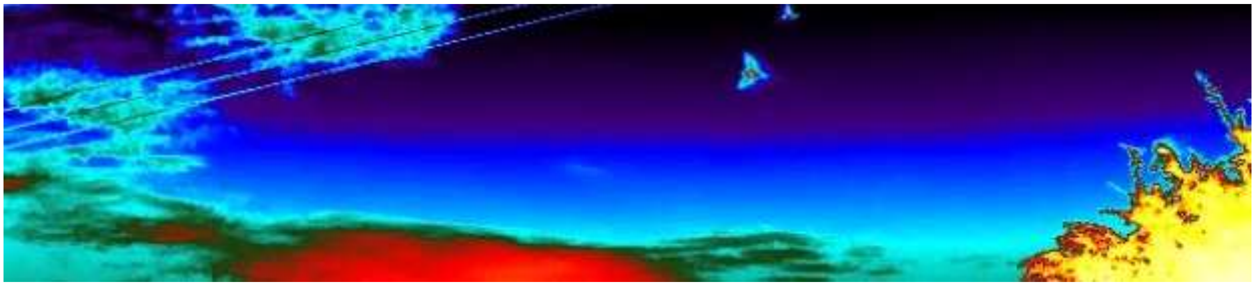

Thermal Imaging: Bat Survey Guidelines

by

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in association

with

The Bat Conservation Trust

Contents

Contents ... 2

Acknowledgements ... 3

1 Introduction ... 1

1.1 Aim ... 1

1.2 What is thermal imaging? ... 1

1.3 Why use thermal imaging for bat surveys? ... 1

1.4 How to use this guidance document ... 2

2 Equipment ... 3

2.1 Level of survey: aid vs method ... 3

2.2 Key considerations ... 5

2.3 Purchase or hire? ... 10

2.4 Accessories ... 12

3 Expertise ... 13

3.1 Knowledge and skills ... 13

4 Survey application ... 15

4.1 Building Surveys: Preliminary Roost Assessments ... 15

4.2 Building Surveys: Emergence and Re-entry ... 15

4.3 Tree Surveys: Preliminary Ground Level Roost Assessments ... 16

4.4 Tree surveys: Emergence and Re-entry ... 16

4.5 Activity surveys ... 16

4.6 Hibernation surveys ... 18

5 Analysis, data management and reporting ... 20

5.1 Analysis ... 20

5.2 Data management ... 22

5.3 Reporting ... 22

6 Health and safety ... 24

6.1 General ... 24

6.2 Assessing the risks ... 24

6.3 Screen use ... 24

6.4 Benefits 25

7 References 1

8 Appendices 2

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1 Introduction

1.1 Aim

This document is aimed at those wishing to use thermal imaging for bat survey work. It is primarily intended for use by ecological consultants surveying for bats; however, the methods described can also be applied to bat conservation and research. At the time of writing, thermal imaging is not widely used as a survey method by UK ecological consultancies. A growing interest in the application of this technique, coupled with the development of more advanced and affordable thermal imaging devices, suggests that there is likely to be a rapid growth in its use for bat (and other wildlife) surveys.

This document is also intended to inform those assessing and evaluating the results of thermal imaging bat surveys. This may include local government ecologists, planning officers and government officials, among others. One of the aims of this document is to give stakeholders a better understanding of thermal imaging, and how it can and should be applied, in order to create meaningful survey results.

1.2 What is thermal imaging?

Thermal imaging is "the science of acquisition and analysis of thermal information from non-contact thermal imaging devices" (Infrared Training Centre (ITC), 2010). Thermal imaging devices detect differences in the natural thermal radiation (heat) of objects in the environment. Thermal imaging devices convert the infrared radiation (heat) they receive into a digital signal. Using software in the thermal imaging device or on an external computer, this signal can be converted into a visual representation of the infrared radiation, known as a thermal image or thermogram.

Thermal imaging is used for a wide range of applications, including: process monitoring, medical, veterinary, research and development, security, and non-destructive testing. Thermal imaging is a non-invasive technique that operates in all light levels. This makes it particularly suited to bat survey applications where light conditions make it otherwise difficult to detect a small, fast-moving object.

1.3 Why use thermal imaging for bat surveys?

Standard bat survey methods – using the naked eye to detect bats – suffer from the effects of visibility bias (Havens & Sharp, 2016) due to deteriorating detection levels in line with levels of available natural light. Because thermal imaging does not rely on the availability of visible light, detectability remains largely constant throughout a typical survey.

Thermal imaging can provide accurate information on roost locations in both trees and built structures. In surveys where thermal imaging data is recorded, it can provide robust evidence of roosting bats and their precise entry and egress points. This evidence is particularly useful in supporting European Protected Species (EPS) licence applications, planning application submissions, project mitigation work, building demolition, or tree-felling works.

1.4 How to use this guidance document

Thermal imaging is a technical discipline and describing its use is often littered with technical terms. This guidance document has been designed to be as reader-friendly as possible, but by its very nature, requires the use of specialist terminology. As such, these specialist terms are shown in purple, in order to direct the reader to the Glossary of terms, provided in Appendix C.

2 Equipment

Choosing the right thermal imaging equipment for the specific application is essential for the collection of good quality, accurate data. There are a wide range of thermal imaging cameras on the market, which are suited to a wide range of different applications. The array of thermal camera models is broadening year on year. At the time of writing, thermal imaging cameras range from small, low-resolution, fixed-lens models and smartphone attachments, through to high-end, interchangeable lens, high-definition and high-speed models. Market prices at the time of writing range from a couple of hundred pounds for a small handheld unit, up to tens of thousands of pounds for high-end models. The purchase price of camera models suitable for use in bat survey applications has dropped dramatically in recent years and is expected to continue to decrease in future years. As with other technologies used for wildlife surveying, different models of thermal imaging devices have their own advantages and limitations.

