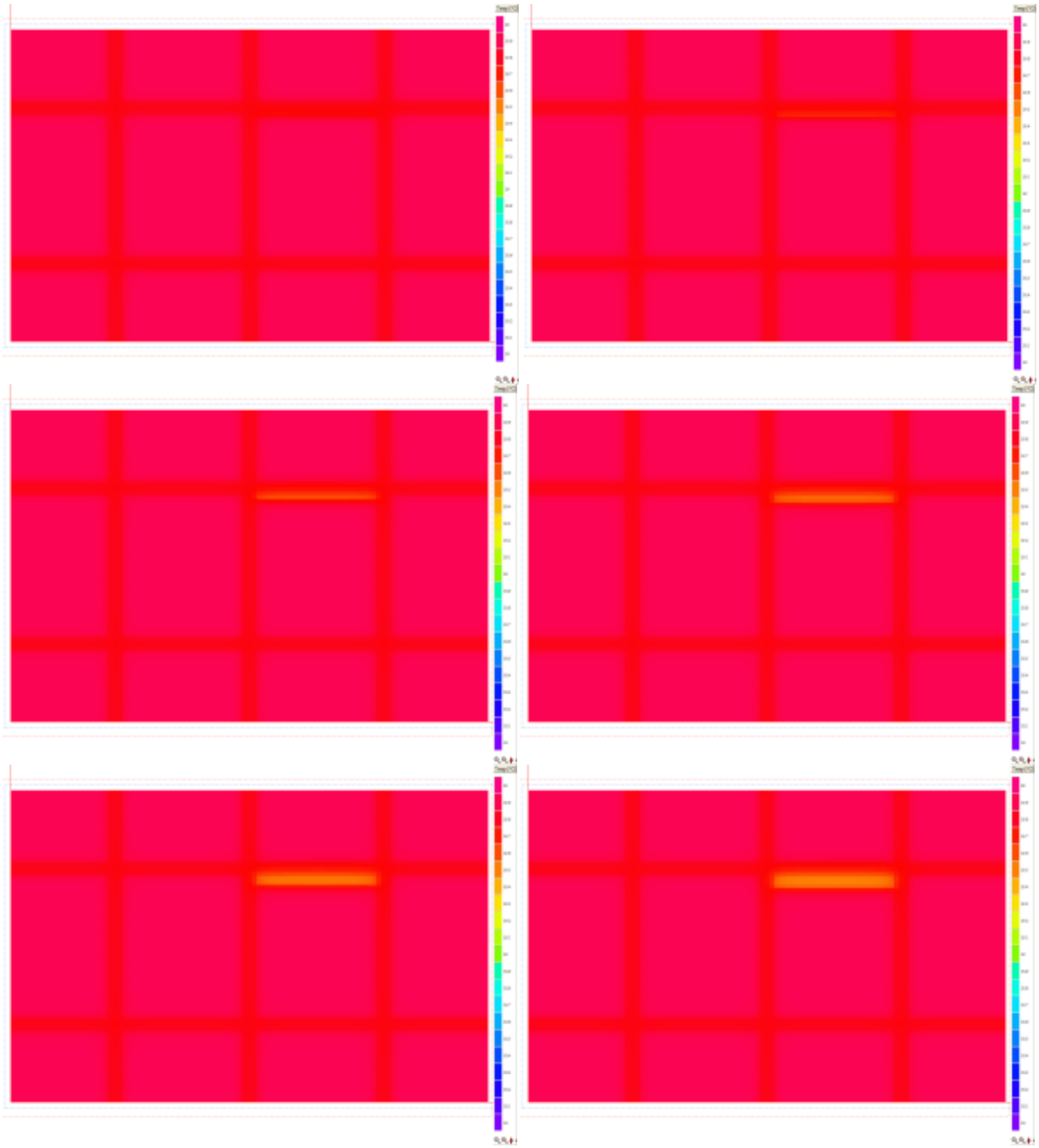

Figure 21: 2.6 insulation with centre right cavity including uninsulated gap between top edge of insulation and underside of dwang. Gap progressively increased from 5 mm to 10 mm, 20 mm, 30 mm, 40 mm and 50 mm.

