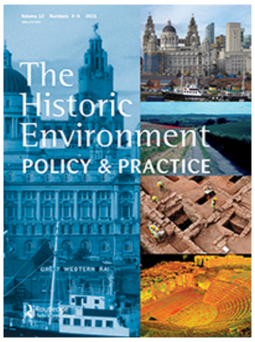

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Thermographic Detection of Hidden Archaeological Features in a Cheshire Thatched Cottage, and Related Aspects of Thermal Performance: Case Study at Roadside Cottage

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ABSTRACT

Thermography can be an important tool for professionals working with traditional buildings. It is recognised by Historic England as providing information on a variety of structural features within buildings. Infrared thermography (IRT) is an acknowledged retrofit tool for reducing carbon emissions from traditional buildings. The paper explores the potential application of thermography as a tool for detecting infrared images emitted by the internal plaster surface of a timber-framed thatched cottage, dating from the 15th/16th century to 20th century. The thermal irregularities from hidden timber features or structural renovations under the thatch can help improve understanding of the evolution of the building and establish the extent of surviving historical fabrics. The images from IRT investigations conducted under different temperature difference conditions in 2010 and 2012 have been compared against the features exposed when re-thatching the property and upgrading insulation levels in 2019. A follow-up survey was carried out in 2021. Related aspects of the thermal performance of the thatched envelope and the effect on internal temperature distribution have also been investigated. The IRT investigations at Roadside Cottage demonstrated the importance of maintaining sufficiently large temperature differences across thatched roof buildings to permit detection of thermal irregularities arising from hidden timber features.

KEYWORDS
Thatched cottage; cruck truss; infrared thermography; hidden archaeological features; traditional timber-framed buildings; thermal properties; u value

Introduction

England and Wales have a notable heritage of vernacular timber architecture. Many of the buildings contain concealed archaeological features that may only be revealed during radical interventions such as re-thatching, rebuilding or demolition. Infra-red thermography (IRT) can provide valuable information on historic buildings, using a non-invasive technique to reveal hidden features and anomalies from surface temperature irregularities.

Thermography can be an important tool for professionals working with traditional buildings. It is recognised by Historic England for providing information on the effectiveness of energy efficiency improvements, levels of deterioration caused by moisture

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ingress, risks created by condensation and location of physical defects as well as electrical faults in historic buildings.[1] IRT is an acknowledged retrofit tool for reducing carbon emissions from traditional buildings.[2]

Studies on detecting hidden archaeological features in historic buildings tend to be on poorly insulated structures, comprised of materials with contrasting thermal properties.[3] However, for traditional thatched properties, detecting hidden features such as timbers and laths can be particularly problematic,[4] since the roof insulation performance is often impressively good,[5] coming close to meeting modern standards for thermal insulation.[6] The high insulation levels tend to result in obscuration of sub-surface anomalies.

This paper explores the potential application of qualitative thermography[7] as a tool for detecting infrared images emitted by the internal plaster surface of a timber-framed thatched cottage dating from the 15th/16th century to 20th century. The thermal irregularities from hidden timber features or structural renovations under the thatch can help improve understanding of the evolution of the building and establish the extent of surviving historical fabrics. The images from infrared thermography (IRT) investigations conducted under different temperature difference conditions in 2010 and 2012 have been compared against the features exposed when re-thatching the property and upgrading insulation levels in 2019. A follow-up survey was carried out in 2021. Related aspects of the thermal performance of the thatched envelope and the effect on internal temperature distribution have also been investigated.

Description of Property and Historical Background

The building that is the subject of the current study, Roadside Cottage, lies in the hamlet of Lindow End, in the parish of Great Warford, south-west of Wilmslow, East Cheshire, England (SJ 81730 78,664). It is a two-storey house, with a rectangular floor plan containing four ground-floor rooms, two upper rooms and a rear, southern, single-storey outshut. It is built in timber and brick with a thatched roof of Norfolk Reed, and was protected as a Grade II Listed Heritage Asset in 1984 (List Entry Number 1,139,548). Although the listing details noted the presence of small timber-framing in the southern elevation, survey work by the South Trafford Archaeological Group in 2011–14 revealed the survival of two cruck trusses in the middle and at the eastern end of the property,[8] as well as extensive timber-framing in the eastern gable and southern elevations, and a demolished third timber-framed bay.