In order to select the appropriate device, you must understand both the specifications and related limitations of the devices on the market. It is critical that the correct thermal imaging devices are used for specific survey scenarios. If in doubt, consult a certified thermographer who is also an experienced bat ecologist (minimum Thermography Level 1 certification status) for assistance with device selection. To look up a suitably experienced person, see the Thermal Ecologist's Directory for a list of trained individuals.

A key consideration when selecting the correct equipment for your specific survey application(s) is the level of survey you intend to employ.

2.1 Level of survey: aid vs method

Broadly speaking there are currently two levels of thermal imaging survey being used for bat applications: aid and method. Both levels require appropriate training in order to ensure that data is collected and analysed, correctly and consistently.

A survey aid is used alongside standard techniques as per the standard guidance (Collins, 2016). A survey method can be used as a replacement for one or more surveyors as an alternative to standard techniques to provide accurate bat survey data, provided that it is done using the correct equipment by suitably trained personnel. Both levels require appropriate training in order to ensure that data is collected – and analysed, where necessary – correctly and consistently. For more details, please see the Training Checklist, provided in Appendix B.

For an overview of the differences between these two approaches, see below and Table 1.

2.1.1 Survey aid

The simplest level is the survey aid. This involves the surveyor using the standard survey protocol following current guidelines (Collins, 2016) to survey for bats, aided by the use of a thermal imaging device (e.g. scope or handheld camera). The benefit of using thermal imaging as an aid is that it increases survey accuracy in variable light conditions. Surveyors need to be aware of the limitations of using thermal imaging as an aid; such limitations include the following points:

- Bats can be missed during times when the surveyor is not looking at or through the thermal imaging device (e.g. writing observation notes or mapping flight paths).
- Equipment with narrow fields of view (e.g. scopes) limit the width of an area that can be surveyed by an individual surveyor.
- Display glare can occur when switching between note-taking and thermal imaging device use.

2.1.2 Survey method

The most comprehensive and accurate level is the thermal survey method. This involves the use of a thermal imaging camera system to record thermal video files (radiometric or non-radiometric), which can then be analysed post-survey. Radiometric files provide the most accurate data and these should be used where possible. Some situations may require the use of non-radiometric data recording to an SD (Secure Digital) card – for example, where a laptop cannot be used on site for health and safety reasons. Using thermal imaging as a survey method generally has higher set-up costs than those associated with the survey aid approach. The survey method can be used instead of, or in combination with, standard techniques, as detailed in Collins (2016).

Table 1 Comparison table – thermal imaging as a survey aid vs survey method

Survey Aid		**Survey Method**	
Advantage	Disadvantage	Advantage	Disadvantage
Avoids visibility bias (better than the human eye in lower light levels)	Prone to human error as may miss bats when scribing	Suitable systems give a high level of accuracy	Higher level of expertise required for survey planning and system operation
Video recording capability not required,	Without video recording there is no	Can cover greater areas than a surveyor,	Higher specification systems required

Survey Aid		Survey Method	
Advantage	Disadvantage	Advantage	Disadvantage
allowing for the use of lower specification devices at relatively low cost	scope to revisit footage to check data (e.g. to verify count data)	lowering number of surveyors/night hours worked	
Allows for use of devices which are more user friendly, requiring a lower level of technical expertise	Devices popular for use as an aid often have limited fields of view, limiting the features that can be covered by the surveyor	Ability to conduct analysis of recorded survey data gives a high level of accuracy	Time, cost and expertise required to carry out analysis
Moderate reduction in human error regarding detection and recognition of bats		Significant reduction in human error regarding detection and recognition of bats	

2.1.3 Species identification

It is important to distinguish between the key levels of discrimination achievable using thermal imaging technology: detection, recognition and identification (Havens & Sharp, 2016). Thermal imaging can be used to detect and recognise bats, but it cannot currently be used to identify bats to species level. For all survey types detailed within these guidelines, **thermal imaging should be used in combination with acoustic recording equipment to enable species identification**. For details of appropriate specifications of acoustic recording equipment, readers should refer to Collins (2016).

2.2 Key considerations

2.2.1 Technical requirements

Choosing the right equipment for the specific survey application is key to survey accuracy. Equipment specifications limit the number and range of survey types that can be completed (see Appendix A for a Quick Reference Guide to Thermal Imaging Bat Survey Device Specifications). The following technical requirements comprise the minimum that should be considered. It is important to note that some applications will require higher specifications. **Lower specifications than those detailed below are not appropriate for consultancy work.**

2.2.2 Spectral range

Thermal detectors are sensitive to infrared radiation in specific wavelength bands, or a spectral range. In general, devices suitable for bat survey applications fall within the Long Wave (LW/LWIR) spectral range category. Some Medium Wave (MW/MWIR) devices can also be used for bat surveys, but these tend to be very high-end cameras, more suited to research and development applications.

2.2.3 Temperature range

For any thermal imaging application, the thermal imaging device should be capable of displaying the temperature range of the background (building/trees etc.) and the target (bat). Thermal imaging devices with an optimal temperature range of -40℃ to +120℃ are adequate for bat survey applications.

2.2.4 Video recording capacity

Survey Aid

Video recording capability is not essential when using thermal imaging as an aid to standard bat surveys. However, the option to record videos may be desirable if surveyors wish to have the ability to check their footage later and correlate observed behaviour with their acoustic recordings. Recording also has the advantage of providing evidence later on, should it be needed.

Survey Method

Video recording capability is an essential requirement when using thermal imaging as a survey method. For the most accurate survey data, thermal imaging video data should be recorded and stored as radiometric data files. Where this is not possible[1], video data can be recorded in a more mainstream video file format such as .AVI or .MOV (for more details on the comparison of file types, see section 5 of this document).