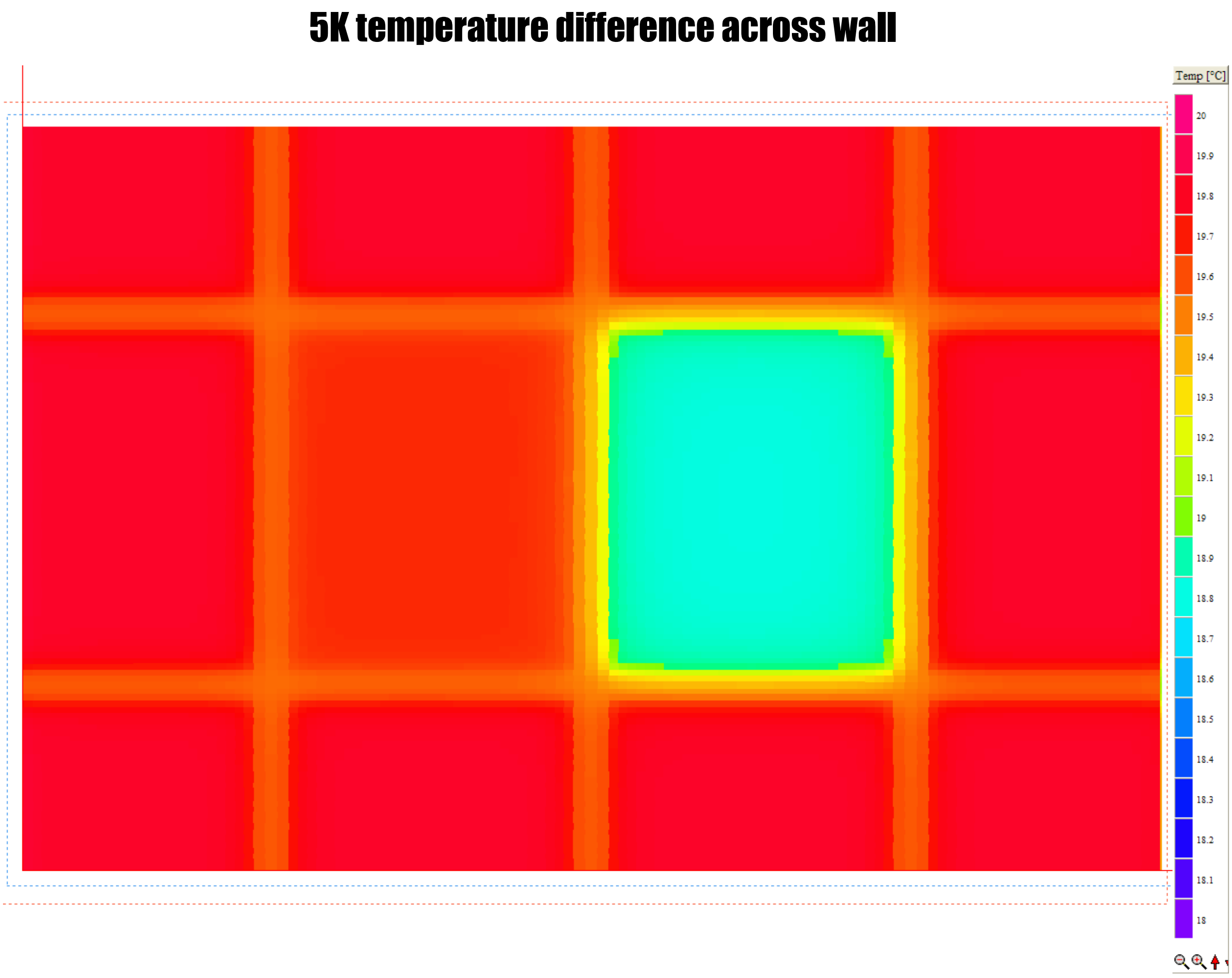

Figure 22: R2.6 insulation except R1.3 in centre left cavity and no insulation in centre right.

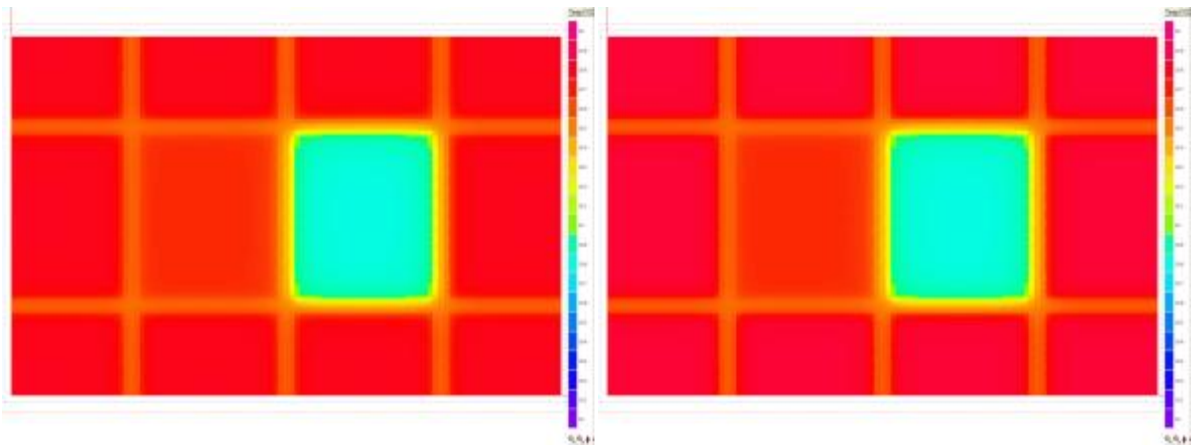

Figure 23: Same as above but using R2.2 insulation instead of R2.6 in left-hand example and using R3.0 in right-hand example.