Cruck buildings are one of the earliest building traditions to survive within the region and as such are one of the most significant, and extensive, categories of archaeological evidence for the late Medieval and early Post-Medieval periods in North West England.[9] The cruck blades themselves are large curved timbers, often referred to as blades and usually made of oak. They were formed by splitting or sawing a single curved tree trunk to form timbers roughly 10 to 12 inches (*c*. 0.30 m) thick. Two such blades were then combined as an A-shaped truss, jointed at the top (the apex). Beams running across the two cruck blades three-quarters of the way up (the collar) and at mid-height (tie-beam) made the structure ridged and allowed the crucks to transfer the full weight of the roof to the ground. Pairs of crucks were linked by beams at apex height (the ridge tree) and at mid-height (the purlins), which formed the framework for the roof. In such a structure the side walls were independent of the roof and were not load-bearing, though the mid-height tie-beam was usually extended beyond the line of the blades as far as the feet of the truss to form the seating for the wall plates (the top of the timber-framed external wall). The size of cruck trusses varied depending upon the quality of timber available but in general the truss was as broad as it was high with the wall plates one storey above ground level.[10]

Such buildings are often associated with the earliest settlement within a manor and are thus good indicators of the spread of Medieval settlement within an area. Yet precisely how many cruck buildings were built in Britain remains unknown. The Vernacular Architecture Group, database, freely available to access on the Archaeological Database website (https://archaeologydataservice.ac.uk/archives/view/vag_cruck/) records at least 4,477 true and 2,232 jointed crucks This also shows that there are records for at least 630 known buildings of this type in North West England (that is 16% of all known crucks), with 125 in Cheshire, 226 in Cumbria, 95 in Greater Manchester and 13 in Merseyside. This includes both surviving and demolished or lost structures Two-thirds of the known dated cruck structures in England were built before 1600 and it seems almost certain that the Roadside Cottage example dates from the 15th/16th centuries.,[11, 12]

The long life of cruck buildings meant that they were altered, rebuilt, and expanded on a regular basis. Roadside cottage was no different. The primary phase of the structure was a three bay, cruck-framed, single storey building 4.4 m wide and probably around 14 m long, with a central open hall, (Figures 1 & 2). This was altered probably in the 17th century when the roof was raised and the hall floored over to give room space upstairs. In the 18th century the exterior walls were largely replaced by handmade brick, judging by the dimensions of the bricks used. It was probably at this date that the third bay of the building, at the western end of the structure, was demolished and the building's length reduced to 9.1 m, although excavation work by the South Trafford Archaeological Group in 2013 and 2014 recovered

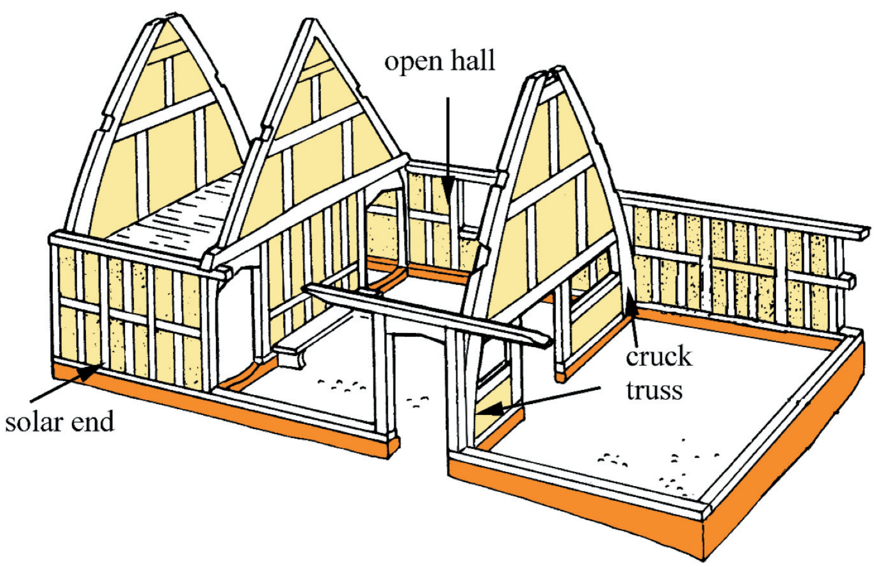

Figure 1. Reconstruction of Medieval Open Hall Cruck-framed House based upon a survey by the South Trafford Archaeological Group and drawn by M Nevell.

