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Evaluation of Thermal Imaging Equipment

Study SD2007-05
Final Report

Prepared by
Office of Research
South Dakota Dept of Transportation
700 E Broadway Ave
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16. Abstract

The overall goal of this project was to investigate the potential of the FLIR T360 camera and provide suggestions for implementing a thermal imaging system within the Department. The FLIR T360 thermal imaging camera system has proven to be a very easy to use tool that if used properly will benefit the Department for many years to come. It was seen that thermal imaging is not to be taken lightly and proper training and knowledge are required to use and implement the camera system in order to achieve quality results.

Multiple field trials were attempted to show the ability and performance of the FLIR T360 while looking at asphalt paving operations, pavement cracks and centerline joints, tank volumes and bridge deck delaminations. Out of the original intended uses for the camera, thermal imaging of asphalt paving projects is the most likely candidate for the camera. This is due to the thermal imaging system being most easily implemented as an aid and tool when conducting quality assurance on asphalt paving operations. Building energy audits are commonly performed in industry and would most likely provide a major benefit to the Department in reduced energy costs as supported from the literature review, but will require further research and development of detailed implementation plans to realize the greatest benefit. Bridge deck delaminations showed positive results; however, due to the scope and time frame of this project, would require further research to corroborate thermal images with standard methods of testing and to create a full implementation plan.

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Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
CRC	Continuously Reinforced Concrete
CDOT	Connecticut Department of Transportation
DOT	Department of Transportation
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
IR	Infrared
NDOR	Nebraska Department of Roads
NTSC	National Television System Committee
PDF	Portable Document Format
PdM	Predictive Maintenance
RAT	Reflected Apparent Temperature
SD	Secure Digital
SDBIT	South Dakota Bureau of Information & Telecommunications
SDDOT	South Dakota Department of Transportation
UMC	University of Missouri Columbia
USB	Universal Serial Bus
WMA	Warm Mix Asphalt

1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

Thermal imaging has become a very sought after form of investigative analysis within many different fields due to its non-destructive nature and being a safe alternative to some standard testing methods. The decrease in cost and availability of different hand-held cameras has made thermal imaging more appealing for many applications. Today's thermal imaging cameras are affordable, easy to use and reliable. They are very similar to modern point-and-shoot digital cameras, but do require adequate training to understand how thermal imaging works and what makes an accurate image. During this project thermal imaging has shown there is potential to provide a safe non-destructive method of testing within multiple applications. The goal for the South Dakota Department of Transportation (SDDOT) is to provide access within the Department to a hand-held thermal image camera for various applications described in this report.

1.2 OBJECTIVES

The goal of this project was to determine the capabilities of the FLIR T360 thermal camera system and what applications have the highest potential to integrate into and benefit the SDDOT. Listed below are the two objectives to accomplish these goals and a description of how they were accomplished.

OBJECTIVE 1

Assess the overall performance and functionality of a FLIR Systems model T360 thermal imaging camera recently acquired by the SDDOT.

This objective was accomplished during Task 1 and Task 2 of the research project. An extensive review of the FLIR documentation provided with the camera and software was conducted to gain an understanding of the basic steps of operating the camera and to develop a level of knowledge needed to analyze images properly. Four online courses developed by FLIR were taken to gain more knowledge about thermal imaging from FLIR (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). Field trials were performed to test the camera system within various applications which helped provide an understanding of how the camera performs under real-world conditions. During the course of the project, many different literature sources were also reviewed to provide additional understanding of the technology and theory of thermal imaging.

OBJECTIVE 2

Identify a list of practical thermal imaging applications that might be employed at the SDDOT that would help improve or enhance analysis capabilities within particular work functions.

A literature review was first conducted and a list of potential field trial applications was developed. This list was presented to the Technical Panel for review and approval before the field trails began. Once approved, the field trials were conducted to determine the potential for each application and to observe the functional performance of the camera. After performing the field trails, the results were presented to the Technical Panel to show how the camera performed with these applications under field conditions. Throughout the project it was discovered that many more potential applications were possible than had originally been discovered; however, due to the scope and timeframe, these were only investigated in the literature review. A final chart based on the field trials and literature review was generated and ranks each applications potential within the SDDOT and the FLIR T360 camera.

1.3 RESEARCH APPROACH

The following tasks were developed for guidance and direction while conducting the research project.

TASK 1
Gain a thorough understanding of the capabilities and functionality of the FLIR T360 thermal imaging camera prior to any trial use.

To become familiar with the thermal imaging system basic training began with reading of the manuals for both the camera and software. Four online web courses were completed on the introduction of thermal imaging and basic operation of the software provided through the FLIR website (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). Additional time using the camera and software package provided operators more experience and understanding of the potential use of the camera within SDDOT.

TASK 2
Evaluate 3-6 primary applications (and non-uses) that are diverse in nature so that a systematic evaluation of the thermal imaging camera's capabilities can be fully attained.

A list of potential applications that could benefit the SDDOT was presented to the Technical Panel. The six items that were decided upon by the Technical Panel to be investigated during field trials are as follows:

1) asphalt paving uniformity (thermal segregation)
2) bridge deck delamination
3) asphalt centerline joints
4) concrete crack detection
5) asphalt crack detection
6) tank volumes

TASK 3
Based on the thermal imaging camera performance during the trial applications, develop a comprehensive list of potential applications where the Department might gain significant advantages through employment of the camera.

Once field trials were completed, results were compiled with a list of potential applications and presented to the panel. This list will help determine potential applications that could feasibly be implemented with the FLIR T360 within SDDOT.

TASK 4
Meet with the Technical Panel to report findings and present a comprehensive list of potential applications for their review and approval.

A meeting with the Technical Panel was conducted to present results and to receive approval of the interim report. At this meeting the results from the field trails were presented along with a list of potential applications and their potential to be used within the SDDOT. Additional applications not included in the field trials, but included in the literature review, were also included in this list.

TASK 5
Prepare a final report summarizing research methodology, findings, conclusions, and recommendations. The report should include an adequate number of actual thermal imaging examples to fully illustrate capabilities inherent to the technology.

The final report was presented to the Technical Panel for review and approval before the completion of the project. The panel approved of the Final Report with suggested changes.

TASK 6
Make an executive presentation to the South Dakota Department of Transportation Research Review Board at the conclusion of the project.

An executive presentation was made to the Research Review Board in April, 2011.

1.4 CONCLUSIONS

The overall goal of this project was to investigate the potential of the FLIR T360 camera and provide suggestions for implementing a thermal imaging system within the Department. The FLIR T360 thermal imaging camera system has proven to be a very easy to use tool that if used properly will benefit the Department for many years to come. It was seen that thermal imaging is not to be taken lightly and proper training and knowledge are required to use and implement the camera system in order to achieve quality results. Out of the original suggested trials for the camera, thermal imaging of asphalt paving projects is the most likely candidate for the camera. This is due to the thermal imaging system being most easily implemented as an aid and tool when conducting quality assurance on asphalt paving operations. Building energy audits are commonly performed in industry and would most likely provide a benefit to the Department as a tool for analyzing building envelope performance and helping reduce energy costs as supported by the literature review, but will require further research and development of detailed implementation plan to realize the greatest benefit. Bridge deck delaminations showed positive results; however, due to the scope and time frame of this project, will require further research to corroborate thermal images with standard methods of testing and to create a full implementation plan.

This project demonstrated there are many potential uses for thermal imaging within the Department and the few applications tested showed positive results. Conclusive results for some of the applications will require more in-depth investigation to better establish correlations of thermal images with traditional methods of testing. Additional refinement of thermal imaging techniques specific to asphalt paving operations should come after continued use of the camera by the Materials & Surfacing Office. Complete development of certain applications was beyond the scope of work of this project given the level of effort and project time lines established for the original study. Listed below in Table 1 are the rankings from "low" to "high" of potential applications and a short summary of the results.

Table 1: Application results and potentials ranked from high (likely) to low (unlikely).

Application	Results	Potential
Asphalt Paving Operations	Easy to see results of the surface, though it was not directly correlated to density or core temperature in this project.	High
Asphalt Crack Detection	Able to see cracks that can be seen with the naked eye, but very small cracks were typically unable to be seen. Also, likely to require an automated system to be of benefit.	Low
Asphalt Centerline Joint Detection	Possible to see joint in right conditions, but unable to see voids and more than likely needs an automated system to be of benefit	Low
Bridge Deck Delamination	Was possible to see temperature differentials, but no investigation was conducted to directly correlate delaminations with the thermal images. The literature review does support this application as feasible under the right atmospheric conditions.	Medium
Concrete Crack Detection	Able to see cracks that can be seen with the naked eye, but very small cracks were typically unable to be seen. Also, likely to require an automated system to be of benefit.	Low
Tank Volumes	With single wall tanks fluid levels were able to be seen, but a temperature differential must be present between the air/fluid interface. May be beneficial during paving operations to see tank volumes at batch plants and inside haul trucks.	Medium
Building Energy Audits	The literature reviewed supported a large benefit that could be gained when analyzing building envelope performance and potentially saving on energy costs.	High
Utility Locating & Inspection	Literature supported that utility locating was feasible, but unlikely to be used over traditional methods.	Low
Culvert Inspection	Little to no information has been studied in this area, but it was suggested as a possible topic for investigation. By seeing moisture infiltration or voids behind culvert walls, the thermal camera may be able to locate problems unseen to the naked eye.	Unknown
Trailer Brake Screening	Literature supported the use of infrared trailer brake screening, although, it is unlikely this camera would be implemented in such a fashion.	Low
Predictive Maintenance	Literature supported the use of this application, but was specifically geared to industrial plant processes. Two applications that could potentially use this type of analysis would be for building maintenance and highway maintenance equipment.	Medium

1.5 RECOMMENDATIONS

Based upon the results of this project, the researcher has the following recommendations:

1) It is recommended the FLIR T360 camera system be kept and maintained by the Office of Materials & Surfacing. This recommendation was based on prioritization of current needs within the Department and the well established utility of thermal imaging in asphalt paving operations as an aid for inspection of quality assurance.

2) It is recommended that individuals wanting to use the camera system should be provided the proper training materials before use. The proper training materials are as follows: FLIR user manuals for camera and software, the Final Report, and the links to free online training courses provided by FLIR (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). These materials should be stored with the camera system and made available to users of the camera.

3) A list of trained users should be established as a record of those that have completed as a minimum, the approved training program outlined in recommendation #2 above. This will ensure that users have attained the minimum level of knowledge necessary to operate the camera properly and avoid unnecessary damage to this expensive piece of equipment. A trained user is defined as someone who has read the FLIR camera and software manuals, the Final Report, and has taken the FLIR online training courses (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). This list should be stored with the camera and maintained by the Office of Materials & Surfacing. The Office of Materials & Surfacing should have the discretion to decide who will be allowed to use the camera system and who will be allowed to become new users of the camera due to the high replacement cost of the camera system.

4) A protocol for labeling and storing the thermal images should be developed by each office that will be using the camera. It is recommended the protocol for each office be followed to ensure the images are organized and easily understood well into the future. The protocol should include an accessible location to store images and a standardized method of naming and organizing folders and images. It is also recommended that a log sheet be provided with each set of images to provide details about images including, but not limited to: location, atmospheric conditions, what is being analyzed, operator, date and time, etc.

5) Further research is recommended on the application of building energy audits. The literature supports the use of thermal imaging as an indispensable tool in conducting energy audits to evaluate building envelope performance and reduce energy costs. Access to the T360 thermal imaging camera will greatly facilitate adoption of routine energy audits at SDDOT.

2.0 PROBLEM DESCRIPTION

2.1 INTRODUCTION

Only in recent years has the cost of thermal imaging technology decreased to a level that has prompted widespread use throughout industry. Thermal imaging technology is a safe alternative compared to many traditional methods of testing and analysis by providing a non-destructive alternative that typically does not require putting the user in harms way. Thermal imaging technology has been shown to have many potential uses in a variety of disciplines. With modern hand-held cameras thermal imaging can be implemented relatively easily.

2.2 PROJECT STATEMENT

Over the past several years, thermal imaging technology has improved and advanced where transportation agencies have been able to develop applications for asphalt paving evaluations, energy use assessments (audits), bridge deck delamination examinations, and many other thermal imaging uses that significantly enhance analysis capabilities across many work functions. The increasing benefits agencies have been able to gain as a result of employing the technology have essentially driven more widespread use nationwide. The South Dakota Department of Transportation (SDDOT) has been monitoring the progress of thermal imaging systems and recently decided the technology had advanced to the point where it would be worthy of consideration relative to implementation at the Department.

In 2009, the Department was able to procure a camera with funds provided by the Federal Highway Administration (FHWA) to support asphalt paving operations. Thermal imaging applications needed to be developed and tested so the Department can gain the greatest advantages from the technology. This effort was to be accomplished as soon as possible so the SDDOT can begin to use the equipment in the most effective ways and realize the greatest return on the investment. As a result, the SDDOT has acquired expertise with the newly acquired system and has identified a set of potential uses whereby the technology could be employed to gain the most benefits.

2.3 REVIEW of THERMAL IMAGING PRINCIPLES

Infrared light is comprised of wavelengths of light from 0.75μm to 1000μm as seen in Figure 1. This is a portion of the electromagnetic spectrum the human eye can not naturally see. Thermal imaging equipment is taking images of wavelengths of light corresponding to temperature which is in the far infrared portion of light. The wavelengths of light are then processed to generate a “false color” image the human eye can see as in Figure 2. The wavelengths of light, longer being warmer, can be measured and correspond to a specific temperature seen in an image where typically bright colors are hot and dark colors are cold.

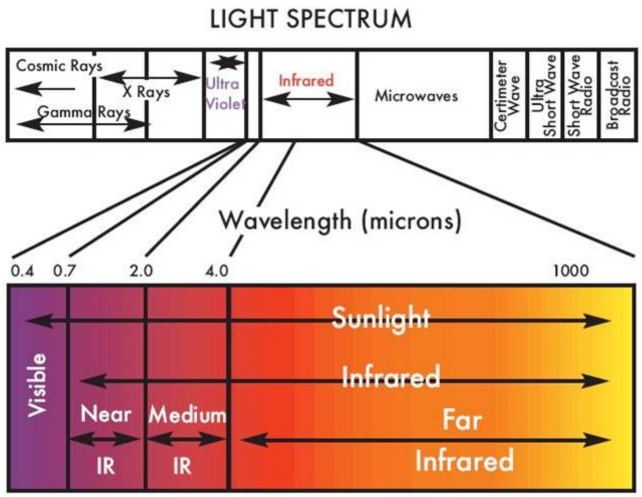

Figure 1: The infrared spectrum is comprised of various wavelengths of light beyond the range of visible light. (9).