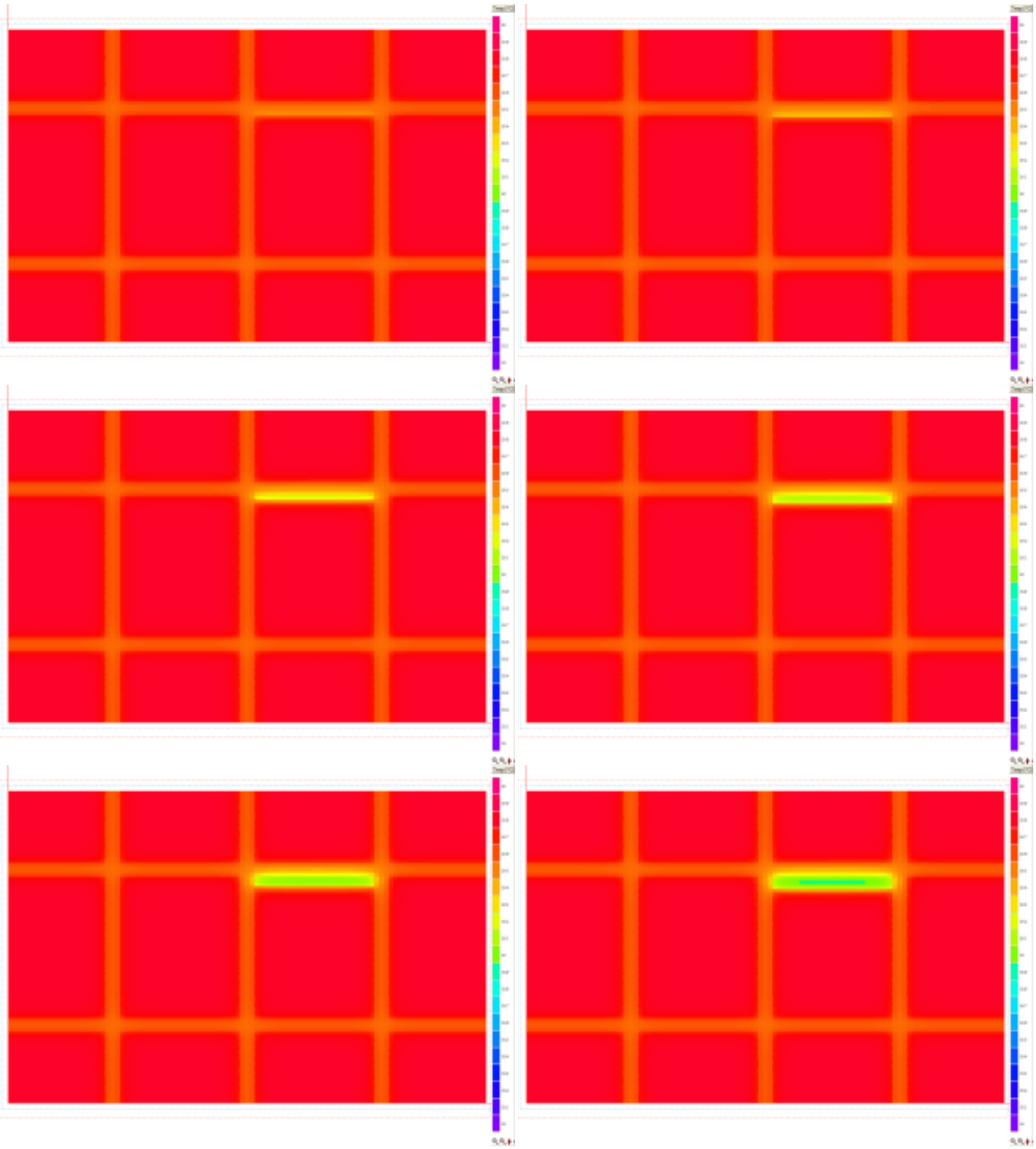

Figure 24: R2.6 insulation with centre right cavity including uninsulated gap between top edge of insulation and underside of dwang. Gap progressively increased from 5 mm to 10 mm, 20 mm, 30 mm, 40 mm and 50 mm.