Video recording options for thermal imaging as a survey method are:

- Radiometric data recorded directly to a laptop – this is the most accurate method and provides the highest quality data. Images can be optimised during analysis.

[1] There will be survey scenarios where it is not possible to record onto a laptop or external recording device. This includes situations where it would be considered unsafe to take a laptop/external device onto site (e.g. high-risk urban areas), or where there is limited space for equipment (e.g. surveying from an elevated platform), or aerial surveys where there is no other practical alternative.

- Radiometric data recorded to an internal SD card – this often results in lower frame rates than required and video quality can be lower. Images can be optimised during analysis.
- Non-radiometric video – this is the least accurate option. Images cannot be optimised during analysis.

2.2.5 Refresh rate

In order to detect and recognise bats in flight, thermal imaging devices with a **video frame rate of 30 Hz or greater are recommended.** Lower frame rates will not provide images of sufficient quality, necessary for the accurate detection of bats in flight and will result in bats being missed.

It is important to check that your actual viewing, or recorded frame rates, are in line with these frame rate requirements. In some circumstances, frame rates decrease during recording due to connection issues, memory card issues, disk speed etc. If this goes unnoticed, bats will be missed. Where it is necessary to use SD cards as an alternative to direct recording onto a laptop, operators should ensure that they have selected an appropriate card speed (see the device manufacturer's guidance) and that the cards have been properly formatted before use.

2.2.6 Cooled or uncooled

The majority of thermal imaging equipment on the market are known as 'uncooled' devices. This means that the detector within the thermal imaging device does not require cryogenic cooling in order to operate. Uncooled cameras are non-invasive and run with little or no noise output, making them ideal for surveying for, or studying bats, with minimal disturbance. Uncooled cameras are generally cheaper and have a better longevity than cooled cameras. In general, uncooled cameras are most appropriate for bat survey applications.

Cooled cameras are high-end specialist thermal imaging cameras that can achieve very high frame rates, thermal sensitivity and quality imagery. These cameras are not necessary for use in bat survey applications, but may be highly desirable for commercial filming or research studies of bats. It should be noted that cooled cameras can be very noisy, which could give rise to disturbance issues and should therefore be used with caution; they should not be used within, or close to bat roosts, when bats are present.

2.2.7 Thermal sensitivity

Thermal sensitivity is generally specified by the NETD (Noise Equivalent Temperature Difference), which is expressed in mK (milli-Kelvin). The lower the NETD number quoted, the better the thermal sensitivity. A thermal sensitivity of 20–50 mK is required for bat survey applications. For more information on NETD, see Havens & Sharp (2016).

2.2.8 Detector resolution

An image size of 320 x 256 pixels is realistically the lowest detector resolution that is useful for bat surveys; however, it should be noted that a resolution of this size will limit the user to small-scale applications (see below). A higher number of pixels (e.g. 640 x 480 or 1020 x 768, which are commonly available) will detect smaller objects at greater distances and therefore higher resolutions will allow for a wider range of survey applications. For example, a device with a resolution of 320 x 256 will be limited to a detection distance of 30–112m, depending on the lens used. This limits the user to survey applications of relatively small structures (such as a discreet feature on a tree or building, or coverage of a small building) and at relatively short range. In contrast, a device with a resolution of 1020 x 768 allows for the detection of bats in flight at much greater distances. Depending on the lens used, this device could achieve detection distances of 104–392m, depending on the lens used. This opens up the possibility of a much wider range of survey applications, including those of large buildings and linear infrastructure schemes.

In some devices, the detector resolution is different to the display resolution. **Care should be taken to ensure that these are not confused**. **Always refer to the <u>detector</u> resolution when assessing a device for a survey application.**

2.2.9 Digital zoom

Some cameras have a digital zoom function. This increases the size of an object **but does not improve the true resolution.**

2.2.10 Lenses

Selecting the correct lens is vital to achieving an adequate survey result; the lens will determine your field of view (FOV), which is key to successfully covering your target survey area.

Some devices have fixed lenses and others have interchangeable lenses. The choice of interchangeable lenses gives the user more flexibility in the survey types they can accomplish with a single device. At the time of writing, optical zoom lenses are not available – cameras are supplied with a single fixed lens or the ability to purchase additional lenses with different FOV.

It is important to select the correct lens for your survey application:

- Wide-angle lenses lend themselves well to emergence/re-entry surveys of built structures where the device can be located relatively close to the structure in question.
- Narrow-angle lenses, which tend to have longer detection distances, are more suited to activity surveys of linear features, or to surveying structures or trees from a vantage point at a distance.

The surveyor must select a lens which enables the bat to be detected within the survey area (see Table 2 below); the surveyor must ensure that the device and lens combination allows them to detect a bat from the device location.

Table 2 Detection distances for a common pipistrelle (*Pipistrellus pipistrellus*) when roosting and in flight

Resolution (pixels)	Lens (degrees)	Maximum detection distance (m) – body length/roosting bat	Maximum detection distance (m) – wingspan/bat in flight
320 x 256	48	6	30
	24	10	62
	13	20	112
640 x 512	45	12	66
	25	20	118
	12.4	42	236
640 x 480	45	12	66

Resolution (pixels)	Lens (degrees)	Maximum detection distance (m) – body length/roosting bat	Maximum detection distance (m) – wingspan/bat in flight
1024 x 768	25	20	118
	15	34	196
	45	18	104
	28	30	168
	12	68	392

2.3 Purchase or hire?

2.3.1 Purchasing

Although prices continue to drop with advances in thermal imaging technology, buying a thermal camera is still a comparatively large capital investment for the bat surveyor. When selecting a thermal imaging device, the overall application needs should be carefully considered and matched to the appropriate camera specifications. If you are unsure as to what camera model specifications are required you should consult a certified thermographer who is also an experienced bat ecologist (see the Thermal Ecologist's Directory for a list).