Thermal imaging detects the thermal radiation that is reflected or emitted from the surface of an object. Thermal radiation is emitted according to the Stefan-Boltzmann Law (4) in that energy is emitted from the surface in proportion to its absolute temperature to the fourth power and its surface emissivity:

$$R = e\sigma T^4 \qquad (eq.1)$$

where,

R = rate of energy radiation per unit of area surface, W/m^2

e = the emissivity of the surface

σ = the Stefan – Boltzmann constant, $5.67x10^{-8}W/(m^2*K^4)$

T = absolute temperature of the surface, Kelvin

The emissivity of an object is its ability to radiate energy and is dependant on the surface in relation to a pure black body. A pure black body has an emissivity of 1.0, a perfect emitter, and a pure white body has an emissivity of 0.0, non-emitting. In between 0.0 and 1.0 falls everything else; i.e. polished copper is around 0.30 and typical concrete is around 0.95.

The use of thermal cameras has become a mainstay because it is considered a non-destructive, safe method of inspection. The operator typically does not need to be put in harms way to perform the testing and does not require any special equipment except that the camera does need an unobstructed view close enough to what is being analyzed. The thermal imaging camera can make it easier to take images of hard to reach areas that originally were deemed hazardous or would require equipment to be shut down during the inspections. It should be noted that while thermal imaging does provide a safe means of investigation, in many instances, the environment where the images are being taken can still be hazardous and all rules of safety should be followed.

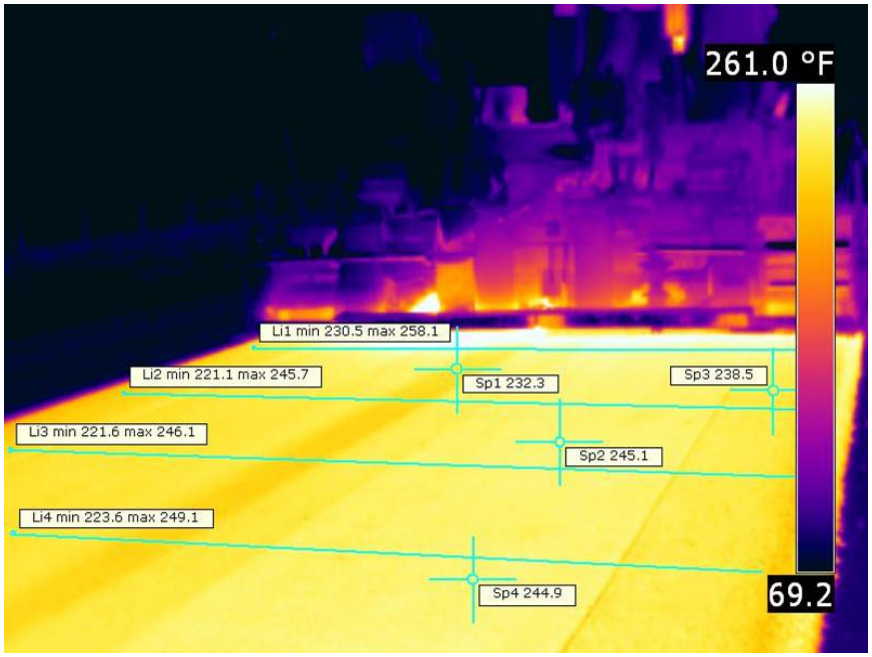

Figure 2: A "false color" image depicting the radiant energy as seen by the camera.

Today an entry-level hand-held infrared camera can acquire images at 120 x 120 pixels and more expensive models can reach up to 640 x 512 pixels. The FLIR T360 used in this project acquires an image of 320 x 240 pixels and can simultaneously provide a 1280 x 1024 pixel full color digital photo (1.3 megapixels). The equipment is designed to be a simple point and shoot camera, much like any modern hand-held digital camera. Even though many camera features are automatic (i.e. focus, exposure, etc.) the overall quality of images still relies heavily on the skill of the operator.

There are a few drawbacks to thermal imaging, the most significant being the initial cost of the equipment. Today, even as costs continue to decline, it is still relatively expensive to purchase a quality hand-held infrared camera. These cameras have a broad range of features with costs ranging from around $1,500 to above $80,000 (6) accordingly. Also, the cameras are not indestructible, can be easily damaged if used improperly or handled carelessly, and are expensive to replace or repair. It should be noted that a single calibration for the FLIR T360 camera costs over $1,000. FLIR does recommend yearly calibration for any camera due to drift in the camera lens even when not in use. Proper and efficient operation requires a reasonable amount of time to learn the camera and its functions. Thermal cameras can be sensitive to atmospheric conditions and it must be known how to compensate for these atmospheric conditions with the camera. Only if used by properly trained personnel who know and understand how to use a thermal camera and optimize its capabilities will it be the most beneficial to the Department.

2.4 LITERATURE REVIEW

Through the process of researching thermal imaging technology and writing specifications to procure a thermal imaging camera, significant material was reviewed from camera suppliers and from other transportation agencies that have employed the technology. A substantial number of white papers related information about thermal imaging applications within specific work disciplines, such as asphalt paving operations, electrical systems at signalized intersections, storage tank levels, security operations, etc.

2.4.1 Asphalt Thermal Segregation

A five year study performed by the Connecticut Department of Transportation (CDOT) looked into the effects of thermal segregation in relation to pavement distresses. Thermal segregation is defined as a spot or area of asphalt pavement that is colder than the rest of the mat which typically leads to early distress in the pavement if the temperatures drop too low during compaction. The study included eleven test sites that exhibited thermal segregation; it was also of interest to see the possibility of detection of particle segregation with thermal imaging. Particle segregation is defined as the separation of a single particle size from the rest of the particle sizes within a mixture. The study "did not conclusively demonstrate a relationship between temperature differentials and pavement distress" (2). Actually, the pavement with the highest temperature differentials performed better than their other test sites, but was the only pavement over a cold-in-place base material. Too many factors could have been the cause of the visible distresses and it was not within the scope of the project to determine this.

The CDOT study showed that when comparing densities, "…cold spots or areas tended to be slightly less dense than their surrounding (normal) pavement" and air voids were on average only 0.9% greater (2). CDOT also concluded that, "…colds spots or areas were not segregated in particle size" (2). This agreed with other similar reports looking at associating cold spots and particle segregation. The research did conclude, "…thermal imaging did provide researchers an opportunity to perform a qualitative analysis" (2). It was shown that temperature of the mat was the critical factor over temperature differential in the ability to compact the mat to the proper densities. The study highly recommended remixing vehicles of some type be used as much as possible to help provide a mat with consistent temperature to aid in proper compaction. It was suggested that early- and late-season paving jobs be more heavily scrutinized in relation to proper temperatures of the mat before compaction due to the extremes of ambient temperatures.

The Peter Kiewit Institute performed a study for the Nebraska Department of Roads (NDOR) and by using coefficients of determination concluded there was no relationship between density (DEN) and temperature differentials (TD) unless the data was organized in "increasing temperature groups" (1). For instance, "when a temperature differential is 2°F the TD/DEN relationship is less than 10%..." and if "the temperature differential is increased to 30°F…the relationship is increased to nearly 70%" (1). This analysis did show that a higher temperature differential may lead to lower density of the pavement which, depending on the magnitude of the differential, could lead to early distress. In the study it was also found using a Material Transfer Vehicle or some type of pickup machine provided very consistent temperatures across the mat with an average temperature differential of 3°F and without the added remixing, the average temperature differential was 13°F (1).

An additional product to come out of the NDOR study was a proper way of documenting and storing thermal images with a data management plan. A Microsoft Access database was created to compile and store images for future use, and images were integrated into Google Maps using a KML file system. This appeared to be a very impressive method for storing and displaying images, their data and showing their location on Google Maps.

2.4.2 Bridge Deck Delamination

The University of Missouri—Columbia (UMC) performed a study with the Missouri Department of Transportation to look at the atmospheric effects on thermal imaging when looking at concrete delaminations. UMC concluded atmospheric conditions play a major role in thermal imaging and determined optimal conditions for taking thermal images of concrete delaminations. In order to receive the highest contrast of temperatures with thermal imaging, "...average wind speeds were lowest on the days with maximum contrast…" and also, "…uninterrupted solar loading…" led to optimum conditions (14). The study described solar loading as direct sunlight without any clouds interrupting the warming process. It was also determined that when looking at a target embedded five inches into concrete a minimum of nine hours of uninterrupted solar loading was required to achieve a maximum thermal gradient (14). It should also be noted it was concluded that the depth of the delamination will determine the best times to collect images. The deeper a delamination exists, the more solar loading will be necessary to show the highest amount of temperature contrast.

Another study done by Washington State Transportation Center for the Washington Department of Transportation examined concrete delamination in bridges using thermal cameras. The study used heaters to induce heat to the underside of box-girder bridges before inspections. Multiple tests were conducted on areas of known delamination and other areas without known delamination. At one location without previous knowledge of delamination "…delamination and poorly consolidated concrete were discovered" (12). Camera results were verified by a hammer test and borings at the same locations. Temperature differentials were found to be as high as 25°F at some locations of delamination and in some cases, flaws could be noticed in as little as 10 minutes of heating according to the report (12).

2.4.3 Asphalt Cracks

A study performed by the University of Central Florida for the Florida Department of Transportation concluded it was possible to detect asphalt cracks down to 1.0mm in size with thermal imaging and recognition software (11). The basis for the research was that there was a problem seeing cracks smaller than 2mm with traditional cameras and the theory was that a temperature differential should be visible with a thermal imaging camera. Sufficient solar heating was required to provide adequate temperature differentials to detect any cracks.

2.4.4 Energy Audits

Thermal imaging cameras can be used as tool to inspect a building envelope while performing building energy audits and can help in determining inefficiencies in building construction, design and performance. The benefits of performing building energy audits can be very little or very large depending on the design of the program, willingness of its users and the investment of capital to improve efficiency.

The US Department of Energy (DOE) states that buildings account for 40% of all energy in the United States (this includes commercial, residential and industrial) (5). Also, the DOE states this energy is more than industrial and transportation energy use combined. By effectively improving building performance, energy use should be reduced which should result in a cost savings. When performing an energy audit, it is imperative that guidelines be followed to make sure a consistent analysis is conducted on buildings within the agency. *EnergyStar, US Green Building Council, Department of Energy and American Society of Heating, Refrigerating and Air-Conditioning Engineers* have created standard methods of performing energy audits.

Currently project SD2008-07 is preparing an Energy Program that will help the Department to incorporate Energy Audits into a routine practice. Even though further study of this topic was not in the scope of the project statement, it is a potential use of the thermal imaging system; however, it is advised that much more research be conducted and an implementation plan be put together if the Department wants to perform energy audits effectively.

2.4.5 Trailer Brake Screening

A study completed by the Georgia Tech Research Institute for the Georgia Department of Transportation developed a low cost infrared camera system to be used in conjunction with ports of entry. The study stated the system, "…is very effective in detecting brake problems" (10). Further, the study also stated, "…once word got out that brake system screening was being conducted with an infrared system, an increase in the percentage of house trailers with operational brakes was noted" (10). Although this topic was not in the scope of the project statement, it is a potential use of a thermal imaging system.

2.4.6 Utility Locating

According to a study done by Purdue University at the Joint Transportation Research Program sponsored by the Indiana Department of Transportation, underground utilities can be seen with a thermal imaging camera. However, it was deemed thermal imaging would less likely be used over other standard practices. Purdue University stated, "…thermal images are sensitive to daily and seasonal changes in weather and this method is only valid for pipelines of chemical, oil, natural gas, water, steam, sewage or tanks" (8). The study went on to say that even though it can locate some utilities there must be a temperature differential in order for it to appear and it can not determine the size or type of utility being seen due to only seeing the radiant energy being emitted.

2.4.7 Predictive Maintenance

Another significant use of thermal imaging is in the field of Predictive Maintenance (PdM). Many large corporations such as FORD, Carrier and Cargill are implementing PdM programs within their facilities to improve performance and reduce downtime caused by catastrophic failures. Thermal imaging is typically one of the many tools used during routine inspections of equipment and facilities. Thermal imaging equipment allows for inspectors to see problems with machinery, motors, steam pipes and electrical connections during normal loads and without having to shut down equipment. Typically, an extensive PdM program will collect images on a regular interval and incorporate them into a Computerized Maintenance Management System (CMMS) that will assist the facilities manager in recognizing trends in equipment performance, pinpointing problems before failure and scheduling repairs during off hours or times that will have little to no impact on operations.

Ford, Carrier and Cargill all claim that their PdM programs have been saving their companies thousands of dollars (3,13,7). Mainly due to switching from a traditional scheduled maintenance program followed by a reactive maintenance procedure, the facilities managers are now keeping track of hundreds of pieces of equipment and how each one is performing. They also claim that with modern hand-held thermal imaging systems, thermal imaging is typically the most cost effective system to implement (3,13,7). Typically with these large-scale PdM programs an individual Asset Manager oversees the CMMS system and the cataloging of all data and new equipment. Thermal imaging is just one small piece of a PdM program and if implemented properly should provide a useful tool for building and equipment managers to see problems before they arise, keep track of the performance of their equipment and provide a more reliable environment.

3.0 RESEARCH OBJECTIVES

The goal of this project was to determine the capabilities of the FLIR T360 thermal camera system and what applications have the highest potential to integrate into and benefit the SDDOT. Listed below are the two objectives to accomplish these goals and a description of how they were accomplished.

OBJECTIVE 1

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OBJECTIVE 2

Identify a list of practical thermal imaging applications that might be employed at the SDDOT that would help improve or enhance analysis capabilities within particular work functions.

A literature review was first conducted and a list of potential field trial applications was developed. This list was presented to the Technical Panel for review and approval before the field trails began. Once approved, the field trials were conducted to determine the potential for each application and to observe the functional performance of the camera. After performing the field trails, the results were presented to the Technical Panel to show how the camera performed with these applications under field conditions. Throughout the project it was discovered that many more potential applications were possible than had originally been discovered; however, due to the scope and timeframe, these were only investigated in the literature review. A final chart based on the field trials and literature review was generated and ranks each applications potential within the SDDOT and the FLIR T360 camera.