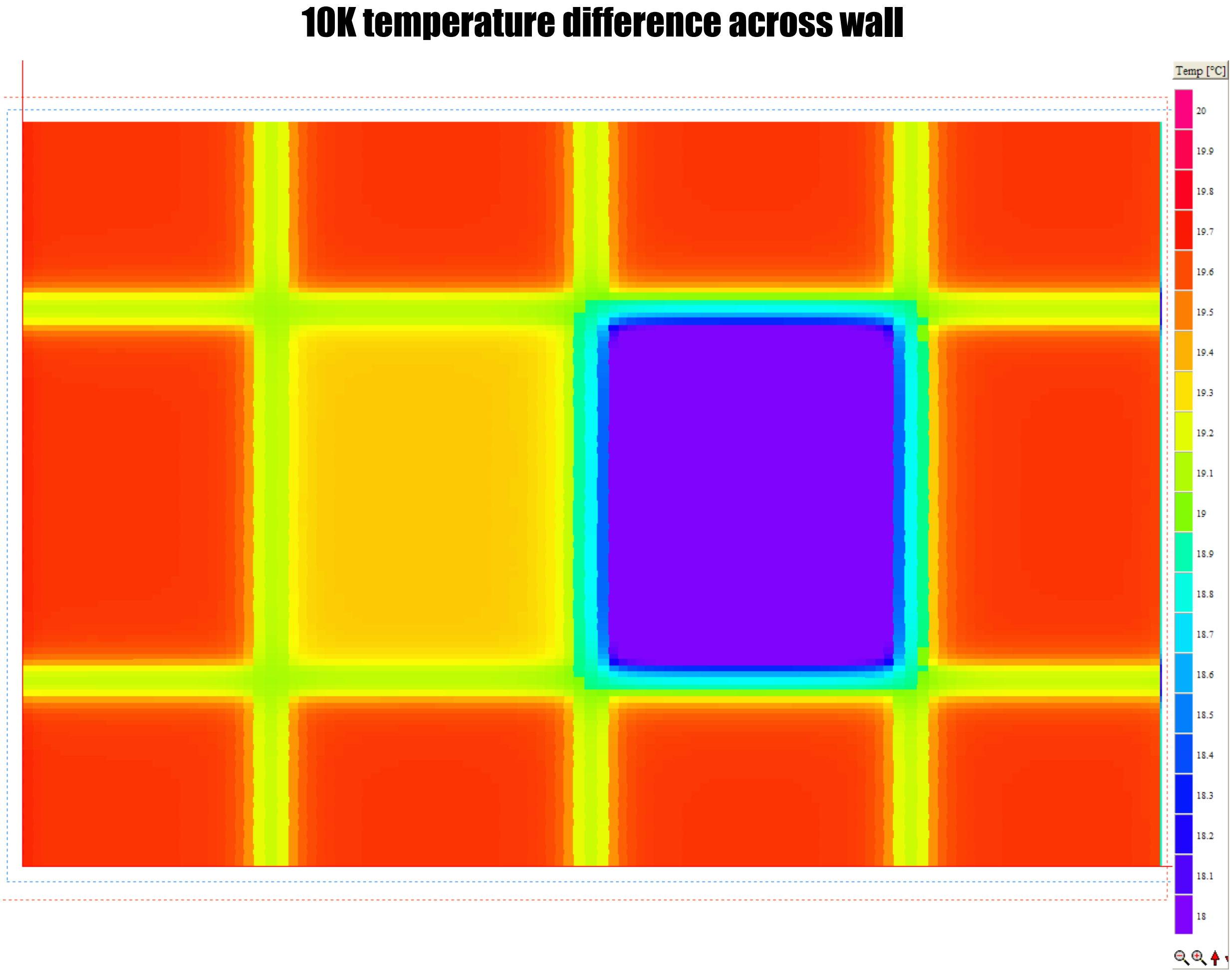

Figure 25: R2.6 insulation except R1.3 in centre left cavity and no insulation in centre right.