2.3.2 Hiring

If you are new to thermal imaging, or you are only planning to use it for short periods of time, it may be prudent to hire equipment appropriate to your needs (see Thermal Ecologist's Directory). This may allow costs to be built into project budgets for specific surveys.

2.3.3 Insurance

Whether you are hiring or buying a thermal camera, it is advisable to ensure that you are adequately covered by insurance for your equipment. If you are hiring, your supplier may require you to have cover for the full replacement value of the camera system.

2.3.4 Weatherproofing

Thermal imaging devices were not designed with bat survey applications in mind. Therefore, not all cameras are suitably weatherproof for bat survey environments. When selecting a camera, assess how weatherproof it is by looking at its International Protection (IP) Rating (International Electrotechnical Commission, 2013). IP Ratings, or codes, classify the level of protection an electrical enclosure provides against external agents, including dust and water. You can find comprehensive guidance on how to read IP ratings here: http://www.enclosurecompany.com/ip-ratings-explained.php.

Should your device not provide adequate protection against the elements, weatherproof housing can be used. These can be purchased readymade for selected models; for others, custom made weatherproof housing may be needed. Housings should have an appropriate IR window for the wavelength band of your device. Standard glass must not be used. If in doubt, consult a certified thermographer for clarification on the suitability of weatherproof housings and IR windows.

2.3.5 Calibration

Thermal imaging devices should be calibrated annually. A calibration check assesses the performance of the thermal device against the manufacturer's specifications and ensures that the device is within the stated accuracy parameters. This process is carried out under environmentally controlled laboratory conditions. This should be completed by the device manufacturer or a certified laboratory, in accordance with national standards. To find the nearest local laboratory, contact the supplier or manufacturer of your specific thermal imaging device. The laboratory conducting the calibration will issue a calibration certificate, which you should keep for your records, along with notes on the performance of the thermal imaging device. It is important to read through these notes to ensure that there were no issues with the device. If issues are detected, these should be rectified before the camera is used for bat survey applications. Although such issues are rare, it is advisable to carry this out over the winter period to reduce any risks to surveys being delayed or cancelled due to technical issues during the survey season.

Calibration is carried out to prevent the effects caused by thermal drift, when the performance of the device deteriorates over time. If this is not carried out, the distance over which you can detect a bat could be greatly reduced, thus invalidating your survey.

When buying or hiring equipment, surveyors should ensure that thermal imaging devices have a valid calibration certificate.

2.4 Accessories

It is important to consider what accessories might be needed to run the thermal imaging device as part of a system, including:

- additional lenses
- tripod
- laptop
- data storage
- power supply
- travel solutions (eg. rucksacks, trolleys, used to move equipment to site)
- weatherproofing.

A good quality, sturdy tripod should be selected, capable of supporting a total load of the weight of the body of the camera and the lens combined. Using an inappropriate tripod puts expensive equipment at risk of damage and can lead to poor data quality, which may be unsuitable for later analysis. Where necessary, consider securing the tripod to reduce movement or accidents. When using semi-automation software to assist the analysis process, it is essential that the tripod enables the surveyor to keep the camera still from the first to the last frame of recording (see section 5 of this document for more details on semi-automation software).

3 Expertise

3.1 Knowledge and skills

Infrared thermography is a specialist technical subject. An understanding of the theory behind the science and the limitations of the technology is necessary to using thermal imaging equipment effectively.

It is essential that ecologists have the correct knowledge and skills in order to deliver good quality, accurate thermal imaging bat survey data for any project. The four key tasks to be completed in a thermal imaging bat survey project are:

1. planning
2. camera operation
3. analysis
4. reporting.

These tasks may be carried out by individual specialists who undertake separate key tasks, or by a single individual who can carry out all steps in the process.

3.1.1 Survey Aid

Ecologists wishing to use thermal imaging as an aid to their bat survey work should ensure that they understand the limitations of their equipment. They must have a working knowledge of basic thermal science and be competent in the use of their chosen device. For a comprehensive breakdown of the knowledge requirements, see Thermal Imaging Bat Surveyor Training Checklist (Appendix B).

Training to use thermal imaging as a survey aid is less intensive than that required for the survey method approach. For training at survey aid level, see the Bat Conservation Trust's website for available training courses, here: https://www.bats.org.uk/our-work/training-and-conferences.

3.1.2 Survey Method

In order to use thermal imaging as a bat survey method, ecologists must have the appropriate expertise. This requires training in thermal science theory, practical equipment use and software application. At the time of writing there are two routes to obtaining the necessary skills and experience:

- receive specialist training from a Trainer who is a professional thermographer (minimum Thermography Level 2) who is also an experienced professional bat ecologist (see Thermal Ecologist's Directory);

or, alternatively,

- experienced bat surveyors may choose to attend a professional thermography course (such as the Level 1/2/3 Thermography Certification – see Thermal Ecologist Directory for a list of training providers), followed by bat-specific training from a Trainer (see first point above) and Continuing Professional Development (CPD).

You do not need to be a certified thermographer to be a competent thermal imaging bat surveyor. However, in order to be considered competent, surveyors do need to have acquired an appropriate level of knowledge and skills (see Thermal Imaging Bat Surveyor Training Checklist in Appendix B).

4 Survey application

4.1 Building Surveys: Preliminary Roost Assessments

Thermal imaging should never be used as a replacement for an internal inspection, as detailed in Mitchell-Jones & McLeish (2004), and Collins (2016). Thermal imaging cannot 'see through' solid objects, as previously discussed in section 4.1. It will not, therefore, detect bats through walls, roofing felt, stud walls etc. It may identify thermal patterns associated with bats behind a surface, but this should not be relied upon, as such patterns could also be produced by variations in moisture, geometry and emissivity. Thermal imaging will not detect torpid bats on or behind a solid surface.