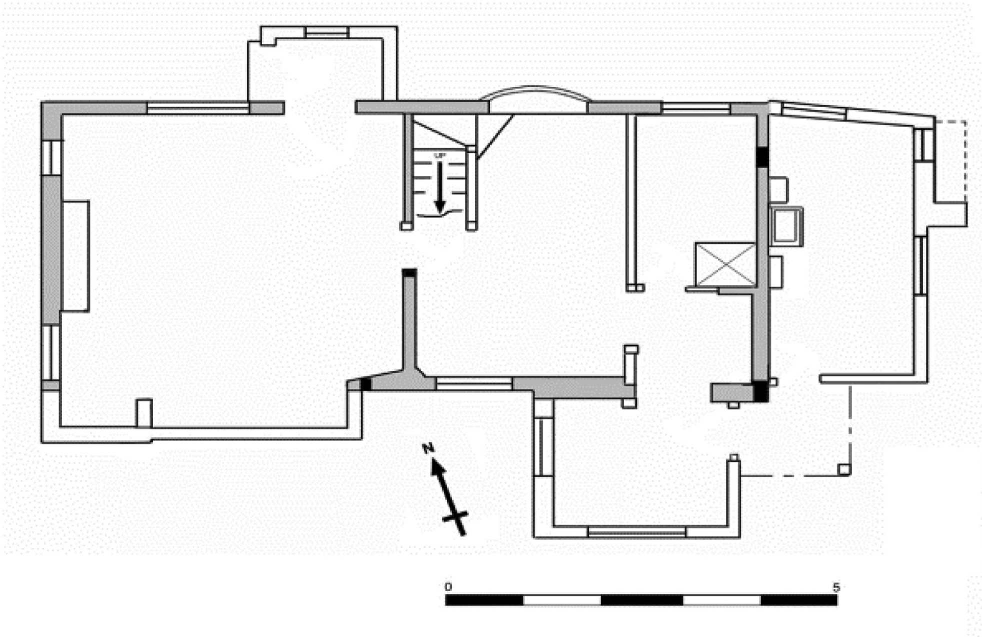

Figure 2. Ground floor plan of Roadside Cottage based upon a survey by the South Trafford Archaeological Group and drawn by M Nevell. The location of the two cruck trusses are shown in black.

evidence for its foundations. The surviving middle bay now became the western bay and was widened to the south. In the later 19th century a second single-story brick-built out shut was added at the south-eastern end of the building and a single-storey brick-bay added to the eastern gable. The interior contains some evidence for minor 20th century alterations.

The current building retains much of the 15th to 17th century timber-framed structure. This includes not only the remains of two cruck trusses but also early roof fabric. Much of this roof structure, the ridge tree, purlins and many of the rafters, appears to be 17th and 18th century in date and presumably coincides with the widening of the hall bay and the raising of the roof line. The current western and eastern gable ends are shown in Figures 3 and 4, respectively.

A 1787 Estate map[13] in Figure 5 shows a 1-m extension to the south-facing lower floor and roof, the outshut, giving the building an 'L shape'. Today, the current building is somewhat truncated from the west by about 4 to 5 m compared to the outline shown on the Estate map. The approximate position of the current gable ends is indicated by dashed lines in Figure 5.

The western gable end appears to have been rebuilt after 1787. This may have been as a result of damage to the original gable elevation due to exposure to prevailing weather from the west, or from waggon traffic negotiating the narrow (< 4-m wide) main highway. According to the 1787 map Roadside Cottage, as the name suggests, was sited immediately adjacent to a road which at the time was the main direct highway between the Cheshire towns of Knutsford and Wilmslow. The modern road now runs some 10 m north

Figure 3. View of Roadside Cottage showing west gable end with ground floor L shape extension to the south (arrow showing area of investigation). Image copyright South Trafford Archaeological Group.

Figure 4. View of Roadside Cottage showing east gable end with ground floor thatched extension. Image copyright South Trafford Archaeological Group.

Figure 5. Stanley Estate Map 1787 Roadside Cottage & settlement – bisected by the old road. *(Courtesy of Cheshire Archives and local Studies, Cheshire Record Office, Duke St Chester, CH1 1RL*).

and parallel to the old road, which has long since disappeared. Today, Roadside Cottage is the only surviving building of a relatively isolated 17th and 18th century hamlet on the southern edge of Lindow Moss.

The surrounding area contains numerous depressions and pits created by the extraction of clay to complete daub infill within nearby timber-framed buildings, as well as for small-scale local brick making activities. A map of soils reported in 1835 confirms the dominance of clay soils in the area.[14] By the early 1700s brick-making had become important near the industrial centres of Macclesfield and Chester.[15] Tithe maps of the 1840s[16] and 1895 /1910 OS maps record an abundance of brick kiln and brick-related field names and sites in the locality of Roadside Cottage,[17, 18] The site of a brickworks is also claimed by the adjacent golf course in 'Burnt Field'. The 1787 Estate map suggests a possible transhipment area close to the cottage, at the junction of the access road to the brickworks and the old highway. It is possible that the occupants in the 18th century (George Ackleston and Thomas Massey are recorded here in 1777 renting 14 statute acres) may have been dual-income farmers involved in brick-making activities.