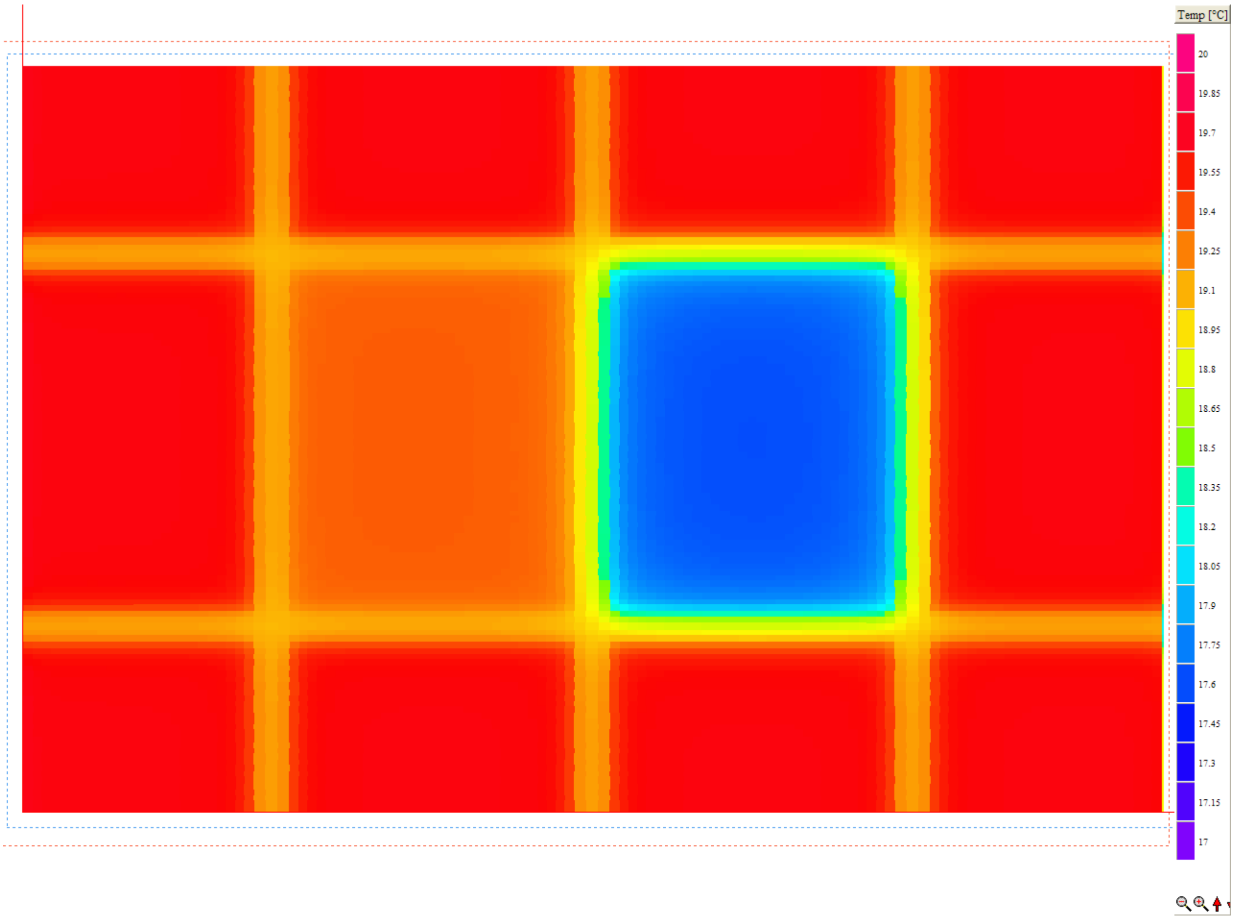

Figure 26: Same as above but temperature span changed from 2K to 3K.

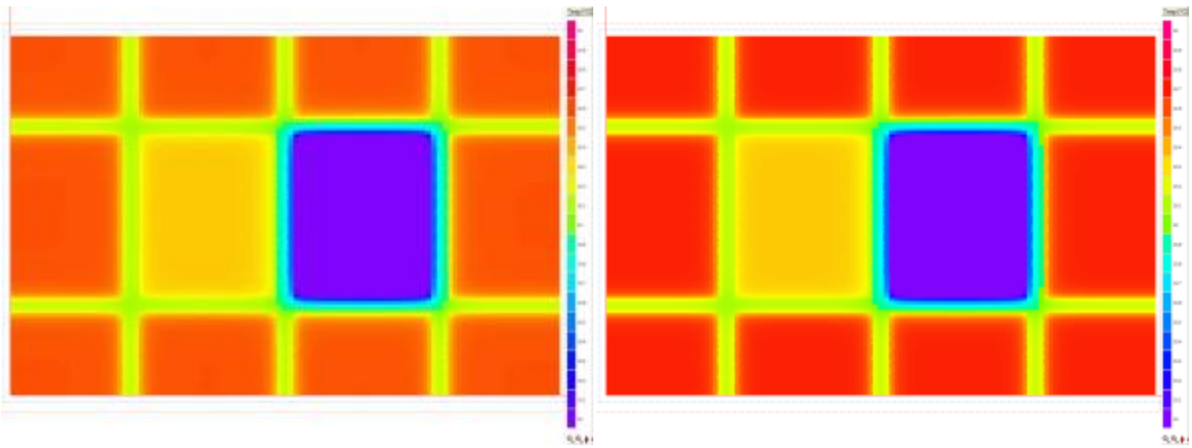

Figure 27: Same as above but using R2.2 insulation instead of R2.6 in left-hand example and using R3.0 in right-hand example.