However, thermal imaging can be used as an additional/complementary tool to aid internal inspections. In open roof spaces, it may be used to observe free-hanging bats. This provides an alternative to shining light (of any wavelength) onto roosting bats, allowing the surveyor to count free-hanging bats with minimal disturbance. This technique should only be used for this application under appropriate environmental conditions. Use of equipment under poor conditions (e.g. high temperature and/or high humidity) can lead to false negative results. It should, therefore, only be used by suitably trained (and licensed) individuals who understand these limitations (see section 3.1.1 of this document).

4.2 Building Surveys: Emergence and Re-entry

Thermal imaging can be used to provide accurate and reliable data relating to dusk emergence surveys and dawn re-entry surveys of a range of built structures.

Thermal imaging is essential for surveys of built structures where the surveyor is at a distance from the potential emergence point (e.g. high structures such as large buildings or towers), where light levels are low (e.g. under bridges and in tunnels) and/or where the number of surveyors required would be prohibitively high (e.g. complex buildings).

Thermal imaging is very useful as a survey tool for emergence and/or re-entry surveys of bridges. Using this method for such surveys can remove ambiguity associated with standard techniques, reducing the likelihood of false positives and false negatives.

Thermal imaging can also be used for smaller built structures, such as domestic houses and outbuildings.

For any built structure, thermal imaging is very useful for late emerging species and particularly for those that are difficult to detect using the traditional methods due to their quiet or directional echolocation calls.

For any species, thermal imaging provides a distinct advantage over traditional methods in shaded areas where light levels are low, even before sunset or after sunrise. This includes courtyards and structures surrounded by high vegetation, walls or fences.

4.3 Tree Surveys: Preliminary Ground Level Roost Assessments

Thermal imaging is not suitable for preliminary ground-level assessments of trees. This is because thermal imaging cannot 'see through' objects, including tree trunks and branches. 'Hotspots' – thermal patterns or signatures detected from the surface of a tree – cannot be attributed to bat roosts. This is because such patterns can also be created by humidity, geometry and material anomalies. For this reason, thermal imaging should **never** be used as a replacement for ground-level or tree climbing surveys to assess trees for bat roost potential or presence (for suitable methods, see Collins (2016)).

4.4 Tree surveys: Emergence and Re-entry

Thermal imaging is a very important tool for dusk emergence and dawn re-entry surveys of trees. It allows for the detection of bats emerging from and/or re-entering roosts at high elevations and/or in low light levels, where ground-based surveyors using standard methods would be unable to detect bats with the naked eye.

For any potential tree roost survey, thermal imaging is essential for visual detection of late emerging species and particularly for those that are difficult to detect using the traditional methods due to their quiet or directional echolocation calls.

Thermal imaging provides a distinct advantage over traditional methods in shaded areas, particularly in woodland, where light levels are low even before sunset or after sunrise.

4.5 Activity surveys

Thermal imaging can be used to provide data on bat activity that cannot be obtained using standard/acoustic methods. It is important to use thermal imaging for projects where knowledge of the spatial patterns of bat activity is key to the understanding of the potential effects of development on bat populations. Thermal imaging data can also be critical when informing the design of effective mitigation.

While acoustic data can provide information on likely species presence and number of calls, or call sequences, it does not allow the ecologist to distinguish between, for example, a single bat flying in circles versus multiple bats commuting across the landscape, which thermal imaging does. Thermal imaging can also be used to monitor bat activity post-development. This can include monitoring of mitigation measures, such as green bridges, hedgerow planting and other connectivity measures, in order to accurately assess their effectiveness.

Thermal imaging activity surveys are most efficient for looking at:

- inaccessible or restricted-access sites, such as active infrastructure or watercourses (note that necessary permissions and legalities must still be observed)
- spatial relationships at the landscape scale to inform the design and mitigation of large-scale projects.

Thermal imaging can be used for wind farm projects for both pre-construction surveys and post-construction monitoring (Scottish Natural Heritage et al, 2019). For pre-construction monitoring surveys, this allows for collection of data on flight lines and foraging behaviour. It can also provide other important behavioural information, particularly during post-construction monitoring, when bat behaviour may change due to the presence of wind turbines.

The timing of activity surveys should be considered carefully. Where a general thermal imaging bat activity survey is required, or where previous information on bat activity is not available, **thermal imaging bat activity surveys should commence from sunset for a minimum period of two hours.** Targeted thermal imaging bat activity surveys focus on specific species, species groups or locations. Such surveys can be planned where acoustic data on temporal bat activity in the survey area is available. This enables survey timings to be planned to sample at key times and places of interest. **Each targeted survey should last for a minimum of two hours, unless the surveyor can justify why this length of survey is not required for a particular scenario.**

Thermal imaging is rarely used for bat activity surveys due to the costs of analysis. As such, it is generally only used in situations where other methods are insufficient to provide the required data. It is envisaged that this will change once semi-automatic procedures are more readily available.

4.6 Hibernation surveys

Thermal imaging is not suitable for hibernation inspection surveys. Even with very sensitive thermal imaging equipment, torpid bats are so closely matched in temperature (and also often emissivity) to their surroundings, they simply blend into the background in a thermal image.

However, thermal imaging could be used within a hibernacula to monitor movements of bats over a winter period. This would enable the detection of bats when they wake periodically from torpor over the course of the hibernation period. This has not, to our knowledge, been trialled, but could be applied on a secure site where such data might be required. In general, most cameras that are available, accessible and suitable for bat survey use, require the presence of a suitably qualified operator. Custom or specialist systems can be procured for remote monitoring, however, this is not currently a commonly used setup. As technology develops, this is likely to become an option for future use.