4.0 TASK DESCRIPTIONS

The following tasks were developed for guidance and direction while conducting the research project.

TASK 1
Gain a thorough understanding of the capabilities and functionality of the FLIR T360 thermal imaging camera prior to any trial use.

To become familiar with the thermal imaging system basic training began with reading of the manuals for both the camera and software. Four online web courses were completed on the introduction of thermal imaging and basic operation of the software provided through the FLIR website (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). Additional time using the camera and software package provided operators more experience and understanding of the potential use of the camera within SDDOT.

TASK 2
Evaluate 3-6 primary applications (and non-uses) that are diverse in nature so that a systematic evaluation of the thermal imaging camera's capabilities can be fully attained.

A list of potential applications that could benefit the SDDOT was presented to the Technical Panel. The six items that were decided upon by the Technical Panel to be investigated during field trials are as follows:

1) asphalt paving uniformity (thermal segregation)
2) bridge deck delamination
3) asphalt centerline joints
4) concrete crack detection
5) asphalt crack detection
6) tank volumes

TASK 3
Based on the thermal imaging camera performance during the trial applications, develop a comprehensive list of potential applications where the Department might gain significant advantages through employment of the camera.

Once field trials were completed, results were compiled with a list of potential applications and presented to the panel. This list will help determine potential applications that could feasibly be implemented with the FLIR T360 within SDDOT.

TASK 4
Meet with the Technical Panel to report findings and present a comprehensive list of potential applications for their review and approval.

A meeting with the Technical Panel was conducted to present results and to receive approval of the interim report. At this meeting the results from the field trails were presented along with a list of potential applications and their potential to be used within the SDDOT. Additional applications not included in the field trials, but included in the literature review, were also included in this list.

TASK 5

Prepare a final report summarizing research methodology, findings, conclusions, and recommendations. The report should include an adequate number of actual thermal imaging examples to fully illustrate capabilities inherent to the technology.

The final report was presented to the Technical Panel for review and approval before the completion of the project. The panel approved of the Final Report with suggested changes.

TASK 6

Make an executive presentation to the South Dakota Department of Transportation Research Review Board at the conclusion of the project.

An executive presentation was made to the Research Review Board in April, 2011.

5.0 FINDINGS AND CONCLUSIONS

5.1 INTRODUCTION

The FLIR T360 thermal imaging camera has proven to be easy to use and will likely be a useful tool for the Department. Results have shown there is potential to use the thermal camera as outlined in the original project plus additional other uses. Thermal images were taken for all six applications suggested by the Technical Panel and the results are encouraging for most applications.

5.2 ASPHALT PAVING UNIFORMITY (THERMAL SEGREGATION)

Images were taken of paving operations including plant operations, haul trucks, re-mixers, pavers, and the mat before and after compaction. Asphalt paving proved to be one of the most useful applications of thermal imaging. Due to the nature of asphalt paving being above ambient air temperatures (250°F-300°F) thermal imaging can clearly see noticeable differences in the surface of the asphalt mat. Imaging of asphalt paving also proved to be easily accomplished due to the slow movement of the equipment which typically allows time for multiple images to be taken and even analyzed before the paving operations moved a considerable distance.

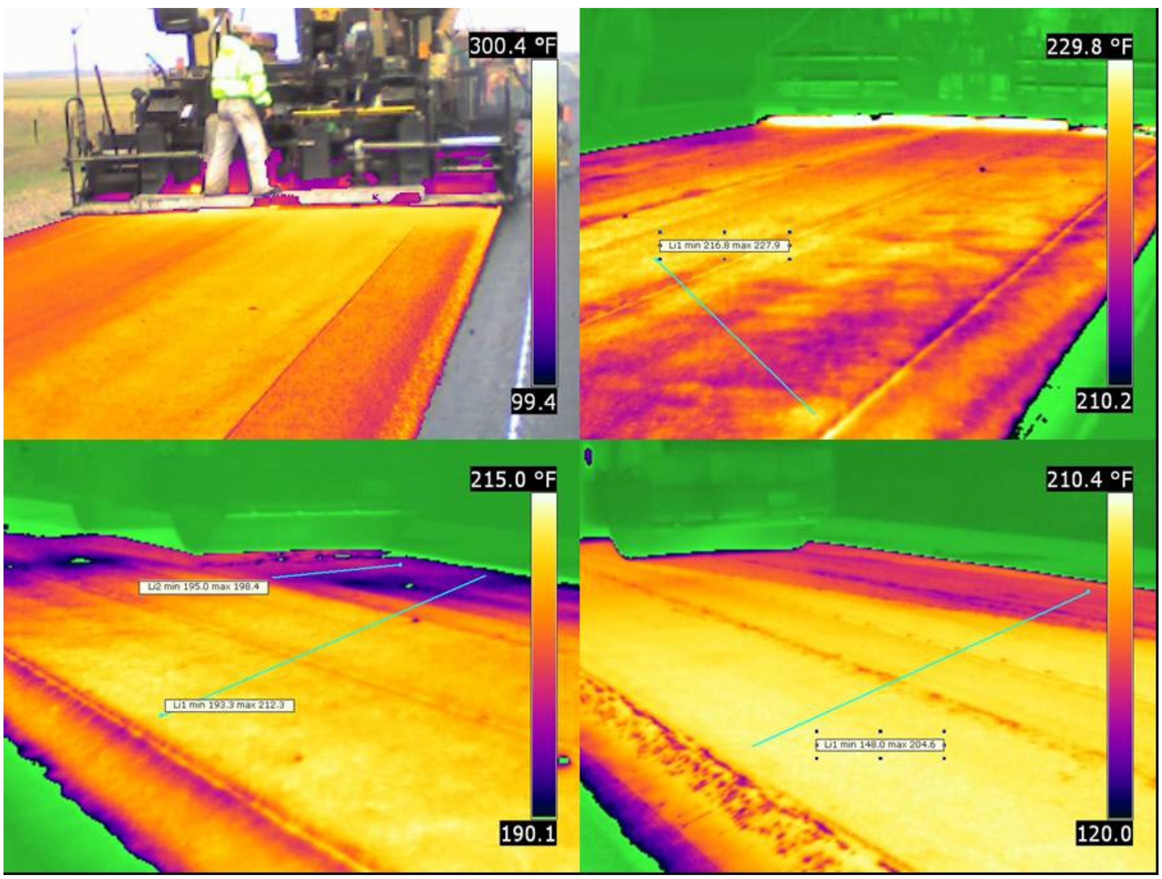


Figure 3: Asphalt paving operation images taken on SD73.

In Figure 3, temperature differentials were shown to be around 30°F across the mat in some areas while other areas were as little as 5°F. These were typical images taken during paving operations.

Even when cooler spots or larger temperature differentials were seen, no signs of segregation or early distress were noted. Field visits were conducted at later dates to establish a correlation with cold spots and distress, but it became apparent that a better method of locating the problem spots was needed due to not being able to find the locations of the cold spots in the images. In the images it was also possible to see marks in the asphalt mat from the paver screeds and the edge forms. By seeing temperature differentials in the mat and cold spots or areas, thermal images were able to pinpoint locations that could be possible problems during the paving operations.

An attempt was made to correlate finished density with temperature of a new mat before compaction using a nuclear densometer. This attempt, even though supported by the literature review, was unsuccessful due to the inability of locating problem areas noted in images after compaction. Field visits were made at later times to attempt to correlate and conduct coring of the mat to test for density of the finished mat. However, there was no physical marking of the location of pinpointed spots within images or on the road surface to come back to. This made for a difficult time in locating pinpointed areas and led to an unsuccessful attempt to correlate finished density with the fresh laid mat temperature. It was suggested to possibly attempt locating problem areas with a hand-held GPS or as seen in the literature review placing small pins into the surface of the mat before compaction may help locate these areas better; this was not attempted.

Another temperature differential apparent in the images is after the first roll of the mat. In one instance the surface temperature dropped over 20°F after the initial roll of the mat and an additional 20°F drop after another pass. This can be seen in the two bottom images of Figure 3. It should be noted the thermal imaging camera is only looking at the surface of the mat and no testing was conducted to compare the core temperature of the mat to the surface temperature. So, it is unknown if the core temperature was also dropping the same amount as the surface. It was seen in the literature review that the mat temperature is a critical factor for the final compaction density. This should be especially critical to monitor in early- and late-season paving operations due to ambient temperatures possibly falling and which could lower the mat temperature too far before final compaction.

Additional images were taken of other asphalt paving operations including material transfer and plant operations. As seen in the top and lower right images of Figure 4, various haul truck operations show large temperature differentials in the material. This is due to radiant heat leaving the surface and the outer layer of asphalt cooling after being dropped from the haul truck. Typically, if needing haul truck asphalt temperatures, much like taking samples of material, it is recommended to remove the outer cooled layer of material before taking any images. After the material had been picked up by a re-mix vehicle and dropped into the paver hopper, as seen in the lower left image of Figure 4, the material had a much more consistent temperature and typically appeared to lead to a consistent temperature across the mat with a temperature differential less than 5°F. No comparison was made against not using a material re-mix vehicle.

Overall, using thermal imaging to conduct a qualitative analysis during asphalt paving showed real promise for the Department. Temperature differentials were able to be seen within in all aspects of asphalt paving operations. Temperatures of the mat surface should be correlated to core temperatures especially when looking at images after the first roller pass. It is also recommended that further attempts be made to correlate density of the finished mat with temperature of the fresh mat before compaction.

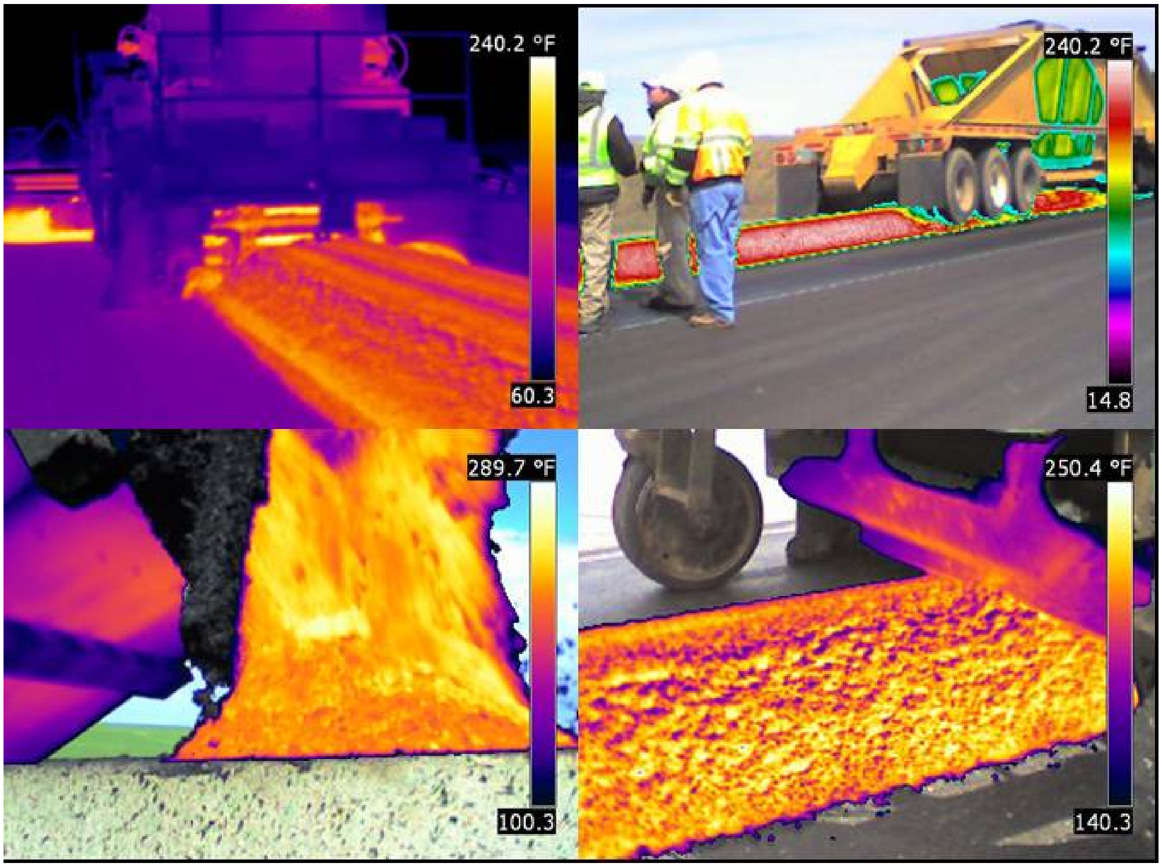


Figure 4: Thermal images of various asphalt paving operations.

5.3 ASPHALT CRACK DETECTION

Thermal imaging was investigated to see if cracks in asphalt pavement were able to be seen either before or after cracks appeared on the surface. Small cracks (<5mm) were typically hard to see with the naked eye, but also were difficult to see with the camera. As seen in Figure 5, due to the narrow width of the crack it was challenging to distinguish the location of the crack due to a very small temperature differential of typically <1°F. Large cracks in asphalt are readily seen with the thermal camera as seen in Figure 6. In this image, a temperature differential of as much as 13°F warmer occurs inside large cracks compared to the asphalt surface. Typically, it was seen that a wide crack (>5mm) would vary by as much as 5°F or more, where a small crack (<5mm) may only vary by 1°F or less. No cracks or voids were able to be found without visible surface cracks. It could be possible to see voids or bottom-up cracks, but due to the hand-held nature of the camera, only small areas of pavement were investigated and neither of these were identified during the investigation.