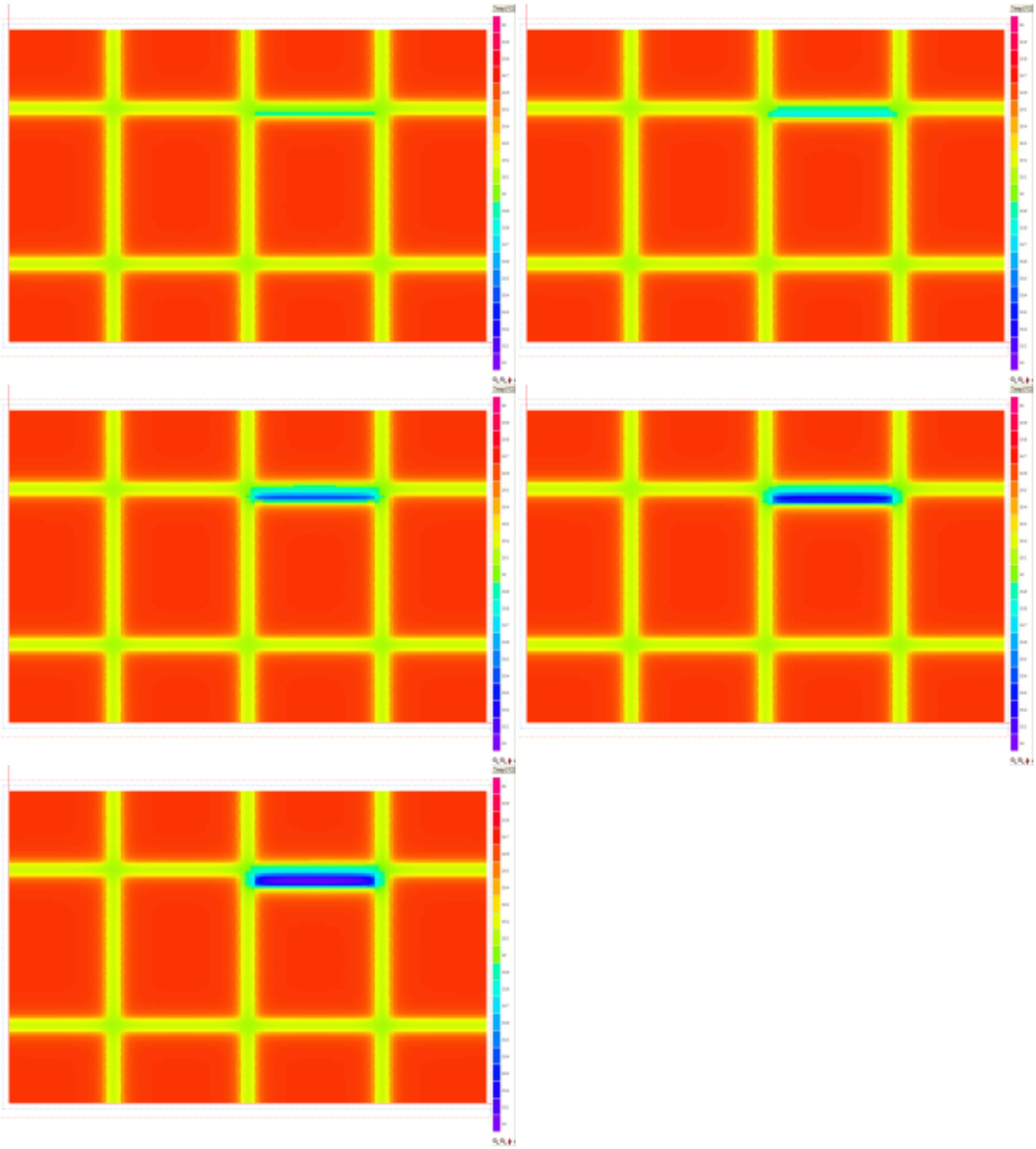

Figure 28: R2.6 insulation with centre right cavity including uninsulated gap between top edge of insulation and underside of dwang. Gap progressively increased from 5 mm to 10 mm, 20 mm, 30 mm and 40 mm.