Table 3 Suitability of Thermal Imaging as a Tool for Specific Bat Survey Applications

Bat Survey Application	Suitable for Thermal Imaging?	Notes
Hibernacula – Manual Survey Visits	No	
Hibernacula – Remote Monitoring	Yes	Suitable for use where the survey site is safe and secure (e.g. locked, a gated tunnel or underground site). Can be used to detect bats when they rouse from torpor periodically – providing information on hibernation locations across the survey period.
Built Structures – Bridge Emergence/Re-entry Surveys	Yes	
Built Structures – Building Emergence/Re-entry Surveys	Yes	
Built Structures – Autumn Swarming Surveys	Yes	
Built Structures – Internal Inspection Bats roosting in or behind solid structures	No	Bats roosting in buildings cannot be detected solely using thermal imaging during internal assessments of built structures. Thermal Imaging should not be used for this application. Refer to Collins (2016) for appropriate methods for this survey application.
Built Structures – Internal Inspection **As an aid ONLY**	Yes	This technique may be used to aid licensed surveyors counting free-hanging bats in open roof structures.
Trees – Emergence/Re-entry Surveys	Yes	

Bat Survey Application	Suitable for Thermal Imaging?	Notes
Trees – Preliminary Ground-level Assessments	No	Bats roosting in trees cannot be detected during preliminary ground-level tree assessments. Thermal imaging should not be used for this application. Refer to Collins (2016) for appropriate methods for this survey application.
Activity Surveys	Yes	This survey application requires careful planning to ensure adequate spatial coverage. Analysis for this survey application can be time and cost intensive, and this should be taken into account in the project planning stages.
Infrastructure Projects – Activity Surveys	Yes	This survey application requires careful planning to ensure adequate spatial coverage. Analysis for this survey application can be time and cost intensive, and this should be taken in to account in the project planning stages.
Wind Farm Projects – Activity Surveys	Yes	This survey application requires careful planning to ensure adequate spatial coverage. Analysis for this survey application can be time and cost intensive, and this should be taken in to account in the project planning stages.

5 Analysis, data management and reporting

5.1 Analysis

5.1.1 Survey Aid

When using thermal imaging as a survey aid, data is collected during the survey itself. This means that further analysis is not necessary. However, surveyors with equipment capable of recording, may wish to review their recorded footage in order to:

- increase their survey accuracy and accountability
- access it for future reference, or evidence, if required.

5.1.2 Survey Method

When using thermal imaging as a survey method, data is analysed in depth after the survey is complete. Radiometric thermal imaging files give the most accurate data outputs as they allow image optimisation, which greatly improves detection, especially where there are complex/cluttered background conditions (e.g. vegetation). Data should be analysed by a trained analyst using specialist software programmes (e.g. FLIR Tools+ or Research MaxIR) as recommended by the equipment manufacturer.

Processing radiometric files involves the following steps:

- image optimisation using colour palette and thermal span parameters within the relevant software package
- review of footage in Real-Time (periodically optimising the images as necessary)
- documentation of each bat flight event in a specifically designed proforma
- correlation of thermal flight events with acoustic data (in order to identify the bat to species level where possible).

For some projects it may also be necessary to map flight events (e.g. activity surveys where spatial patterns are important) although this adds considerable time and cost implications to a project.

Non-radiometric files (e.g. .AVI or .MOV) should be analysed by an experienced analyst. Unlike the radiometric data, non-radiometric files cannot be optimised during post-survey processing. This restricts thermal parameters to those selected during the survey set-up process, making it particularly important that these are correctly adjusted by the camera operator at the time of survey. The analyst will watch all recorded thermal video footage in Real-Time and document bat flight events in a specifically designed proforma. The analyst may also map flight events, depending on project data requirements.

Emergence or re-entry survey data analysis outputs generally include the time, and the numbers and locations of bats emerging and/or re-entering the roost. Flight event mapping is generally only required when specific design features could impede key flight lines, including installation of potential barriers to movement such as:

- lighting
- stairwells
- building extensions.

In such cases, flight events should be mapped in relation to potential obstructions, where possible.

Analysis of activity survey data can be particularly time consuming. Often this will not only involve documentation of flight events, but also mapping of flight lines in relation to the existing habitats and/or the proposed development scheme. As such, thermal imaging is rarely used for this application due to prohibitive associated costs. However, for some project applications it is necessary to use this technique in order to collect adequate data on bat flight lines at landscape scale. This is particularly important when considering large scale schemes, such as infrastructure projects, where spatial patterns of bat activity are key to predicting potential effects, designing mitigation and planning monitoring of such schemes. Accurate analysis of thermal imaging bat activity footage requires the use of radiometric data recordings.

Analysis of both radiometric and non-radiometric files is a time-consuming process, which can be a considerable factor in overall costs of thermal imaging bat surveys. Semi-automatic analysis programs have been developed to assist in the handling of thermal imaging data, collected during bat surveys. At the time of writing, such a program is ready for testing with known datasets and, subject to resources, should be available for use in 2020/2021 (KFW Scientific & Creative, *in development*). The availability of such software will make thermal imaging bat survey projects more cost effective and more widely applicable. Such software will require data to be collected in accordance with strict protocols in order for it to improve the efficiency of data processing. In the meantime, it is important that survey data analysis is planned properly to allow for the most efficient processing, in order to obtain the required data outputs.

Bats do not always echolocate (Chiu et al, 2008) and when they do, emitted echolocation calls can be highly directional (Surlykke et al, 2009); therefore, analysts must review *all* thermal imaging survey footage recorded and must not limit their review to footage associated with echolocation calls detected on acoustic recording devices only. The latter approach could result in bats being missed. This consideration is particularly important for later emerging species with quieter echolocation calls.

5.2 Data management

Radiometric data files are space-hungry. It is therefore **essential that data management systems are planned in advance of data collection so that sufficient storage space is allocated**. Recording directly to an appropriately specified laptop and then transferring recorded files to a hard disk drive (HDD) for short term storage is recommended. These can then be backed up onto a server later. Shockproof and waterproof HDDs are available and are very useful for field survey use. It is essential that HDDs are correctly formatted before use.