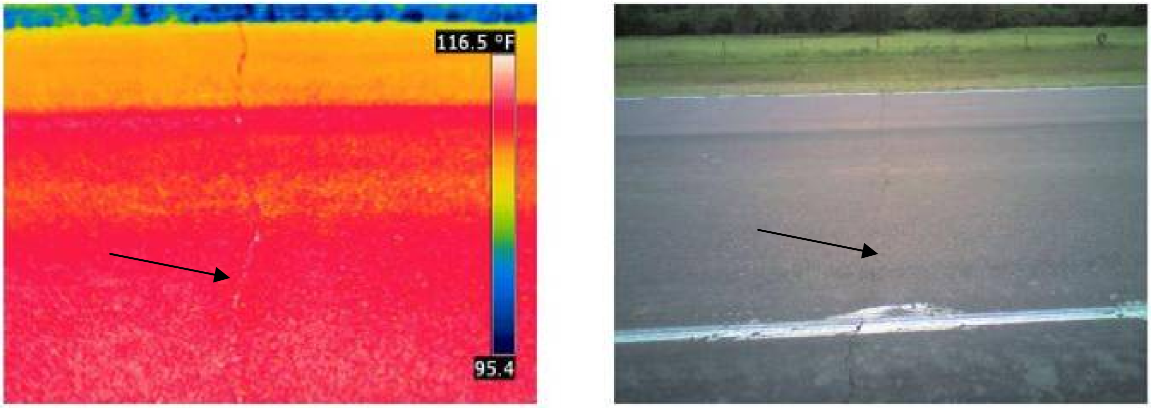


Figure 5: Asphalt crack detection photos taken on SD38 east of Mitchell, SD.

Another noticeable difference seen when looking for cracks in asphalt is surface condition of the pavement. It was noticed that the temperature differential varied based on the condition and color of the surface. If the surface was clean and black with little to no oil loss, the differential was typically greater, but if the surface had exposed aggregate due to oil loss there was typically little to no temperature differential which led to not seeing any cracks.

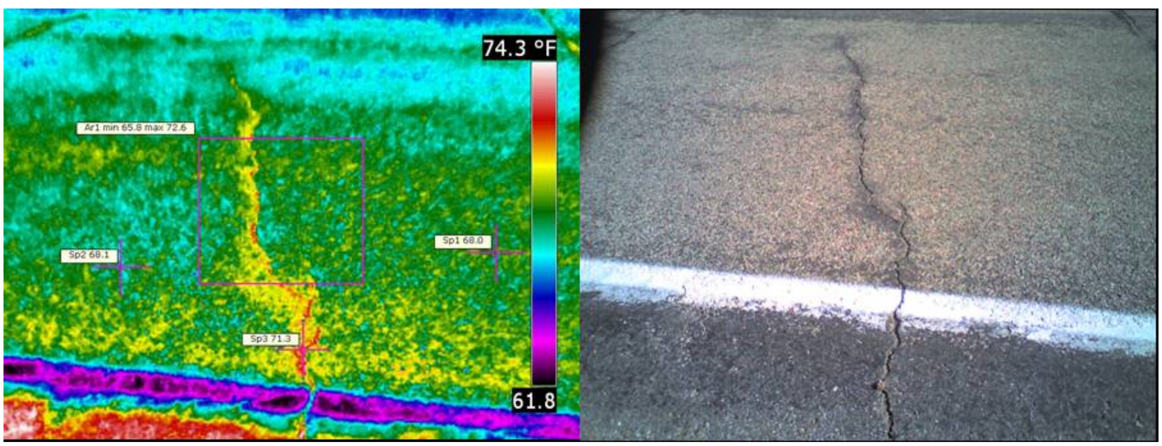


Figure 6: Asphalt crack detection photos taken on SD1804 north of Pierre, SD.

5.4 IMAGING OF ASPHALT CENTERLINE JOINTS

Asphalt centerline joints were investigated to determine if voids or other joint deficiencies were detectable with thermal imaging. Joints in the center mainline on asphalt roads were usually visible under the ideal conditions. Ideal conditions consist of a newer pavement with no chip seal having been applied and sufficient solar loading has occurred; a temperature gradient was then noticeable at the joint. As seen in Figure 7 and Figure 8, there was no exposed aggregate from oil loss and a good cover of oil still existed that provided a well exposed joint and did show a temperature differential of a few degrees highlighting joint geometry. However, on older pavements with chip seals or exposed aggregate due to oil loss it was typically harder to discern the precise location of joints in images.

Figure 7: Asphalt centerline joint on SD1804 north of Pierre, SD.

It may be possible to see voids from the pavement surface by seeing temperature differentials, but during this project no voids were discovered and it is unknown if voids did exist where images were taken. Due to the hand-held nature of the camera only small areas are surveyed which leads to the possibility that voids may exist, but missed due to not finding them without some indication on the surface of the pavement.

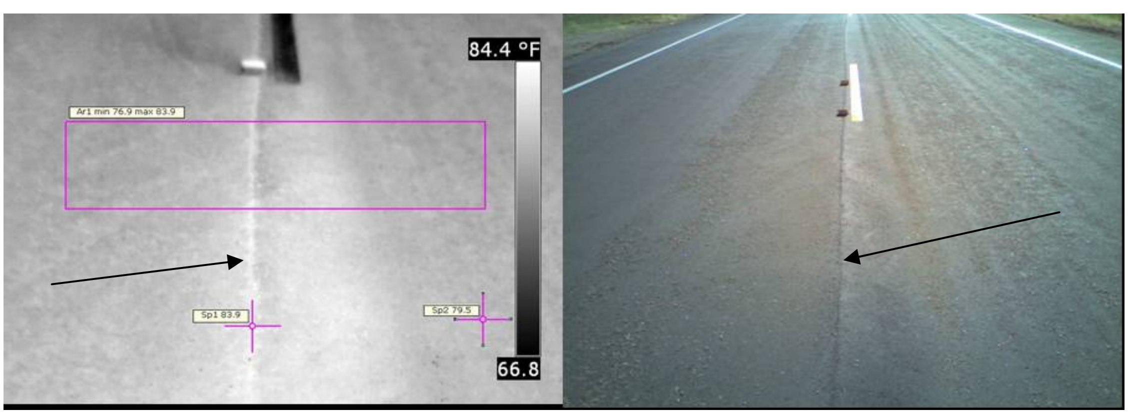


Figure 8: Asphalt centerline joint on SD1804 north of Pierre, SD.

5.5 BRIDGE DECK DELAMINATION

The bridge selected for investigation was chosen due to a previous inspection by traditional methods (chain drag) conducted by SDDOT where known delaminations were marked on the deck with marking paint. The marked areas known to have delaminations showed temperature differentials with warmer temperatures around 1~2.5°F higher, as seen in Figure 9 (top); where bright yellow is warmer and dark purple is cooler. The top image is showing an overview of the northbound lane of the deck which clearly shows the painted lines from the traditional testing and a warm spot inside the painted lines. In the top picture of Figure 9 there is a temperature differential of about 1~1.5°F higher within the marked delaminations. The bottom photo is a close-up image of the bridge deck where it is easy to see the warmer (yellow) areas; the transverse tining is also visible in this image.

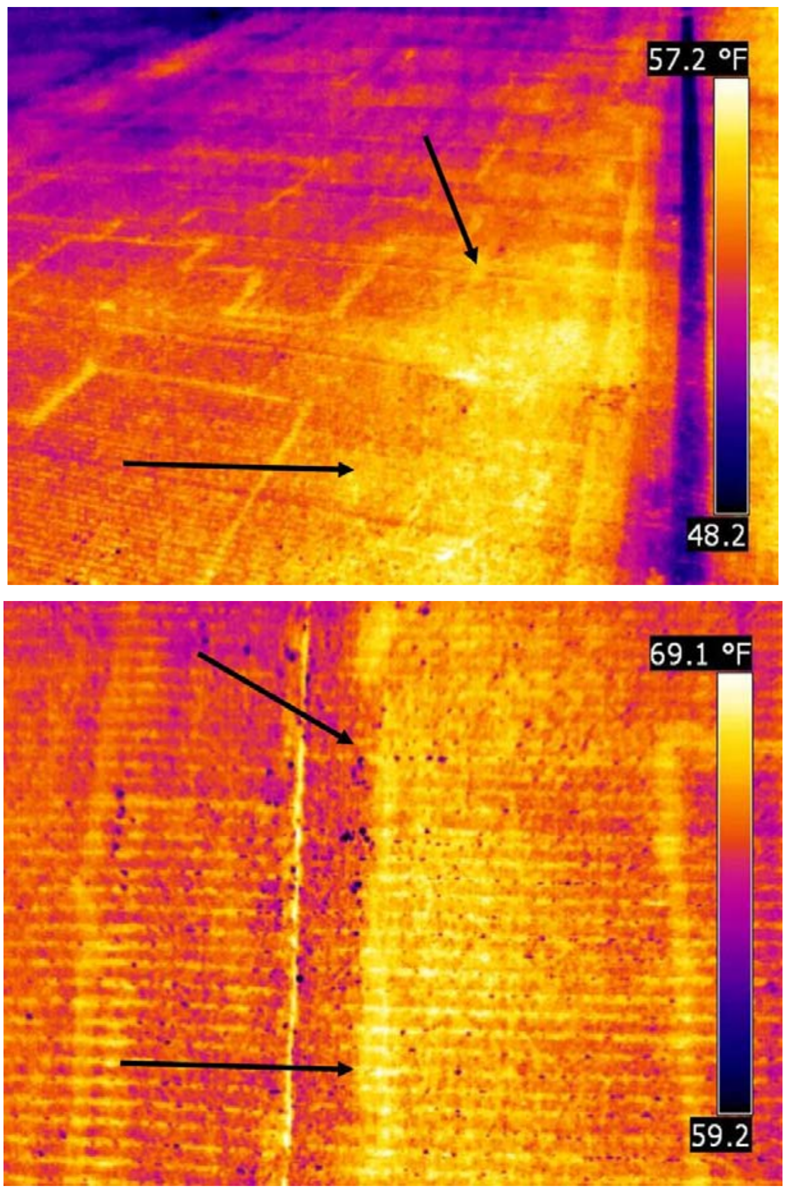


Figure 9: Thermal images of bridge deck delamination on SD1804 west of Gettysburg, SD. Overview of northbound lane (top) & close up at centerline between slabs (bottom).

In Figure 10, warm spots were seen with the camera again and are pointed out in the images. Again, the spray painted markings are visible in the images. In the top left image, the dark line is the centerline pavement marking. There is a noticeable difference in the temperature ranges as seen in the high and low values of the temperature scales. This is due to the top left image being taken in the morning around 11:00am while the other three were taken in the afternoon around 1:00pm. Looking at these images it was seen there was the possibility of seeing delaminations, but the temperature differential was only in the range of 1-2°F. No coring was performed to verify results or see actual delaminations.

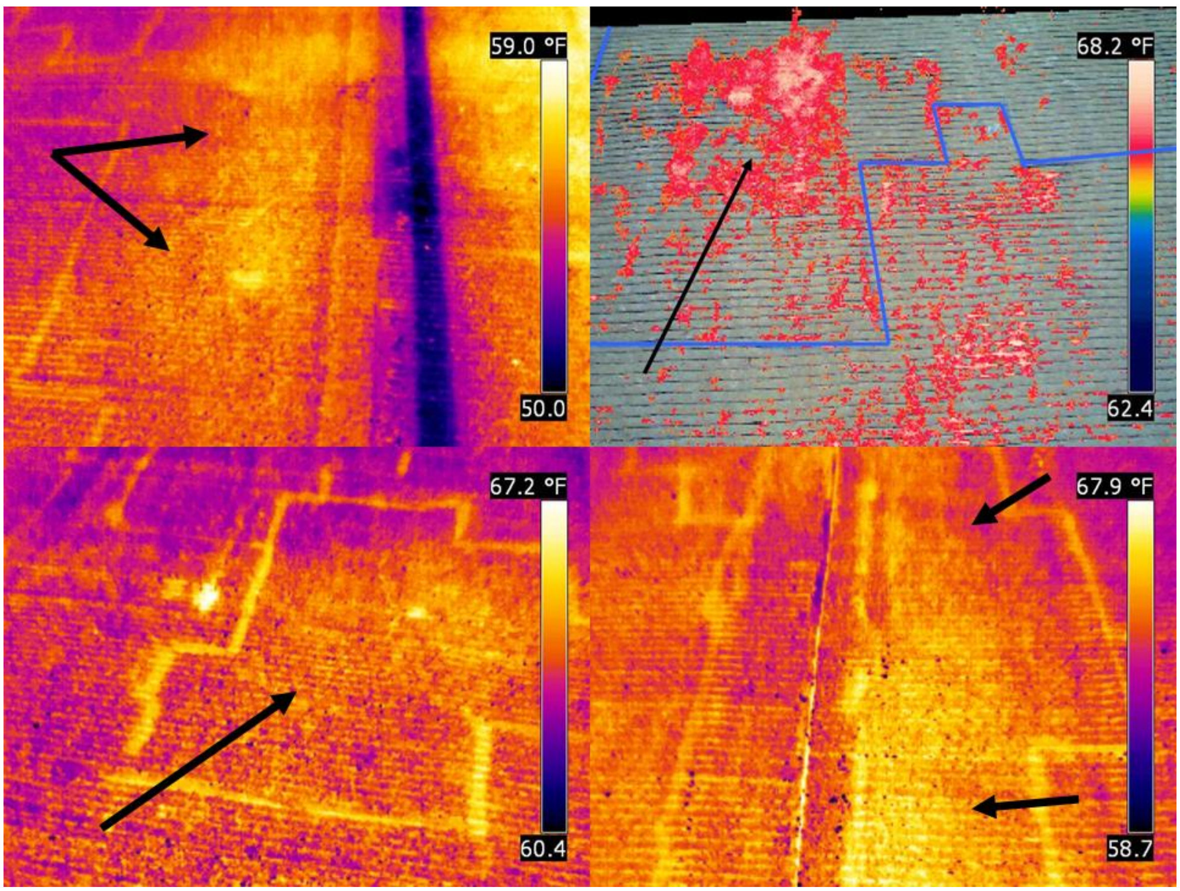


Figure 10: Thermal images of bridge deck delamination on SD1804 west of Gettysburg, SD.

These images were taken on a late fall day with a constant 10~15 mph wind blowing from the northwest, the ambient air temperature was roughly 65°F and the time of day was close to noon. These were not ideal conditions to perform the study due to a slightly short amount of thermal heating time, but mainly the increased heat loss and interference due to the wind. Based on analysis of borings from similar decks, void thickness associated with bridge deck delamination is typically in the sub-millimeter range adding to the difficulties of detection. Results obtained from thermal images for the application of bridge deck delamination inspections were inconclusive, likely due to the unfavorable atmospheric conditions, but also due to the need to perform a much more extensive study on the subject to correlate with traditional methods of testing. Additional work focusing on correlation with traditional methods will be needed to increase confidence in the methodology.