The thatch roof of Roadside Cottage consists of Norfolk Reed approximately 300 mm thick. The pitch of the roof is generally greater than 45° whereas that over the partial L-shaped extension is somewhat less. As a consequence, an inaccessible space existed between the upper level internal plastered wall and the thatched area above the extension to the south (arrowed in Figure 3). The extension was thought to be roughly coincident with the area of a central hall in the original building. Thermographic investigations were focussed over the upper floor, particularly the internal south facing roof structure, to detect any hidden features behind the internal plastered surface.

Thermographic Investigations and Thatch

The thermal conditions to which a building is exposed during the thermographic examination are important. Cameras for building thermography detect long wave IR (8–14 μm) emitted by objects at temperatures above absolute zero. The warmer the object, the more IR it emits, and for useful thermal images to be recorded there needs to be a temperature contrast across the surface. The bigger the temperature contrast, the better the thermal images. The temperature contrast can be optimised by carrying out thermal imaging during the winter months when the temperature difference between the interior and exterior of buildings is greatest.

This investigation followed a simplified qualitative procedure[31] for an IRT camera to detect thermal irregularities in a building envelope. The thermographic examination was performed with temperature differences across the envelope large enough to permit the detection of meaningful temperature contrast on the surface. It was also important to carry out the survey under steady state conditions of temperature and pressure difference across the envelope. This means that the test should not be carried out when the outside or inside air is liable to vary considerably, or when the structure is exposed to direct solar radiation, or when the wind varies markedly. The radiative properties of the surfaces (emissivity) under examination should also be as uniform as possible.

Thatch roofs are a type of 'warm roof' construction forming a continuous well-insulated layer above the timber structure, rafters and laths. Consequently, timbers and internal surfaces can be maintained relatively dry at enhanced temperatures by the 'tea cosy' effect of the external continuous thatch layer. This effect can be a significant drawback in detecting thermal anomalies under the thatch, since only a small percentage of the temperature drop is across the internal plaster and timber structure beneath the continuous thatch insulation layer. As a result, the range of temperature gradients in the region of hidden features beneath the thatch becomes limited, thereby minimising variations in internal surface temperature profiles. The emissivity of plaster surfaces at Roadside Cottage was consistent, but the materials themselves can be thick, which can contribute towards obscuration of sub-surface thermal anomalies.

A high-performance FLIR B425 infrared camera, with a thermal sensitivity specification of better than 0.05°C, was used to examine the internal plaster surface. An important consideration for the thatched property was the requirement that the temperature difference across the envelope be maintained large enough, and constant, to permit detection of thermal anomalies. Although the property was heated, the temperature differential requirement meant that the number of suitable days of sufficiently low and still outdoor temperature conditions, was limited.

The difficulties in detecting thermal irregularities can also be mitigated by using a higher performance camera. Thermal sensitivity describes how small a temperature difference the camera can detect. The better the thermal sensitivity, the smaller the minimum temperature difference the thermal imaging camera can pick up and visualise. The most advanced thermal imaging cameras for building applications can have a thermal sensitivity of better than 0.03 °C.

Figure 6. Internal view of south facing roof timbers and daub surface. Image copyright South Trafford Archaeological Group.

Thermographic Investigations before Thatch Removal

As shown in Figure 6 the internal surface beneath the thatch was characterised by irregular natural tree branch shapes, roughly hewn roof purlins (approximately 200 mm x 200 mm cross-section) and common rafters (approximately 100 mm x 100 mm cross-section), with painted lime plaster (average thickness 50 mm) in between. Some of the walls retained older daub layers, consisting of a heavy clay, interspersed with chalk and combined with straw. An exposed area of daub can be seen near the top right of the doorway. The rectangular panel at floor level consisted of a 50 mm thick layer of plaster, and was of particular interest as it appeared to conceal an entrance to a potentiallly large space over the extension.

The initial thermographic survey was carried out in daytime in the winter of 2010, under still conditions and a substantial temperature difference ΔT of 19°C. The surface materials were dry at the time of the investigation. The insulation properties of wood are superior to that of the plaster layer and the higher temperature profiles of the substantial timber rafters and purlin are clearly visible in Figure 7. Between the common rafters horizontal bands of slightly warmer surface temperatures are also evident, interpreted to be supporting laths behind the lime plaster layer. Further examination of another part of the ceiling also showed images of laths, irregularly arranged behind the plaster surface (Figure 8).