5.3 Reporting

A well written report is key to the success of any thermal imaging bat survey project. However well a project is planned, conducted and analysed, this is all wasted effort without a report to communicate the relevant information to all stakeholders.

Thermal imaging bat survey projects should be reported by an experienced bat ecologist who is also a trained thermal imaging professional (either as a certified thermographer or a trained camera operator) who can interpret and communicate the survey methodology, analysis procedure, survey results and their potential implications to the reader.

Thermal imaging bat survey reports should provide the following information in a clear and robust way:

- level of survey used: aid or method
- rationale for the chosen survey methodology
- thermal imaging equipment used (including all device models and key specification details)
- recording settings used (where possible)
- results (e.g. number of bat flight events, flight direction, flight behaviour)
- type of data recorded (survey notes/radiometric data/non-radiometric data)
- rationale for use of non-radiometric data (where applicable)
- operator details (e.g. Certified Thermographer or trained Camera Operator)
- analyst details (e.g. Certified Thermographer or trained Analyst)

- analysis software details (including program name and version used)
- analysis procedure used (manual/semi-automatic).

6 Health and safety

6.1 General

The use of thermal imaging for bat surveys necessitates specific Health & Safety considerations in addition to those usually employed when using standard bat survey practices. For more general information on Health & Safety for bat surveys, refer to Chapter 2 of Collins (2016).

6.2 Assessing the risks

As with any project, a full risk assessment should be carried out when planning your thermal imaging bat surveys. As part of this you should consider the potential for encounters with hostile members of the public, opportunist thieves etc. Thermal imaging devices and related accessories are expensive and likely to attract unwanted attention from passers-by. If using thermal imaging equipment in public areas, assess the risks prior to survey. When assessing the risks it is important to think about what you might do if a situation arose. Explore whether there are any precautions you can take to minimise the risks involved.

This may include:

- consideration of alternative/safer camera locations
- employment of a security guard to accompany the surveyor[2]
- use of vehicle mounted cameras
- use of other survey methods in situations where risks cannot be reduced to an acceptable level.

6.3 Screen use

If using a laptop and thermal imaging camera to record it is important to consider the implications of screen use. Laptop screen brightness should be lowered accordingly, in order to minimise glare to the surveyor and avoid attracting unwanted attention from passers-by. Likewise, camera display screens should be turned off when not required.

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[2] Security professionals are occasionally used for projects where it is considered that the use of thermal imaging, in combination with site factors, confers a high level of risk. This is by no means standard practice, but is an option where circumstances necessitate survey work in high risk areas such as busy urban locations and/or on controversial projects.

Analysts should take care to minimise the potential effects of computer vision syndrome (Blehm et al, 2005) by taking regular breaks and observing current ocular health advice. Analysts should have regular eye tests to maintain both their ocular health and the accuracy of their analysis outputs. The Royal College of Optometrists recommend that eye tests should be carried out every two years for most adults (The Royal College of Optometrists, 2019).

6.4 Benefits

Use of thermal imaging for bat surveys can also have health and safety benefits. In some situations it can reduce the number of surveyors required and thus reduce the number of night hours being worked on a project. Night work has significant negative impacts in the workplace by deteriorating individual performance and increasing accident rates (Harrington, 2001). It is also associated with health conditions including mental health issues and cardiovascular disease (Harrington, 2001).

Using thermal imaging on infrastructure projects can reduce the need for ecologists to set foot onto live infrastructure. Where vantage points such as bridges can be utilised, the need for access onto live infrastructure can be avoided altogether. Not only does this approach lessen the number of people at risk while night working on roads or railways, but can also significantly reduce project costs where line closures or traffic management would usually be required in order to implement standard methods (such as walked transects, emergence surveys etc.). It can also avoid the time and cost of administration, and arrangement of access to live infrastructure.

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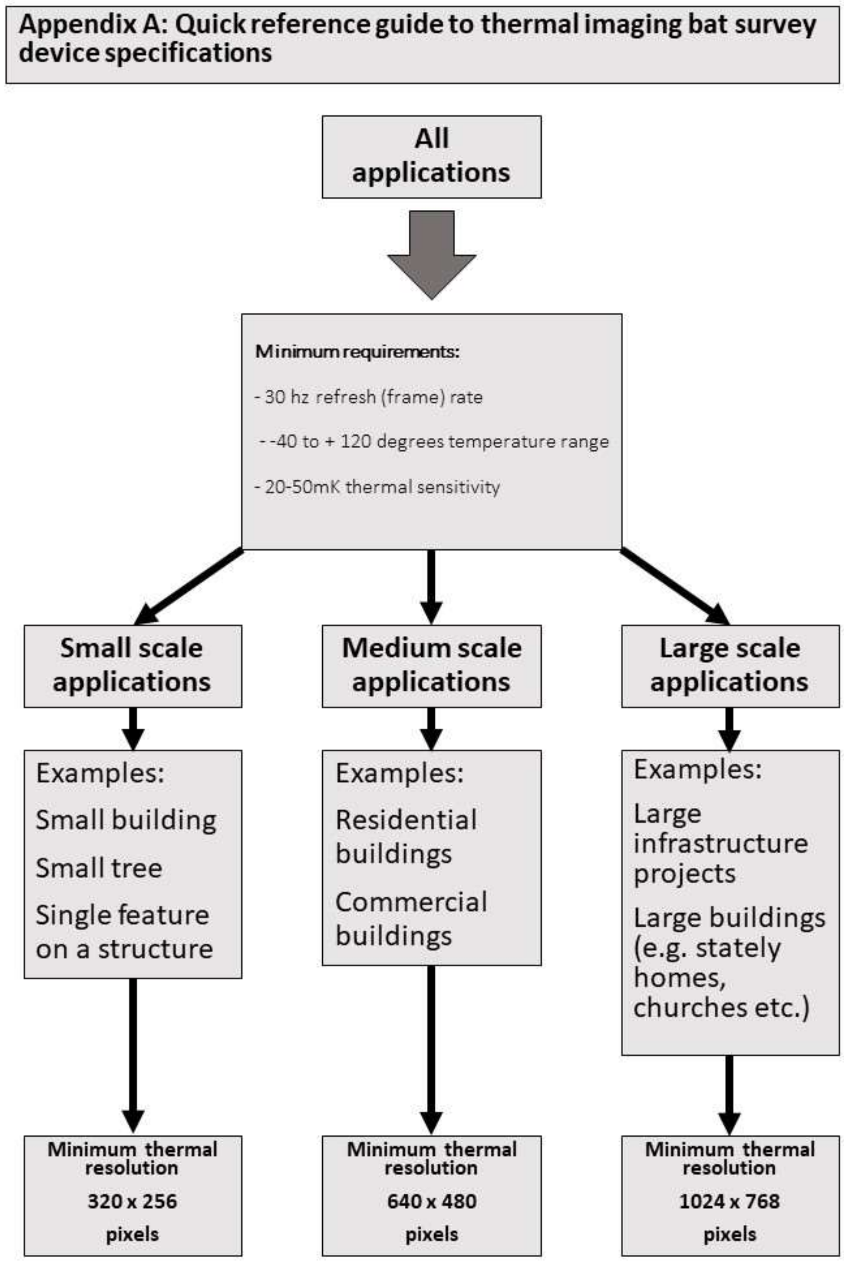
8 Appendices