5.6 CONCRETE CRACK DETECTION

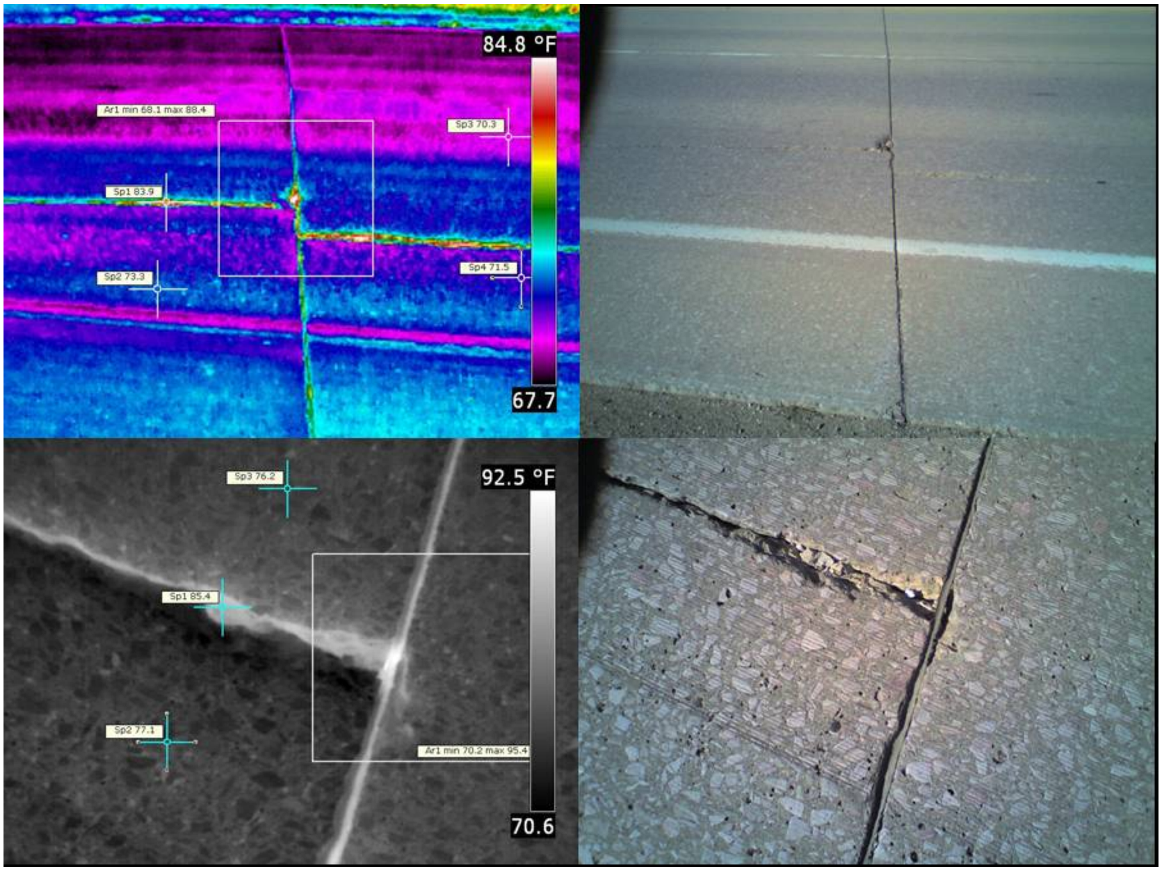


Figure 11: Concrete crack detection photos taken on US83 north of Pierre, SD.

Much like asphalt cracks, concrete pavements were investigated to determine the possibility of seeing cracks that were unseen to the naked eye and voids that may exist below the surface. As seen in Figure 11, a breezy day in the afternoon in October with about 65°F ambient air temperature netted a temperature differential of about 20°F with the inside of the crack averaging 90°F and the surface averaging 70°F. These cracks and joints were relatively large and open and had been heated all day without clouds or shade. Large cracks and joints in concrete are easily seen with the thermal camera. When looking at pavements, like continuously reinforced concrete (CRC), the cracks are typically small and tight which did net a much smaller temperature differential around 2°F as seen in Figure 11. In some cases, CRC became difficult to see any temperature differential especially in the afternoon when cracks were tightest and generally were very tight (<1mm).

Another issue with concrete paement was with the tining of the surface. When transverse tining existed it became very difficult to differentiate the crack from the tining and at times the crack did not stand out. As seen in the bottom left image in Figure 12, the cracks are more noticeable after changing the color palette and limiting what temperatures were shown with software. Transverse cracks were more noticeable with longitudinal tining due to the crack running perpendicular to the tining.

It may be possible to see voids or cracking not visible on the surface or normal cameras with thermal imaging, but due to the nature of the hand-held camera only small areas were investigated. Further investigation to determine the location of known voids or very small cracks and correlating the images with traditional investigation would need to be completed to draw a firm conclusion.

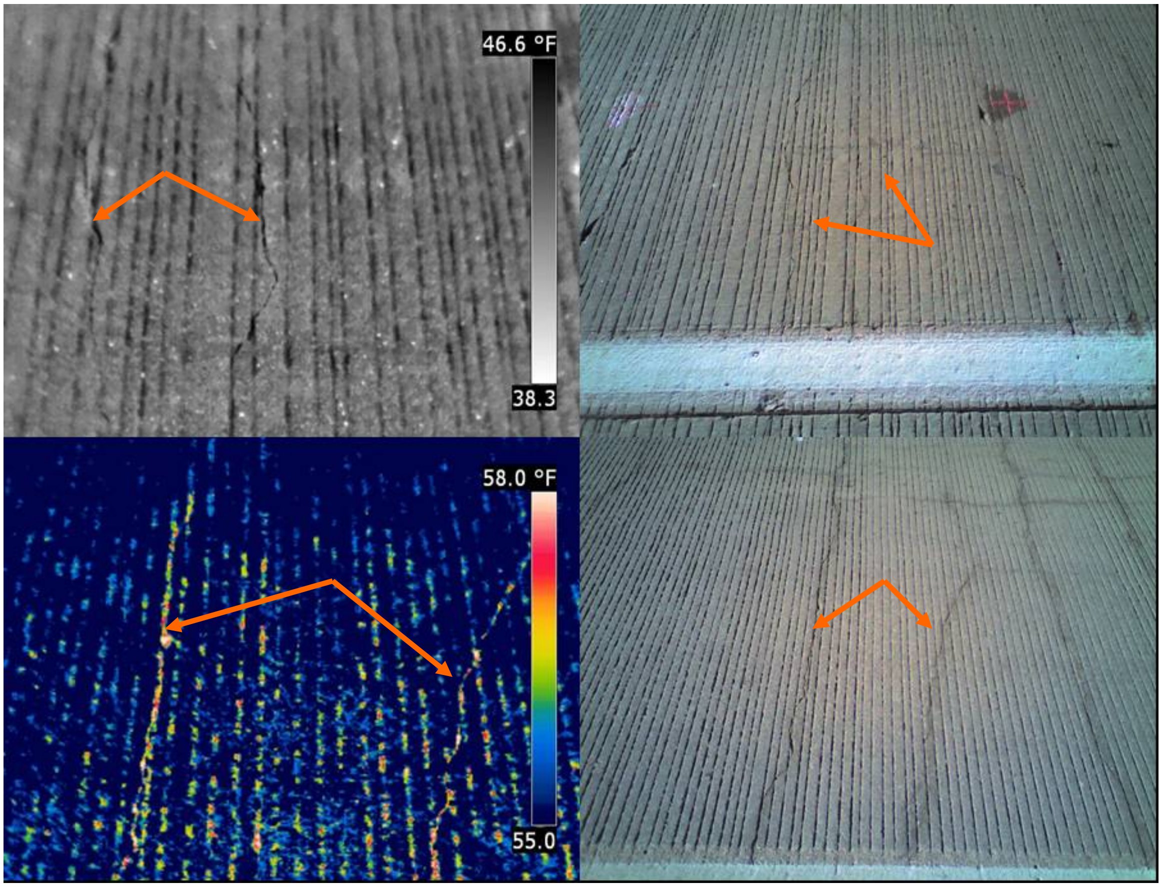


Figure 12: Concrete crack detection photos taken on I-90 east of Sioux Falls, SD.

5.7 STORAGE TANK VOLUMES

As seen in Figure 13, a clear definition of the tank fluid level is indicated by the change in the temperature at the air/fluid interface (white line in left photo). Thermal imaging could potentially be useful for quick estimates of fluid levels in tanks; however, to perform an accurate measurement, further measurements and more specifics about the tank dimensions would need to be known. In order to see the fluid level in a tank, there must be a temperature differential between the fluid and the air in the tank which possibly, if the fluid and air were at equilibrium, an interface would not be noticeable. This temperature differential can only be seen if the fluid is touching the outside layer of the tank.

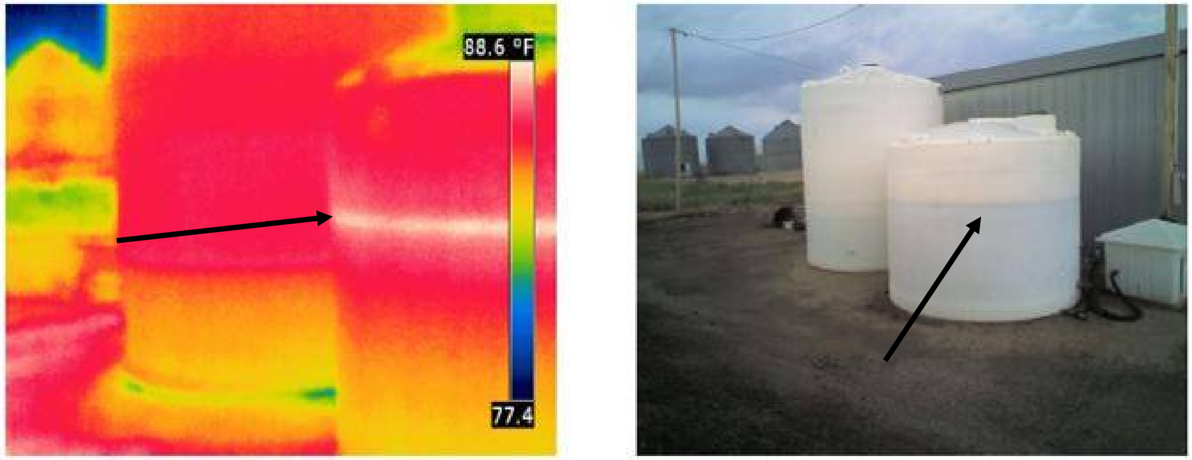


Figure 13: Tank level photos taken at SDDOT maintenance shop at Presho, SD.

Fluid levels are unable to be seen with the camera in double-walled tanks due to no interaction of the fluid with the outer layer, unless a leak existed. When looking at hot-mixed asphalt haul trucks on asphalt paving operations, materials in contact with the outer surface of the trucks was able to be seen with the camera as seen in Figure 4. There may be more potential to use thermal imaging when looking at tank volumes at asphalt plants and during other SDDOT operations where rough estimates of tank volumes are needed.

5.8 CAMERA OPERATION

The functionality of the FLIR T360 camera proved to be very easy and straight forward. After reading through the provided instruction manual and completing the online tutorials from FLIR (Introduction to IR Camera Operation, T-Series Basics), the FLIR T360 became a familiar tool. When first using the camera it is rather bulky in size compared to a modern-day digital camera and sized similar to a professional SLR camera. This may prove to be cumbersome to users with smaller hands and also weighing nearly two pounds can be tiresome to the arms if carried all day. One very beneficial feature on the T-series camera is the up and down 120° rotating lense. This feature allows the user to rotate the lense up or down to capture images that normally would require bending or kneeling. This also reduces back and neck strain if having to take images overhead or down below something by rotating the lense to see what is being investigated. Overall, the camera has a very ergonomic design which helps reduce fatigue and also by placing the majority of controls, including a joystick for menu navigation, within reach of the thumb or index fingers leaving the left hand free to stabilize the camera or select menu buttons. A simple description of the camera buttons and features can be found in Appendix H.

Once the camera is on and running, it is as simple as the push of a button to operate the camera. Some handy features have been built into the camera to suit the operator when conducting an investigation. When taking an image, the “save/preview” button is pressed to take an image. This feature, depending on how quickly the button is pressed, allows the user the option to either take images quickly and automatically save the image or previewing the image and choosing to discard or save the image. Some of the other notable features of the camera include a laser pointer to pinpoint image locations, a video output that is NTSC compatible so it can connect to a TV, capture card in a computer or a VCR, and the capability of being remotely controlled with a USB connection to a computer. In order for the camera to be remotely controlled free software from FLIR, called *IR Player*, must be downloaded and installed on a computer. Once installed, through a micro-USB port on the camera and a USB connection on a computer, full control of the camera is transferred over to the computer.

To take individual temperature measurements with the T360 multiple options are available. The T360 has the option to use spot or area measurements to see single points or an area. This is very helpful when looking at specific points of an object or looking at a broad area such as pavement. Also, the camera can display the minimum, maximum and average temperatures it senses in real-time. Another very useful feature built into the T360 camera is the "simultaneous" mode. This mode allows a built-in normal color digital camera to take images at the same time as the infrared camera providing two images: one normal digital image and one thermal image. This proved to be very useful when performing analysis in the office by being able to see the whole picture and not just the thermal image. Another function built into the camera is called "fusion." This function allows the operator to set temperature constraints within the thermal lense to see only a specified interval of temperatures while performing field analysis and only displays the thermal colors when the specified temperature is observed. This really can be a useful tool when looking for specific temperature ranges with the camera in the field.

When first starting the camera in the field it is recommended to let the camera boot up and sit for roughly five minutes before commencing with taking images. This will allow the camera to adjust for atmospheric conditions, warm up the sensor and allow readings to stabilize. Two critical settings need to be determined in the field and adjusted within the camera: emissivity and reflected apparent temperature. These two settings are discussed further in section 5.8.2. The camera also has two options for saving images to storage devices. A secure digital (SD) card slot is provided on the top of the camera for inserting and leaving an SD card in, to store images to and is the recommended method of storage. A USB port is provided on the bottom to allow the attachment of a small thumb drive if the SD card is unavailable. This makes for multiple options to save images onto both storage media and then transferring to a computer later for storage and analysis. Some problems that were obvious with using a thumb drive were that it one, hung down below the camera and could potentially fall out or be knocked out and two, if storing to a thumb drive, the drive may be removed at the end of the day and will have a higher potential of being misplaced compared to the SD card inside the camera. It should be noted images are stored identically no matter which type of storage media is used.