The image on the rectangular panel surface in Figure 8 suggested the possibility of a window frame 0.8 m wide by 0.6 m high, with a central mullion. In many medieval peasant houses the window was little more than a hole in the wall, closed by a board or cloth/leather. This profile appeared to be a more sophisticated window structure. It is possible that at one time it may have been the area of a ‘smoke’ window vent above a central hall with a central hearth set in the floor and open to the rafters. There is evidence of a simple window smoke vent under the eaves of a 16th century National Trust property in nearby Little Bollington.[19]

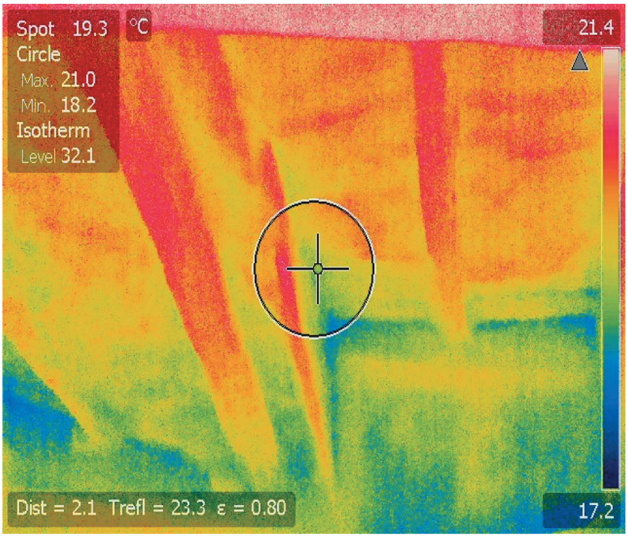

Figure 7. Thermographic image (before upgrade) showing the area of the rectangular panel at floor level and roof timbers above (ΔT = 19°C, $T_{indoors}$ = 21°C). Image copyright Anthony Simpson.

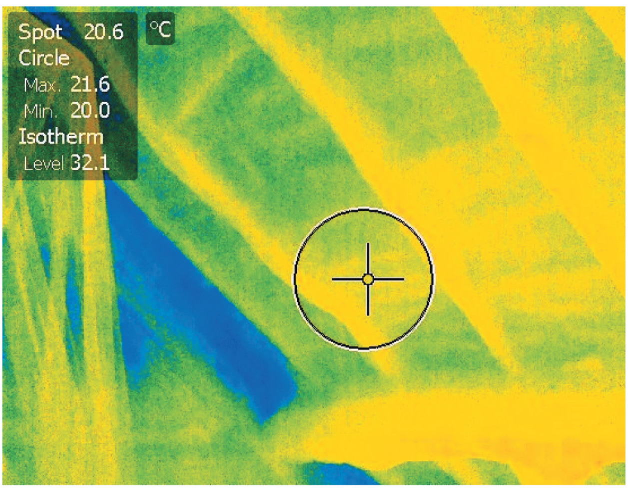

Figure 8. Thermographic image (before upgrade) showing outline of laths between roof timbers above daub coating (ΔT = 19°C, $T_{indoors}$ = 21°C). Image copyright Anthony Simpson.

For comparison, a second daytime thermographic survey was carried out in 2012, with a much reduced ΔT of 9°C, under still conditions of 9°C outdoors and 18°C indoors. In this case the image of the window frame on the panel surface shown in Figure 9 was significantly diminished, only the top 'T' shape being clearly visible. Furthermore, images of a lath structure over the plaster surface were no longer evident under the reduced temperature gradient.

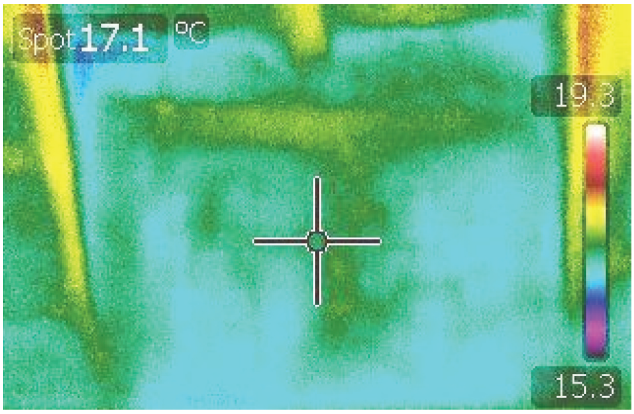

Figure 9. Thermographic image (before upgrade) showing the area of the rectangular panel at floor level (ΔT = 9°C, $T_{indoors}$ = 18°C). Image copyright Anthony Simpson.