A) Quick Reference Guide to Thermal Imaging Bat Survey Device Specifications

B) Thermal Imaging Bat Surveyor Training Checklist

C) Glossary

Appendix A: Quick Reference Guide to Thermal Imaging Bat Survey Device Specifications



Appendix B: <u>Thermal Imaging Bat Surveyor Training Checklists</u>

Level: Aid

- ☐ Basic Thermal Science
- ☐ Survey planning
- ☐ Survey implelmentation
- ☐ Equipment selection
- ☐ Reporting

I ___________________________________ confirm that I have completed the above training to use thermal imaging as an aid for bat surveys.

Signed (Surveyor): ____

Date: ________________________

I ____________________________________ confirm that __________________________________ has completed the above training to use thermal imaging as an aid for bat surveys.

Signed (Trainer): ____

Date: ________________________

Level: Method

- ☐ Basic Thermal Science
- ☐ Survey planning
- ☐ Equipment selection
- ☐ Survey implementation
- ☐ Analysis
- ☐ Reporting

I ____________________________________ confirm that I have completed the above training to use thermal imaging as a method for bat surveys.

Signed (Surveyor): ____

Date: ________________________

I _____________________________________ confirm that ___________________________________ has completed the above training to use thermal imaging as a method for bat surveys.

Signed (Trainer): ____

Date: ________________________

Glossary

Bat flight event - from the point in time and space that a bat in flight enters thermal imaging device field of view until the point it leaves the thermal imaging device field of view.

Certified Camera Operator - a thermal imaging bat surveyor who has been trained and certified by a Trainer.

Certified Thermographer - a person who has been trained and certified in thermography. Thermographers must be certified by an organisation which is assessed and declared as an examination and certification body conforming to International Organisation for Standardisation (ISO) standards (including: ISO 17050, ISO 9001, 17024 and ISO 18436).

Emissivity - describes the relative ability of a surface to radiate thermal energy. This is expressed as a value between 0-1.0 which represents the "ratio of a target's surface radiance to that of a blackbody at the same temperature" (ITC, 2010). Emissivity differences across surfaces can make them look 'hotter' or 'colder' than they actually are.

False negative - wrongly indicates bats are not using a roost, structure or habitat feature. This occurs when bats are reported to be be absent or are not detected, when in fact bats were present and using a roost, structure or feature.

False positive - wrongly indicates bats are using a roost, structure or habitat feature. This occurs when bats are reported to be emerging or re-entering a roost, or using a structure or feature when in fact bats were present in the area but did not actually emerge, re-enter or use the structure or feature in question.

Image optimisation - the process by which thermograms/thermal images/thermal videos are adapted using specialist software by an analyst. This can involve changes in thermal span, colour palette and other parameters to allow for maximum accuracy. Also often referred to as 'processing'.

Non-radiometric data - thermal imaging video files which are saved in a standard video format such as .AVI, .MOV or .MP4. These files cannot be optimised in thermal image processing software, so cannot allow for the same level of accuracy of radiometric data. Files are relatively small in comparison to radiometric data files.

Radiometric data - thermal imaging video files which are saved in a non-standard format specific to the thermal imaging camera software. These files can be optimised in thermal image processing software for maximum accuracy. Files are relatively large in comparison to non-radiometric data files in standard formats.

Semi-automatic analysis - a process of analysis of thermal imaging video files. This involves the use of a specialist software program which detects moving objects. Each moving object is then manually checked by a trained analyst. This process, once fully tested, could offer huge time and cost savings for thermal imaging bat survey projects.

Thermal Span - refers to the range of temperatures, highest to lowest, selected in a thermal camera software or thermal image processing software.

Thermogram - *"a thermal map or image of a target where the grey tones or colour hues correspond to the distribution of infrared thermal radiant energy over the surface of the target"* (ITC, 2010).

Trainer - in this document refers to a certified level 2 thermographer who is also an experienced bat ecologist.

Visibility bias - is an issue when using the naked eye to detect bats. Visibility varies with light level over the course of a bat survey and therefore skews the detectability of bats. For example, more bats might be detected at the start of a dusk survey when light levels are highest and proportionally less bats detected towards the end of the survey when dark has fallen.