Within the settings of the T360 camera, adjustments can be made to limit or expand temperature scales and cutout above, below and in-between temperatures. To simplify use, in the field the T360 will automatically adjust temperature scales or they can be manually adjusted if needed. There are also settings for ambient air temperature, reflective apparent temperature, emissivity and humidity. One minor note when using the camera; a faint clicking noise will be heard from time to time and is completely normal. The shutter is making a "non-uniformity correction" and if necessary can be turned off for a short period of time (<30min.). If this function is disabled for more than 30 minutes, damage to the shutter will result. A basic set of instructions for using the T360 can be found in Appendix C.

A problem that arose while performing field trials was coming back from the field, downloading images and ending up with blurry images. The camera does have an auto-focus which usually provides quality images, but the camera may not focus on the desired object if no sharp edge exists for the camera to focus on. Manually adjusting the image to refine the focus on the object is sometimes required. It is critical to be sure the images are not blurry to provide an accurate image and to not miss seeing an important problem. A large tripod was tested and typically provides much better images as it tends to stabilize the camera and helps eliminate the chance of blurry images; it was especially helpful when taking images of a single spot multiple times.

5.8.1 IMPLEMENTING THE CAMERA

It should be understood that to be proficient at thermal imaging much more knowledge is necessary than just knowing how to use the camera. As seen in Figure 14, a large number of topics should be included in a thermographers training and knowledge base. The basic knowledge should include knowing about the camera and its functions, but also a basic understanding of IR and thermal science is also recommended to understand the how and why of thermal imagery. The thermographer should also have a good understanding and background of what the application is being investigated to help determine what images may have a significant affect and where the focus of the investigation should be. With time, an IR thermographer will also gain experience in performing proper IR inspections and will know what analysis techniques are required for each application. A well rounded IR thermographer should have all of these topics in their training, but also with time, skills will develop within all of these topics. The camera itself is relatively easy to use, but the technical aspects of thermal imagining require a much better understanding of the subject and how many different factors can have adverse effects on the images.

Before heading to the field with the camera it is recommended that the user has met the required minimum training for using the camera. The recommended minimum training should be a thorough reading of the FLIR user manuals for the camera and software, the Final Report, and the online training courses from FLIR (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). The online courses do provide short quizzes and should be adequate for basic training. These materials should be provided and available with the camera at all times.

Overall, once the basic training has been accomplished, the next step in using the camera should be spending time in the field and gaining the much needed experience behind the camera. Thermal imaging will produce better results with more experience gained while using the equipment. Further experience will also give the operator knowledge of what works best under specific conditions and will also provide results that show how one image may show problems better than others.

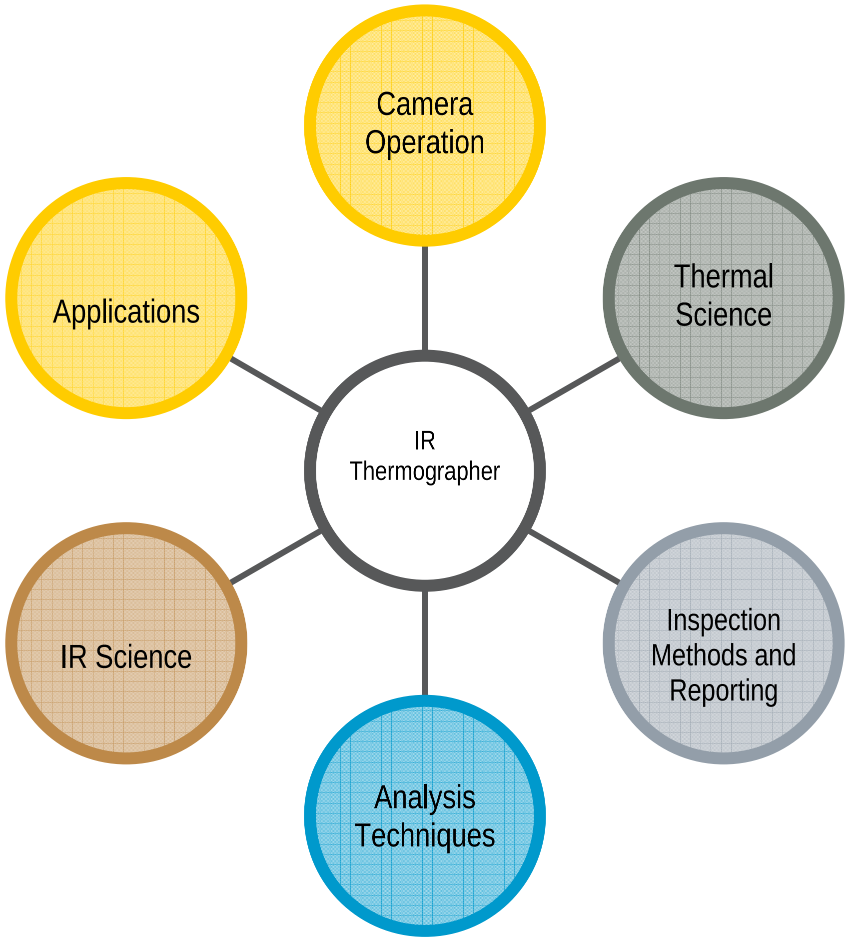


Figure 14: The fundamentals of knowledge necessary to be a proficient IR Thermographer.

5.8.2 CRITICAL SETTINGS

There are two critical settings on some thermal imaging cameras, including the FLIR T360, which must be input when trying to obtain an accurate measure of temperature: *emissivity* and *reflected apparent temperature*. These two settings can be adjusted in the office with the accompanying software, but knowing them in the field is critical to achieving an accurate temperature reading. FLIR does specify default settings if these two parameters are not known upfront, but again the accuracy will be diminished.

The emissivity of an object is its ability to radiate energy as described earlier. A setting within the T360 camera can adjust this, but slight variations in the emissivity can give inaccurate results. Emissivity can be measured in the field by using a piece of black electrical tape and a thermal camera. A simple set of instructions to measure emissivity have been provided in Appendix D.

The reflected apparent temperature is a compensation for radiation from the surrounding area of the object being analyzed; i.e. reflected heat from other objects nearby; such as the person taking the images. In effect, the camera is measuring the reflected radiation coming from behind and around the camera and adjusting this setting will compensate for this radiation. This can also be measured fairly accurately in the field by a few simple steps found in Appendix E. Temperatures in the images may not be highly accurate unless it is known that the selected settings are accurate.

5.8.3 ATMOSPHERIC FACTORS

Atmospheric factors play a huge role when using a thermal camera. Due to the nature of thermal imaging and that all objects give off some sort of radiant energy, many aspects of the environment come into play such as: wind, humidity, ambient air temperature, solar heating (day-time), solar cooling (night-time), cloud cover, precipitation, etc. All of these factors have an effect on how the camera will perform by affecting the radiated or emitted energy captured by the cameras sensor. For example, cloud cover will cool the surface of an object giving lower temperature readings. Heavy rain will distort the image completely as the thermal profiles are masked by a film of water. Likewise, wind will distort an image by cooling the surface of the object and the ambient air between the camera sensor and the objects surface. It is very critical the operator understand these factors before the camera is operated in the field. By choosing the right time of day with the right weather conditions, the quality and accuracy of the images will increase considerably.

5.9 SOFTWARE

Two software packages were provided with the FLIR camera system: *QuickReport* and *Reporter 8.3*. The *QuickReport* software, seen in Figure 15, is simplified and designed as easy to use software that is downloadable for free from FLIR's website. It has very few features compared to the *Reporter 8.3* software, but when first starting out with a thermal camera it is a good place to begin to learn how to adjust and analyze images. Some adjustments that can be performed with *QuickReport* are emissivity, reflected apparent temperature, atmospheric temperature, relative humidity, and distance to object. *QuickReport* can adjust the temperature scales automatically and manually, add point, line and area temperature measurements, and change the color palette. Finally, it is possible to create a simplified report for export into a PDF (portable document format) file which can print out date and times of the image, locations, etc. A simple instruction guide is provided in Appendix F.

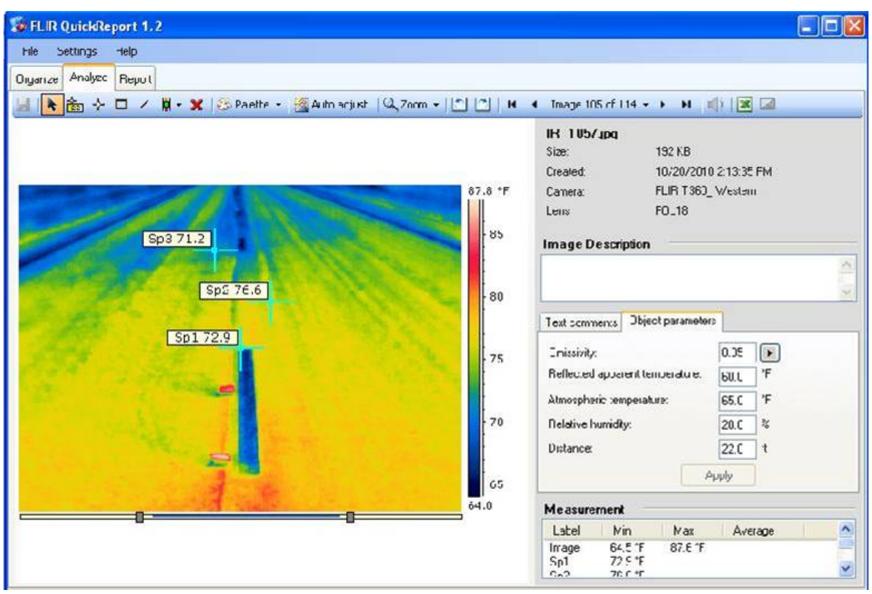


Figure 15: Shown above is the provided *QuickReport* software.

The *Reporter 8.3* software provides significantly more options to analyze an image. Like *QuickReport*, *Reporter 8.3* has all the above mentioned adjustments, but is integrated into Microsoft *Word* with additional tools, including more temperature measuring tools and a much better image "fusion" tool. A "fusion" image is basically an overlay or a blending of the thermal image with a digital image to see how the thermal image "fits" into the whole picture of what is being analyzed. An example of one type of fusion image and a sample report using the *Reporter 8.3* software is shown in Appendix A.

Within *Word*, *Reporter 8.3* reports can be created to provide much more detail about the images including plots of histograms, IR profiles, trending charts and other details for analyzing the images. Trending charts are a convenient method of tracking a specific objects temperature over time and can provide the user with insight into how the object is performing (IE: seeing the temperature of a bearing on a generator over time could highlight lubrication problems if the temperature is increasing). One nice feature of the *Reporter 8.3* software, templates can be generated which can help create standard field reports quickly and consistently between operators. A simple instruction guide for using the *Reporter 8.3* software is provided in Appendix G.

It is recommended that a single protocol be generated specific to the needs of each office so images are not lost or misused. It is also recommended that an accessible location of storing the images is created for each office that uses the camera. A protocol for storing images has been developed by the Office of Materials & Surfacing. An example protocol is as follows:

Folder Name: PCN, Road, County, What it is

Image Name: PCN, Road, What it is, Letter, (1 for digital and 2 for infrared)

Examples:

Folder – PCN 01T4 Hwy 79 Harding Co Warm Mix

Image – 01T4 Hwy 79 A (1).jpg

5.10 CONCLUSIONS

The overall goal of this project was to investigate the potential of the FLIR T360 camera and provide suggestions for implementing a thermal imaging system within the Department. The FLIR T360 thermal imaging camera system has proven to be a very easy to use tool that if used properly will benefit the Department for many years to come. It was seen that thermal imaging is not to be taken lightly and proper training and knowledge are required to use and implement the camera system in order to achieve quality results. Out of the original suggested trials for the camera, thermal imaging of asphalt paving projects is the most likely candidate for the camera. This is due to the thermal imaging system being most easily implemented as an aid and tool when conducting quality assurance on asphalt paving operations. Building energy audits are commonly performed in industry and would most likely provide a benefit to the Department as a tool for analyzing building envelope performance and helping reduce energy costs as supported by the literature review, but will require further research and development of detailed implementation plan to realize the greatest benefit. Bridge deck delaminations showed positive results; however, due to the scope and time frame of this project, will require further research to corroborate thermal images with standard methods of testing and to create a full implementation plan.

This project demonstrated there are many potential uses for thermal imaging within the Department and the few applications tested showed positive results. Conclusive results for some of the applications will require more in-depth investigation to better establish correlations of thermal images with traditional methods of testing. Additional refinement of thermal imaging techniques specific to asphalt paving operations should come after continued use of the camera by the Materials & Surfacing Office. Complete development of certain applications was beyond the scope of work of this project given the level of effort and project time lines established for the original study. Listed below in Table 2 are the rankings from "low" to "high" of potential applications and a short summary of the results.

Table 2: Application results and potentials ranked from high (likely) to low (unlikely).

Application	Results	Potential
Asphalt Paving Operations	Easy to see results of the surface, though it was not directly correlated to density or core temperature in this project.	High
Asphalt Crack Detection	Able to see cracks that can be seen with the naked eye, but very small cracks were typically unable to be seen. Also, likely to require an automated system to be of benefit.	Low
Asphalt Centerline Joint Detection	Possible to see joint in right conditions, but unable to see voids and more than likely needs an automated system to be of benefit	Low
Bridge Deck Delamination	Was possible to see temperature differentials, but no investigation was conducted to directly correlate delaminations with the thermal images. The literature review does support this application as feasible under the right atmospheric conditions.	Medium
Concrete Crack Detection	Able to see cracks that can be seen with the naked eye, but very small cracks were typically unable to be seen. Also, likely to require an automated system to be of benefit.	Low
Tank Volumes	With single wall tanks fluid levels were able to be seen, but a temperature differential must be present between the air/fluid interface. May be beneficial during paving operations to see tank volumes at batch plants and inside haul trucks.	Medium
Building Energy Audits	The literature reviewed supported a large benefit that could be gained when analyzing building envelope performance and potentially saving on energy costs.	High
Utility Locating & Inspection	Literature supported that utility locating was feasible, but unlikely to be used over traditional methods.	Low
Culvert Inspection	Little to no information has been studied in this area, but it was suggested as a possible topic for investigation. By seeing moisture infiltration or voids behind culvert walls, the thermal camera may be able to locate problems unseen to the naked eye.	Unknown

Trailer Brake Screening	Literature supported the use of infrared trailer brake screening, although, it is unlikely this camera would be implemented in such a fashion.	Low
Predictive Maintenance	Literature supported the use of this application, but was specifically geared to industrial plant processes. Two applications that could potentially use this type of analysis would be for building maintenance and highway maintenance equipment.	Medium

6.0 RECOMMENDATIONS

Based upon the results of this project, the researcher has the following recommendations:

1) It is recommended the FLIR T360 camera system be kept and maintained by the Office of Materials & Surfacing. This recommendation was based on prioritization of current needs within the Department and the well established utility of thermal imaging in asphalt paving operations as an aid for inspection of quality assurance.