Inspection of Roof after Thatch Removal

At the time of the investigations the thatch on the cottage was more than 40 years old. This was removed in July 2019 and the cottage re-thatched, following an upgrade of insulation levels by inserting an additional 50 mm of mineral fibre insulation between the roof timbers, as well as renewing the roofing felt. For a limited time period the area under thermographic investigation was opened for inspection (Figure 10) revealing a very old unglazed dormer window frame, with an infill of clay mortar/brick fragments. The shape, size and position of the dormer matched that of the infrared image observed on the rectangular panel in the inside bedroom in Figure 7. It is thought that the infill took place in the 18th century or earlier when the cottage was extended south forming an L shape, and covered with a new shallower-pitch thatch roof. To avoid window tax many windows in this period were sealed, ready to be reglazed at a later date.[20]

The presence of laths (approximately 70 mm x 10 mm in cross section) was confirmed. The 'horizontal' laths were irregularly arranged and bonded to plaster, as shown in Figure 11. Timber-framing with wattle and daub panels was the dominant form of building construction in many parts of England and Wales from the mid-12th century. Lath eventually became common when plaster superseded daub from the 18th century.[21]

Thermographic Investigations after Insulation Upgrade

Some 20 months after the insulation upgrade and re-thatching of Roadside Cottage a follow-up thermographic survey was carried out in daytime on 8 and 9 March 2021, under relatively still conditions and temperature differences of ΔT = 9 and 15°C.

The increased level of insulation meant that under a temperature gradient of 9°C the image of the T-shape of the window frame on the panel surface shown in Figure 12, was more diffuse and just visible, and images of lath structure no longer evident. However, at an enhanced difference of 15°C the window frame and the lath structure is clearly visible again in Figures 13 and 14.

Figure 10. Infilled dormer-type window frame uncovered during re-thatching in July 2019. Image copyright Anthony Simpson.

Thermal Conductivity/resistance of Thatch

Compared to other traditional roof coverings, thatch has a much larger insulating value because of its greater thickness. In order to assess the thermal performance, the average thickness (300 mm) and thermal conductivity of the Norfolk reed thatch at Roadside Cottage was measured.

Thermal conductivity increases with increasing moisture content. Thatch is naturally weather-resistant, and the increase in moisture content due to water retention is unlikely to be significant, as the hollow reed tubes, and roof pitches of 45° or more, allow precipitation to drain quickly from the roof, before it can penetrate the structure. For elements such as thatch, directly exposed to rain, the average moisture content over the seasons is likely to be variable. The standard moisture content for 'exposed' external walls of rendered or un-rendered masonry directly exposed to the rain, may be conventionally taken to be 5% by weight.[22]

The Thermal Measurement Laboratory (TML) at the University of Salford is a UKAS accredited laboratory and a UK Approved/European Notified Body for the measurement of thermal resistance/thermal conductivity to ISO 8301,[23] BS EN 12667[24] and BS EN 12664.[25] The scope of test standard EN12667 covers measurements for thermal resistances greater than 0.5 m^2K/W. All calibrations were traceable to international standards.

Figure 11. Laths bonded to plaster uncovered during re-thatching in July 2019. Image copyright Anthony Simpson.

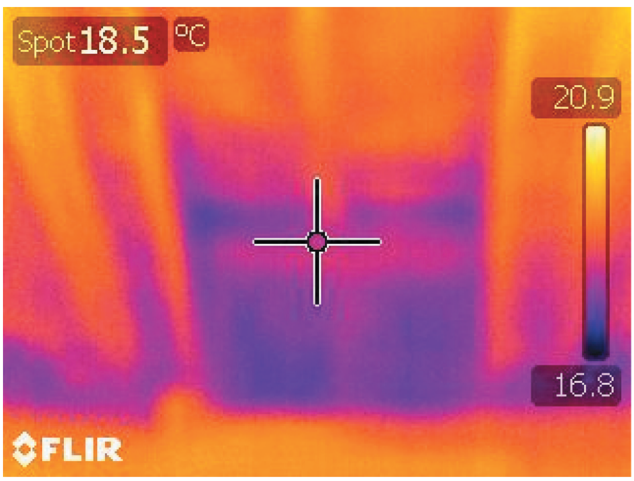

Figure 12. Thermographic image (after upgrade) showing the area of the rectangular panel at floor level and roof timbers above ($\Delta T = 9$°C, $T_{indoors} = 19$°C). Image copyright Anthony Simpson.

A sample of the reed thatch removed from Roadside Cottage was cut to a length of 500 mm and assembled in an insulated test frame (internal dimensions 500 mm x 500 mm square x 180 mm deep), as shown in Figure 15. The thermal conductivity was measured at a sample thickness of 181 mm, under a constant pressure of 7 KPa, using a single specimen 600 × 600 mm square heat flow metre apparatus which complies with test standards ISO 8301 and BS EN 12667.