15K temperature difference across wall

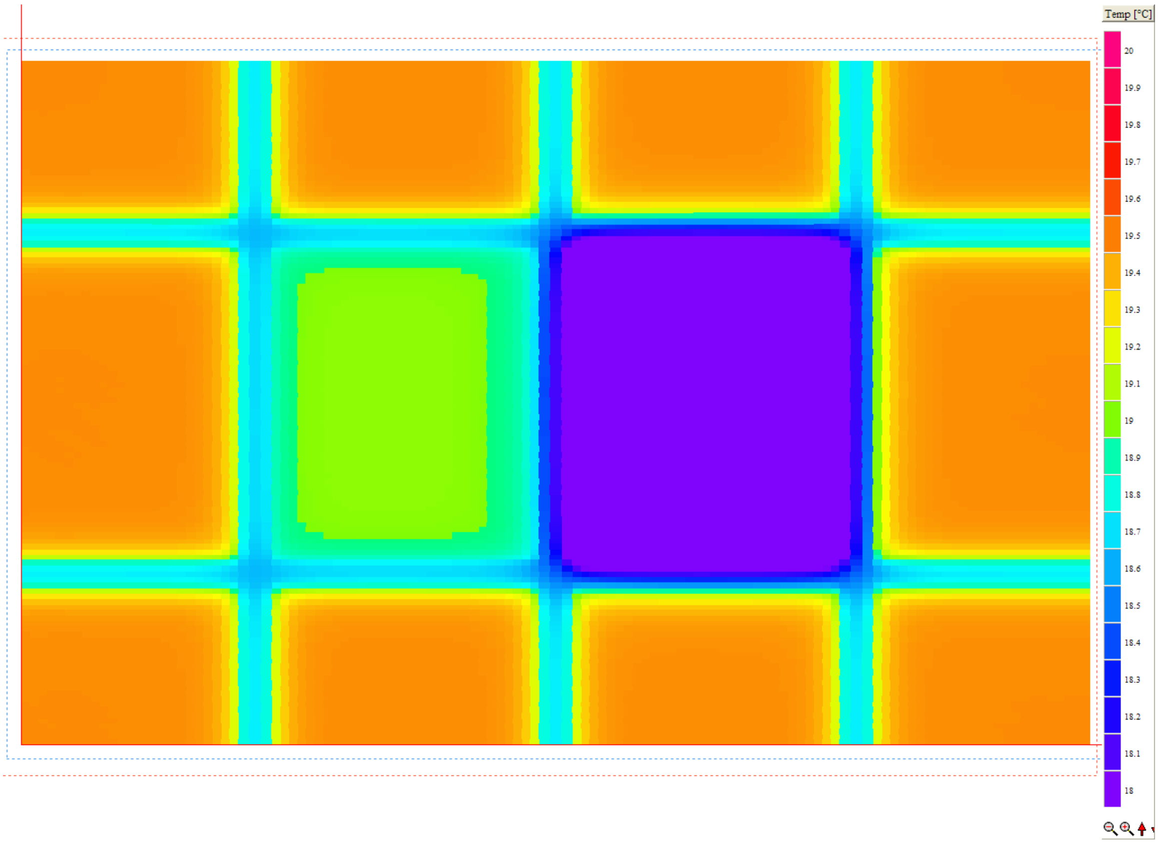

Figure 29: R2.6 insulation except R1.3 in centre left cavity and no insulation in centre right.

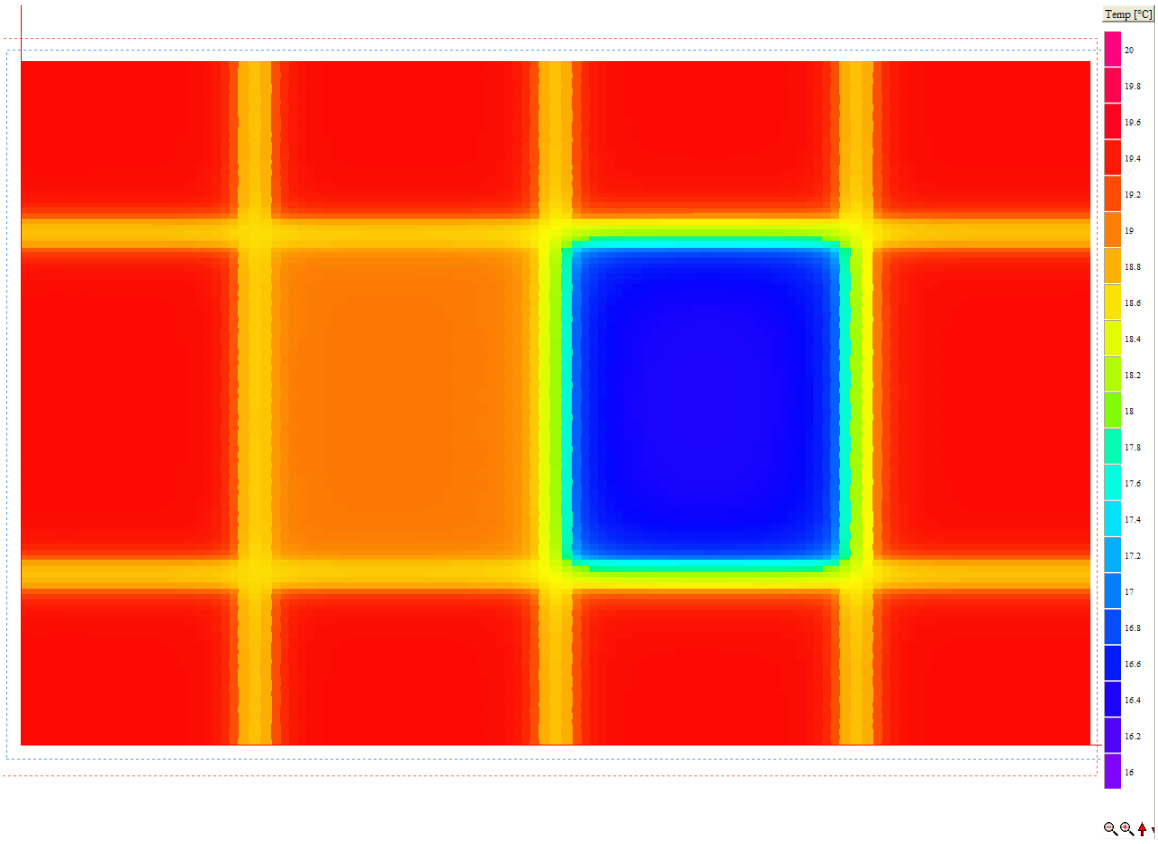

Figure 30: Same as above but temperature span changed from 2K to 4K.