2) It is recommended that individuals wanting to use the camera system should be provided the proper training materials before use. The proper training materials are as follows: FLIR user manuals for camera and software, the Final Report, and the links to free online training courses provided by FLIR (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). These materials should be stored with the camera system and made available to users of the camera.

3) A list of trained users should be established as a record of those that have completed as a minimum, the approved training program outlined in recommendation #2 above. This will ensure that users have attained the minimum level of knowledge necessary to operate the camera properly and avoid unnecessary damage to this expensive piece of equipment. A trained user is defined as someone who has read the FLIR camera and software manuals, the Final Report, and has taken the FLIR online training courses (Introduction to IR Camera Operation, T-Series Basics, Introduction to QuickReport, Introduction to Reporter 8). This list should be stored with the camera and maintained by the Office of Materials & Surfacing. The Office of Materials & Surfacing should have the discretion to decide who will be allowed to use the camera system and who will be allowed to become new users of the camera due to the high replacement cost of the camera system.

4) A protocol for labeling and storing the thermal images should be developed by each office that will be using the camera. It is recommended the protocol for each office be followed to ensure the images are organized and easily understood well into the future. The protocol should include an accessible location to store images and a standardized method of naming and organizing folders and images. It is also recommended that a log sheet be provided with each set of images to provide details about images including, but not limited to: location, atmospheric conditions, what is being analyzed, operator, date and time, etc.

5) Further research is recommended on the application of building energy audits. The literature supports the use of thermal imaging as an indispensable tool in conducting energy audits to evaluate building envelope performance and reduce energy costs. Access to the T360 thermal imaging camera will greatly facilitate adoption of routine energy audits at SDDOT.

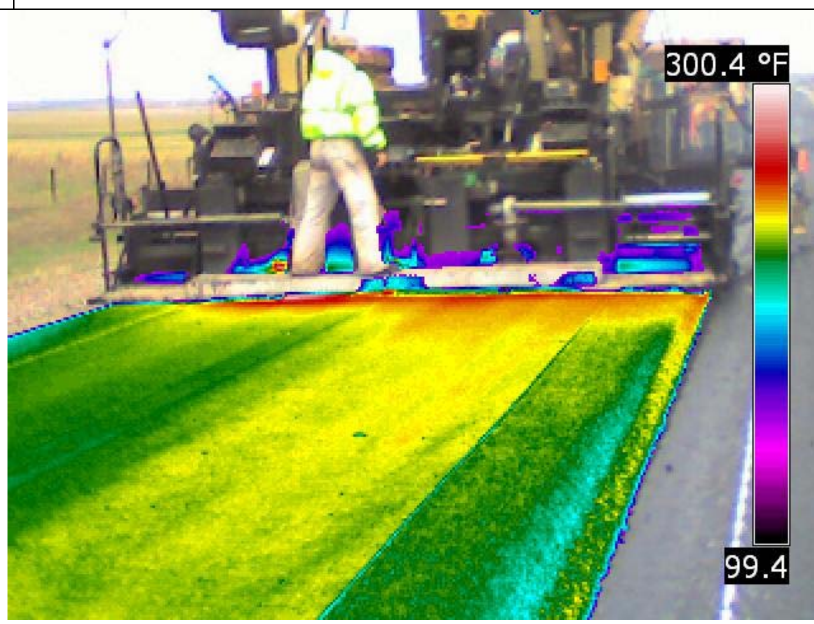
7.0 REFERENCES

1. Cho, Yong K. *Infrared Thermography-Driven Flaw Detection and Evaluation of Hot Mix Asphalt Pavements*. Tech. no. P309. Nebraska Department of Roads, Jan. 2010. Web. 2 Nov. 2010.
2. Henault, John W., and Donald A. Larsen. Thermal Imaging of Hot-Mix Asphalt Paving Projects in Connecticut. Tech. no. 1946. Transportation Research Record: Journal of the Transportation Research Board, 2006. Web. 5 Nov. 2010.
3. Carrier. *Predictive Maintenance*. Carrier, 2002. Print.
4. Çengel, Yunus A., and Michael A. Boles. Thermodynamics: an Engineering Approach. Boston: McGraw-Hill Higher Education, 2006. Print.
5. *Energy Efficiency Trends in Commercial and Residential Buildings*. Publication. Department of Energy, 2007. Print.
6. FLIR Infrared Cameras. FLIR Systems, 22 Oct. 2010. Web. 22 Oct. 2010. <http://www.flir.com/thermography/americas/us/>.
7. Howarth, Wade. "Predictive Maintenance Saves Money, Improves Plant Reliability." *Pharmceutical Processing* May 2004. Web. 10 Mar. 2011.
8. Jeong, Hung Seok. Imaging and Locating Buried Utilities. Tech. no. FHWA/IN/JTRP-2003/12. Indiana Department of Transportation, Oct. 2002. Web. 2 Nov. 2010.
9. "Light Spectrum." Electronic News. Http://helosaunas.com/images/light%20spectrum.JPG. Web. 05 Jan. 2011. <http://electronic.districsides.com/>.
10. Muzio, Robert. "DEMONSTRATION PROJECT FOR THERMAL IMAGING SAFETY SCREENING SYSTEM." Georgia Department of Transportation, June 2002. Web. 2 Nov. 2010. http://www.dot.state.ga.us/doingbusiness/research/Documents/reports/r-RP2014.pdf>.
11. Oloufa, Amr A. *GPS*-Aided *Asphalt Condition Rating Using Infrared Thermography*. Tech. Florida Department of Transportation, 31 July 2004. Web. 10 Nov. 2010.
12. Pollock, David G. Detection of Voids in Prestressed Concrete Bridges Using Thermal Imaging and Ground-Penetrating Radar. Tech. no. FHWA Project DTFH61-05-C-00008, Task No. 8. Washington State Department of Transportation, Dec. 2008. Web. 2 Nov. 2010.
13. Pratten, John. "Thermography at Ford's Dearborn Stamping Plant." *Maintenance Technology*. Fluke Corporation, 1 Jan. 2007. Web. 10 Mar. 2011.
14. Washer, Glenn. Effects of Environmental Variables on the Infrared Imaging of Subsurface Features in Concrete Bridges. Tech. Missouri Department of Transportation, 1 Aug. 2008. Web. 2 Nov. 2010.
15. Willoughby, Kim A. *Construction-Related Variability in Mat Density Due to Temperature Differentials*. Tech. no. TRB2003-001535. Washington State Department of Transportation, July 2002. Web. 2 Nov. 2010.

APPENDIX A: THERMAL IMAGING SAMPLE REPORT

Office of Materials & Surfacing
Thermal Imaging Report

Date:	Tuesday, February 1, 2011
PCEMS:	
Location:	
MRM:	



Date	04/29/2010
Filename	IR_0285_2.jpg
Image Time	11:11:08 AM
Emissivity	0.98
Object Distance	3.3 ft
Reflected Temperature	68.0 °F
Atmospheric Temperature	68.0 °F
Relative Humidity	50.0 %
Ar1 Max. Temperature	242.5 °F
Ar1 Min. Temperature	203.0 °F
Ar1 Average Temperature	232.4 °F
Ar1 Max - Min Temperature	39.5 °F

Comments: This is a sample field report generated for this research report only and not for official use.

APPENDIX B: SDDOT SPECIFICATIONS FOR A THERMAL IMAGING CAMERA

The SDDOT Offices of Research and Materials & Surfacing need to purchase a Thermal Imaging Camera to satisfy several functional needs related to bituminous asphalt production and paving operations. An immediate need relates to a project specification to perform thermal imaging of asphalt pavement test sections throughout the course of SDDOT Research Project SD2008-03, "Evaluation of Warm Mix Asphalt Concrete Pavement in South Dakota Conditions" during the project period of performance from the current time and through September 30, 2012. There are also many other needs* for thermal imaging of Hot Mix Asphalt (HMA) production and paving operations on planned highway projects that will run concurrently to, and well beyond the duration of the Warm Mix Asphalt (WMA) research project. Finally, there may well be several other thermal imaging applications that will be discovered after the camera is put into use at the Department.

An assessment of needs as defined for thermal imaging on WMA test sections and HMA highway projects at the SDDOT over the next several years has resulted in the following system requirements:

ITEM	SPECIFICATION/*JUSTIFICATION*
Thermal Imaging Camera:	
Fields of view/minimum focus distances	Standard, 25ºx19º / 0.4 m (1.31 ft.)
	Add-on optics, wide angle lens, 45°/10mm
	Determined to provide the necessary fields of view and focus distances for recording images of asphalt mats from various close, or far distances on project sites.
Thermal sensitivity	.06°C, or less, at 35°C (86°F)
	A greater sensitivity allowance would not produce desirable results on WMA projects in particular.
Detector type	Focal Plane Array (FPA), uncooled microbolometer
	Standard for these functional requirements.
Detector resolution	Minimum of 320 X 240 pixels
	For SDDOT thermal imaging requirements on highway projects, less resolution would not be acceptable.
Object temperature ranges	–20°C to +120°C (–4°F to +248°F), 0°C to 350°C (32°F to 662°F)
	Since WMA pavements are often produced at temperatures between 180°F and 280°F, and HMA pavements at temperatures greater than 300°F, a broad temperature detection range is needed.
Accuracy	±2°C (±3.6°F) or ±2% of reading, minimum
	Since the thermal imaging will often be used to determine if the asphalt is being placed according to the specified pavement mix design, accuracy cannot be less than this specification.
Laser locator	Built-in diode laser (red)
	Without a laser locator, it is often very difficult to identify imaging "targets" in asphalt paving environments, and could thereby also compromise safety.
Camera lens zoom and pan/focus	Digital,1-4X continuous/auto & manual focus

ITEM	SPECIFICATION/*JUSTIFICATION*
	This is deemed as the acceptable zoom and pan range for the functional requirements, and both auto and manual focus are necessary for adapting image focusing to field conditions.
Camera display	Built-in touch-screen LCD display, 3.5 in.
	Relative to the field conditions imposed and varying light conditions on construction project sites, these are deemed as the minimum for display functionality.
Visible light camera resolution	1280 x 1024 (1.3 megapixels)
	(Same justification as for "Camera display", above.)
Measurement modes	Capable of measuring 5 spots, 5 box areas, isotherm, and automatic hot/cold spots, minimum.
	Minimum requirements for measuring temperatures across the desired spectrum within image areas of HMA and WMA pavements.
Measurement corrections	Capable of correcting for reflected ambient temperature and emissivity
	Mandatory for the functional requirements posed by asphalt paving environments.
Operating temperature range	At least -15°C to +50°C (5°F to 122°F)
	The required temperature operating range to ensure workability in outdoor highway project environments.
Encapsulation	IP 54, IEC 529
	Must be environmentally sealed and suitable for harsh environments with an IP54 enclosure rating in accordance with IEC 529 and certified by an independent certification lab.
Shock resistance	25G, IEC 68-2-29
	Must have an appropriate shock specification suitable for harsh environments with a shock rating of at least 25G in accordance with IEC 68-2-29 and certified by an independent certification lab.
Camera lens shield	Polarized sun shield
	Required to shield reflective light from the lens when working in bright sunlight conditions on highway project sites.
Digital storage type and capacity	Removable SD Memory Card capable of storing at least 1000 JPEG images
	Remote locations and long periods of use drive these requirements.
Battery type	Rechargeable Lithium-Ion battery
	(Same justification as for "Digital storage type and capacity", above.)
Automobile power adaptor	12 volt auto adapter
	Must have an available Automobile adaptor for operations in the field.
Weight	Less than 2 pounds
	Field use requires a camera that is not too heavy.
Video output	NTSC Video
	Standard video output to allow viewing of images on a larger screen in the office, or elsewhere.
Image transfer	USB cable

ITEM	SPECIFICATION/*JUSTIFICATION*
	Essential for downloading images for viewing, processing, analysis, etc.
Transporting and carrying equipment	Camera case, lens cap, and hip/belt mounted holster
	Usage on project sites will require the camera to be kept close at hand at times, and also safely tucked away when not actually being used.
Software for Thermal Imaging Camera:	
Image transfer	Capability to transfer images to a laptop or desktop computer.
	Software must be included to allow transfer of image files via a USB cable to a laptop or desktop computer.
Reporting and analysis	Reporter Standard Software.
	Basic analysis and reporting software for in-depth thermal analysis and reporting. The software must be capable of storing radiometric images that will be fully integrated with Microsoft® Word, and also provides the following: • *Customized infrared (IR) image and digital photo fusion* • *Predictive trending functionality* • *Flexibility in report design and layout* • *Robust temperature analysis* • *Well-guided report generation* • *Automatic Association of IR and Visual Images* • *Automatic Report Generation by Drag and Drop*
Full warranty	One (1) year premier service warranty
	Warranty to provide an inspection & calibration program, full hardware & software repairs, provision of all parts & labor, and a 3-day guarantee against lost production time.
Extended warranty	One (1) year service plus (extended warranty)
	Extended warranty to provide additional time and savings.
Training	Entry-level Infrared Thermography training
	Within one year of delivery of the camera system, Level I Infrared Thermography training will be provided that is recognized by NETA (National Electrical Testing Association, an accredited standards developer for the American National Standards Institute, ANSI), and that also meets or exceeds ASNT SNT-TC-1A guidelines. This must be accomplished so that operational expertise can be developed within the SDDOT to ultimately support the departmental needs for proper thermal image generation and collection.