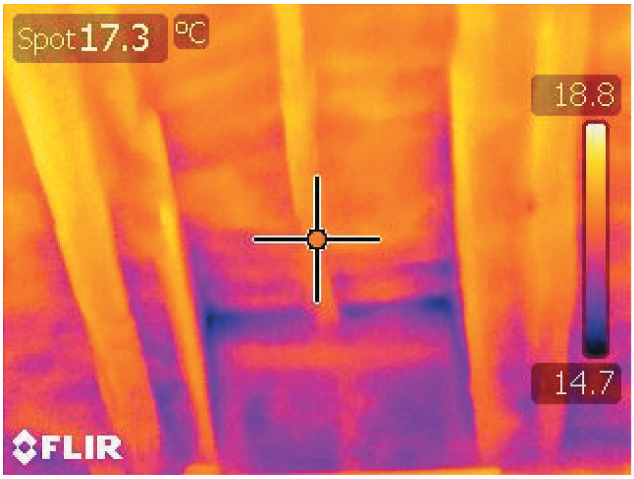

Figure 13. Thermographic image (after upgrade) showing the area of the rectangular panel at floor level and roof timbers above (ΔT = 15°C, $T_{indoors}$ = 17°C). Image copyright Anthony Simpson.

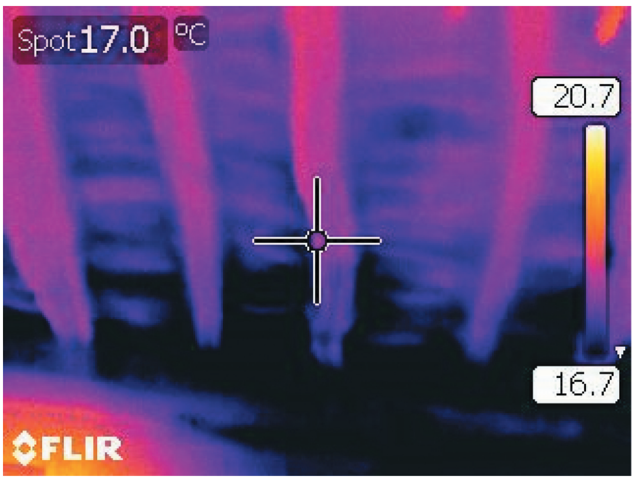

Figure 14. Thermographic image (after upgrade) showing outline of laths between roof timbers above daub coating (ΔT = 15°C, $T_{indoors}$ = 17°C). Image copyright Anthony Simpson.

Based on TML measurements at various moisture contents, the thermal conductivity was found to be 0.066 W/mK at a mean temperature of 10°C for a moisture content of 5% by weight. The derived thermal resistance for 300 mm thickness of exposed thatch, which is given by thickness/thermal conductivity, was found to be an impressive 4.55 m^2K/W. This is similar to thermal resistance levels found in many modern insulation products, albeit thinner, used in building applications (Table 1).

Figure 15. Preparing sample of original thatch removed from the roof for thermal conductivity testing. Image copyright Anthony Simpson.

Table 1. Comparative thickness of modern insulation products to achieve the same thermal resistance as 300 mm of Norfolk Reed Thatch.

Insulation Product	Thermal Conductivity (W/m.K)	Thickness (mm)
Phenolic	0.018–0.020	85
Polyurethane	0.020–0.024	100
Expanded Polystyrene	0.030–0.032	140
Mineral Fibre	0.035	160
Norfolk Reed Thatch	0.066	300

(There is a large range of thermal insulation boards, batts and rolls, which have been tested by the Thermal Measurement Laboratory, offering nominal thermal conductivity performances shown in Table 1)

Thermal Performance and Effect on Temperature Distribution in Thatch Roof

The thermal transmittance (U value) of the thatch roof construction has been calculated based on the accepted method of International Standard EN ISO 6946[26] and conventions for U value calculations BR443.[27]

The thermal resistance R or the ability of an individual component to resist heat flow (m^2K/W) is given by

$$R = d/\lambda \quad (1)$$

where d = thickness (m) and λ = thermal conductivity (W/mK).

For a flat roof the U value can simply be be calculated from

$$U = 1/(R_{si} + R_1 + R_2 + \ldots . + R_{so}) \quad (2)$$

where: R_{si} = inside surface resistance

R_1,R_2 = thermal resistance of components

R_{so} = outside surface resistance.

Traditional thatched cottages will often be a one and a half story structure with sloping ceilings, and the pitch of the roof must be allowed for in calculating U values. For a pitched roof the *U* value is

$$U = 1/((R_{si} + R_1 + R_2 + \ldots . + R_{so}) * \cos\theta) \quad (3)$$

where θ is the angle of pitch.

For discontinuities, due to the presence of dissimilar materials such as timber elements, uni-directional heat flow can be disturbed and thermal bridges formed. For discrete bridges, contained wholly within the main structure where the size of the bridged area in relation to the rest of the structure is small, the proportional area method may be employed to calculate the effective thermal resistance.[32]

For the thatch roof investigated with a pitch of 45° the U value is calculated using Equation (3), and thermal resistance values in Table 2, to be 0.28 W/m^2.K, allowing for the timber components. After upgrade the U value improved to 0.22 W m^2.K (Table 3).