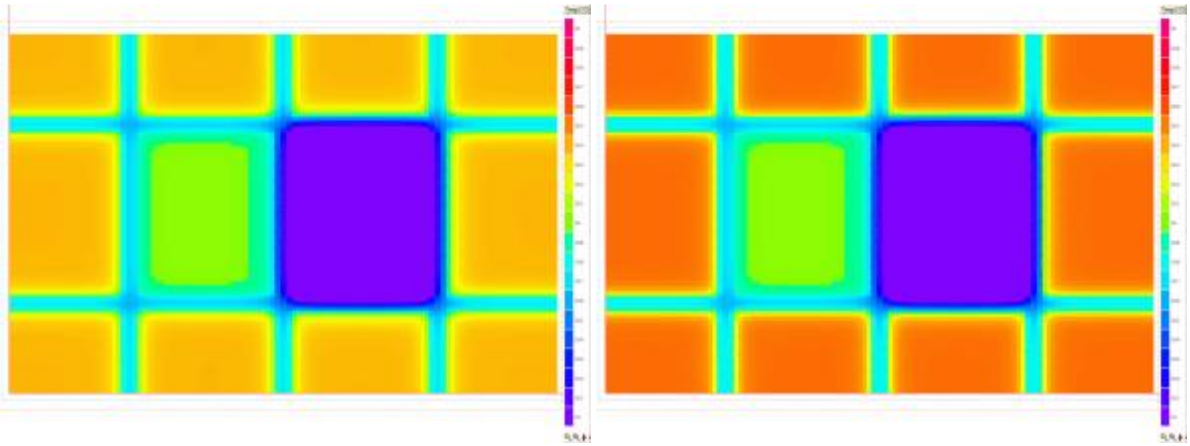

Figure 31: Same as above but using R2.2 insulation instead of R2.6 in left-hand example and using R3.0 in right-hand example.

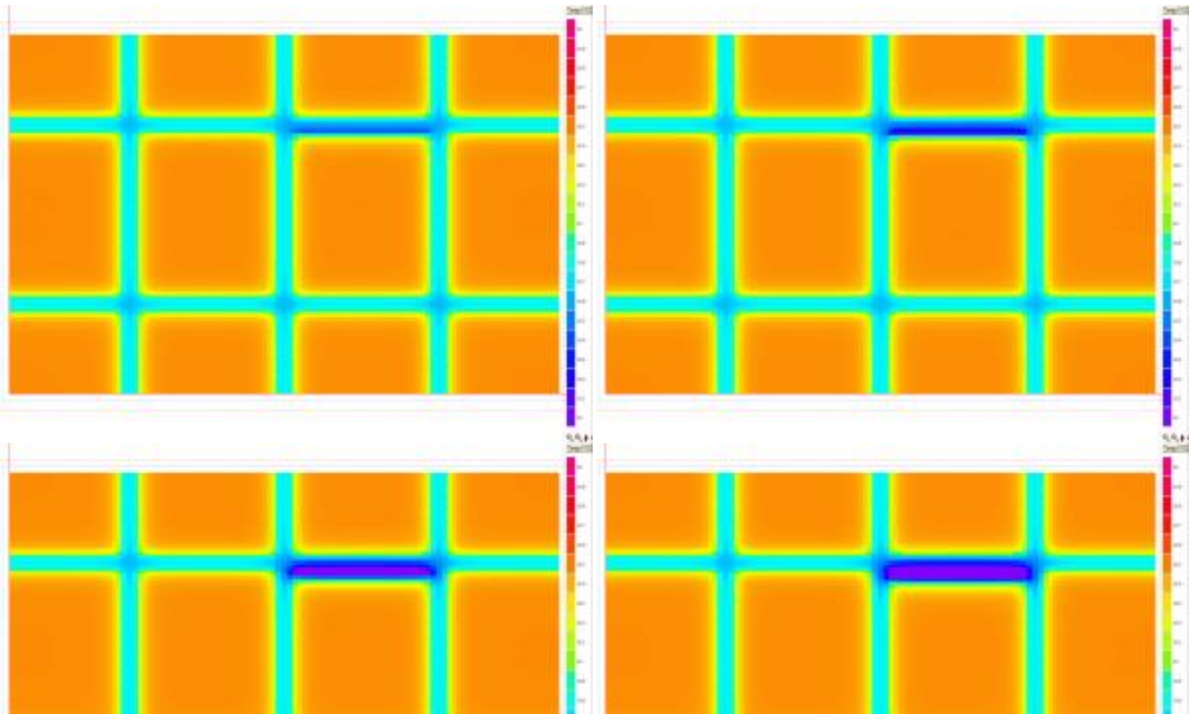

Figure 32: R2.6 insulation with centre right cavity including uninsulated gap between top edge of insulation and underside of dwang. Gap progressively increased from 5 mm to 10 mm, 20 mm and 30 mm.