The standard in Part L of the Building Regulations (incorporating 2010, 2011, 2013, 2016 and 2018 amendments) for replacement roofs insulated at rafter level is for a U value of no more than 0.18 W/m^{2}K. The regulation specifies that a reasonable provision for an upgrade is those thermal elements whose U value is greater than a threshold of 0.35 W/m^{2}K. Before any insulation upgrade the Norfolk reed thatched roof at Roadside Cottage came close to meeting modern standards for thermal insulation, being well below the threshold. Building Regulations allow exemptions and special considerations for historic buildings and buildings of traditional construction.[29]

Temperature drops in structures and the thermal resistance of components are directly related. The approximate temperature profile within the thatched structure can be estimated from the ratio of thermal resistance properties of the continuous layers.

Table 2. Thermal properties of continuous layers in thatched roof structure (before upgrade).

Component	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m^{2}K/W)	Data Source
Rso External surface resistance	-	-	0.04	[33]
Rt Norfolk Reed thatch (5% m/c, 91 kg/m^3)	300	0.066	4.55	TML
Ra Ventilated airspace	-	-	0.10	[34]
Rp Lime Plaster 1820 kg/m^3)	50	0.80	0.06	[30]
Rsi Internal surface resistance	-	-	0.10	[35]
Total thermal resistance			4.85	

Table 3. Thermal properties of continuous layers in thatched roof structure (after upgrade).

Component	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m^{2}K/W)	Data Source
Rso External surface resistance	-	-	0.04	[36]
Rt Norfolk Reed thatch (5% m/c, 91 kg/m^3)	300	0.066	4.55	TML
Ri Mineral fibre insulation	50	0.034	1.45	[28]
Ra Ventilated airspace	-	-	0.10	[37]
Rp Lime Plaster (1820 kg/m^3)	50	0.80	0.06	[38]
Rsi Internal surface resistance	-	-	0.10	[39]
Total thermal resistance			6.30	

Calculation of the total thermal resistance, by summing the individual continuous layers, shows that at least 94% of the total is accounted for by the 300 mm thatch layer. This simplified model highlights why temperature gradients across the thatch layer dominate, placing a great restriction on the range of temperatures between the thatch and the internal plaster surface being surveyed, to about 3% of the total.

For both the original and the upgraded thatch roof and an overall temperature differences of 15 and 19°C, there is likely to be a drop of only 0.4 to 0.6°C between the thatch and lime plaster internal surface, while for a 9°C difference it would be proportionally less at about 0.2 to 0.3°C. Estimates suggest that for $\Delta T = 19$°C a 10 mm thick lath, of typical thermal resistance 0.08 m^2K/W, would raise the plaster surface temperature beneath a lath by about 0.05°C This level of increase may just be detectable with high performance cameras (thermal sensitivity specification of < 0.05 K). This emphasises the overriding importance of conducting IRT investigations, to find hidden features beneath thatch, only when temperature gradients are substantial. IRT images of heavier 70 mm thick timber in the hidden dormer framework were found to be stronger, as the contrast of thermal resistance levels was larger, particularly between timber and masonry infill.

Conclusions

The investigations at Roadside Cottage demonstrated that thermal irregularities arising from hidden archaeological timber features in a thatched roof building can be detected by high-performance IRT cameras, providing that the temperature difference across the envelope is sufficiently large. The thermal conductivity of the Norfolk Reed thatch material was measured and the thermal resistance of the 300 mm thick thatch layer determined, indicating that the U value of the roof (0.28 W/m^2K original and 0.22 W/m^2K after insulation upgrade) was close to meeting modern standards for thermal insulation. The thermal resistance of the thatch layer dominated the overall performance, severely restricting the range of temperatures across the hidden timber elements to less than 3% of the total drop between the thatch and plaster surface.

This thermographic study was unusual in that it continued over a period of 11 years embracing the time before and after re-thatching, thereby allowing direct correlation between images and hidden features beneath the thatch. Based on this case study, it is recommended that IRT surveys of hidden features in thatched roofs should be performed with large temperatures drops of over 15°C or more. Under this condition lighter timber elements, such as laths behind the internal plaster surface, were found to be just detectable with a high-performance IRT camera of thermal sensitivity specification $<$ 0.05 K. Although thermographic images were detected at temperature differentials as low as 9°C from a redundant dormer window frame constructed of more substantial timbers with a masonry infill, greater interpretation of the features can be achieved with larger temperature differences or with higher performance IRT cameras. Consideration should also be given to the large range of thatch thicknesses on timber framed buildings, extending up to 500 mm, which can further supress temperature contrast on the surface.

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