APPENDIX C: BASIC STEPS FOR USING THE FLIR T360

1. Locate the power button; the bottom right corner below the screen is a small button with an “I” on it, press until the camera powers on. Let off power button once camera begins to start. Camera will boot up for ~15 seconds before the camera is ready to take images. It is recommended to allow the camera to equilibrate for five minutes. ***Note**: Be sure batteries are fully charged as one battery lasts only four hours*.	
2. To take an image, aim the camera and push the auto-focus button once to allow the camera to focus (sliding button on front right of camera with “AF” on it). Also, adjust manually if needed with this same button by pushing right or left. ***Note**: Be sure lense cap is open.*	
3. When the desired object appears focused, press the silver button on the right front to capture an image. By pressing the button quickly (1sec.) it will capture and save an image or by holding the button down for longer (>1 sec.) it will ask you if you want to save or delete the image	

4. To download saved images, attach the accompanying USB cable to a computer and the micro USB port on the camera or use a USB flash drive to transfer. Another option is to remove the SD card from the top of the camera and connect to a computer with a SD card reader. Once connected to the computer, copy the images directly from the storage device or, if FLIR software is installed, use the software to download the images.

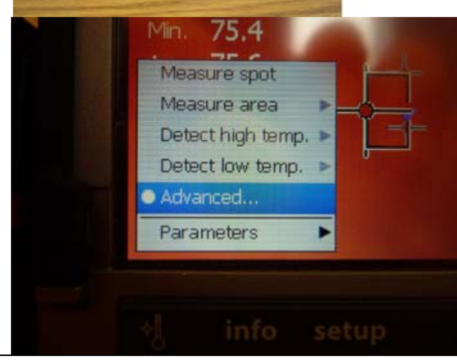
Note*: In order to use a USB thumb drive, the SD card can not be inside the camera.*

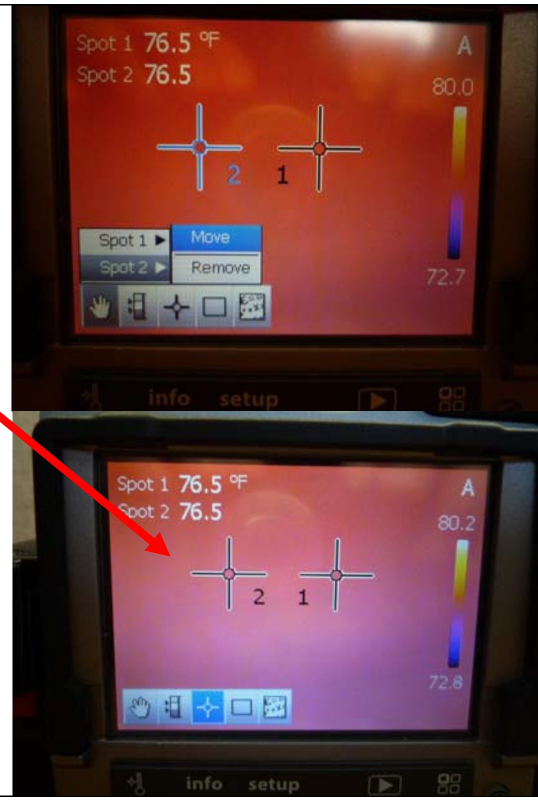
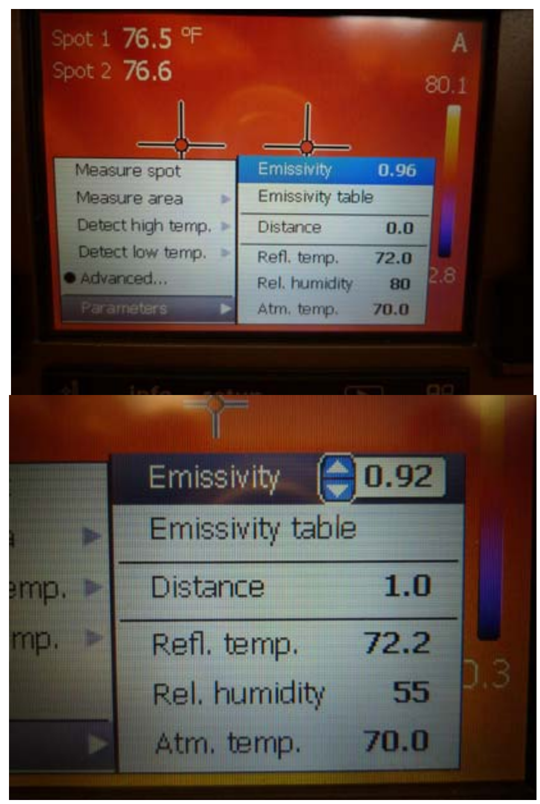
5. To turn off the camera, simply hold the power button down until the camera shuts off. If the power button is pressed quickly the camera will go into sleep mode and does not fully shut off and will drain the batteries. It should be noted that all data, once stored, will not be lost if the batteries are allowed to die.

APPENDIX D: MEASURING EMISSIVITY

List of materials:
Thermal camera capable of adjusting Emissivity (FLIR T360)
Black electrical tape

Obtaining emissivity for temperatures below 500°F:

1. Power the camera on. ***Note**: Be sure to open lens cap.*	
2. Place a piece of black electrical tape on the object wanting to be imaged and allow it to equilibrate to the same temperature as the object. ***Note**: Ideally the tape and object should be heated above ambient air temperature for the best results.*	
3. Two "spot" measurements need to be added to the screen. First select the "measure" button and select "advanced".	

4. Remove all previous measurement icons by selecting the first icon on the left. Then select the “add spot” icon; the third icon from the left. **Two “spot” measurements will be needed: one located on the black tape and one located on the object being measured.** Once inserted, move the “spot” icons as necessary by selecting the first icon on the left under the “advanced” menu. Press the “measure” button to exit this screen.	
5. Once the “spot” measurements have been set up, select the measure icon to exit. Then select the measure button again and select “parameters”, highlight “emissivity” and push the toggle button. Blue up/down arrows should appear and allow adjustment of “emissivity” with the toggle. Set emissivity to 0.97 and record the temperature of the “spot” measurement on the black tape.	

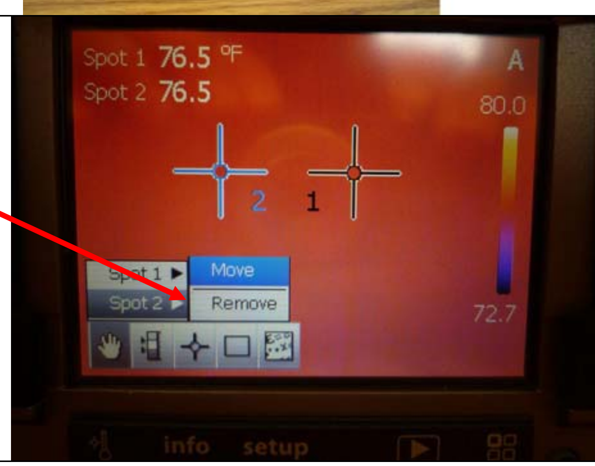
6. Adjust emissivity until the other "spot" reads the recorded temperature from step 7. Press the toggle button to exit "emissivity" and then press the "measure" button to exit the menu. ***Note***: *See "Note" in Step 2, if the tape and object are at room temperature it will be very difficult to get these two temperature readings the same. If possible, heat the object and tape above ambient air temperature and repeat the measurement.*	
The emissivity has now been measured properly. ***Note:*** *This procedure should be performed each time the object being imaged changes or there is a noticeable change in the surface.*	

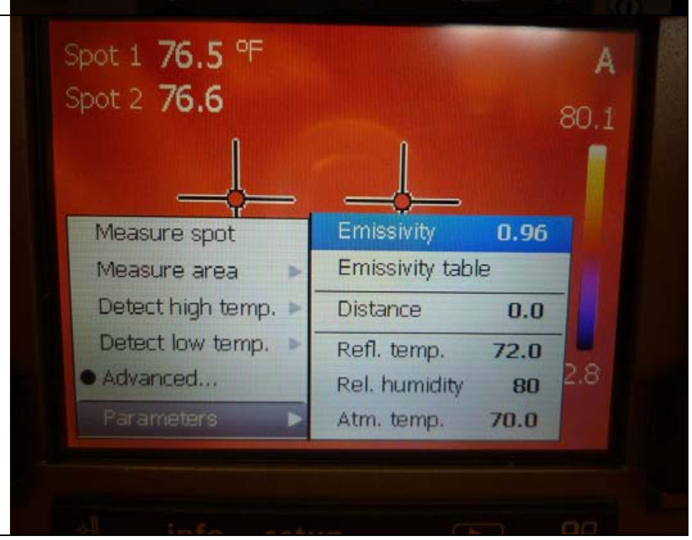
APPENDIX E: MEASURING REFLECTED APPARENT TEMPERATURE

List of materials:
Thermal camera capable of adjusting Reflected Apparent Temperature (FLIR T360)
Large piece of aluminum foil

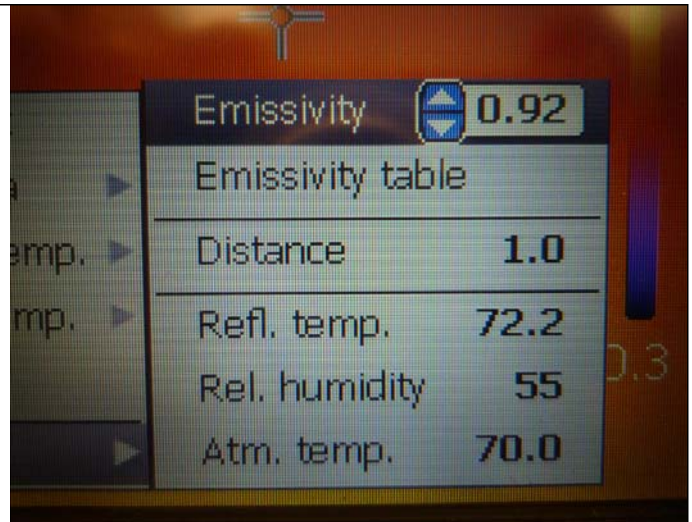
Steps to obtain Reflected Apparent Temperature (RAT) value:

<table>
<tr>
<td>1. Power the camera on.

***Note**: Be sure to open lense cap.*</td>
<td>
</td>
</tr>
<tr>
<td>2. An “area” measurement needs to be set up. Click on the “measure” button.</td>
<td>
</td>
</tr>
<tr>
<td>3. Select “advanced” and select the first icon on the left to remove all existing measurements on the screen. Select “remove” to remove each existing measurement tool.</td>
<td>
</td>
</tr>
</table>

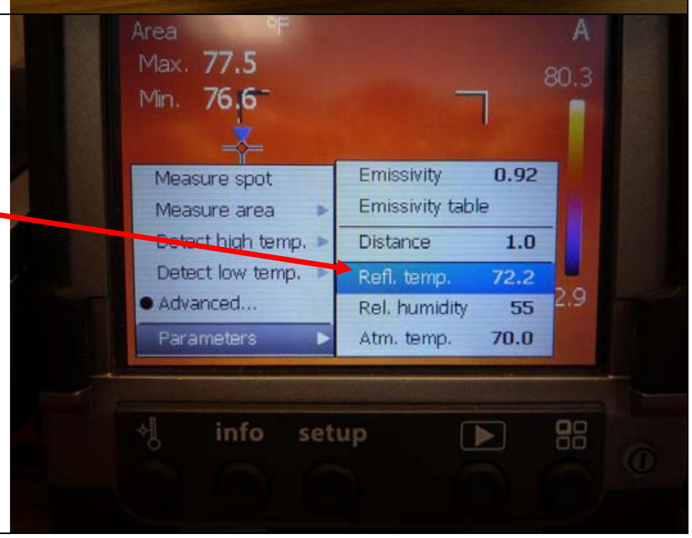
<table>
<tr>
<td>4. Once all measurements are removed, select the “add area” tool: the fourth icon from the left. This will add an area measurement to the screen.</td>
<td>
</td>
</tr>
<tr>
<td>5. The area can be re-sized by selecting the first icon on the left again. The average temperature will need to be shown and can be selected in this same menu. Select the “measure” button to exit the menu once the area is resized and the average temperature is displayed.</td>
<td>
</td>
</tr>
<tr>
<td>6. Select the measure button, then “parameters” and navigate to “emissivity”.</td>
<td>
</td>
</tr>
</table>

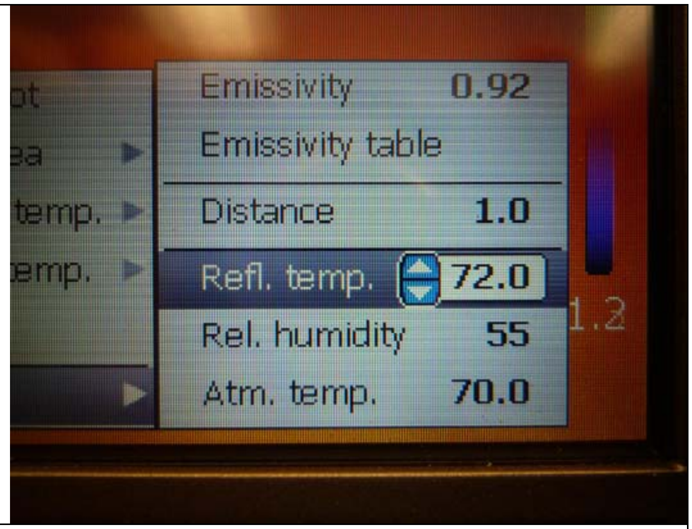
7. After emissivity has been highlighted press the toggle button and adjust to 1.0. Select the “measure” button to exit the menu.



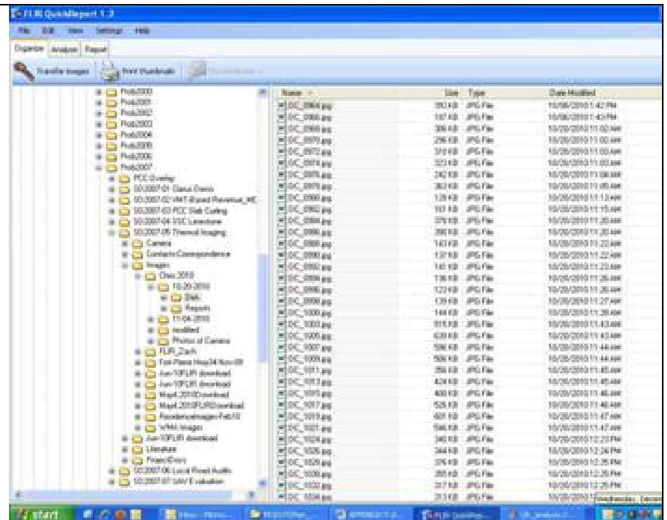
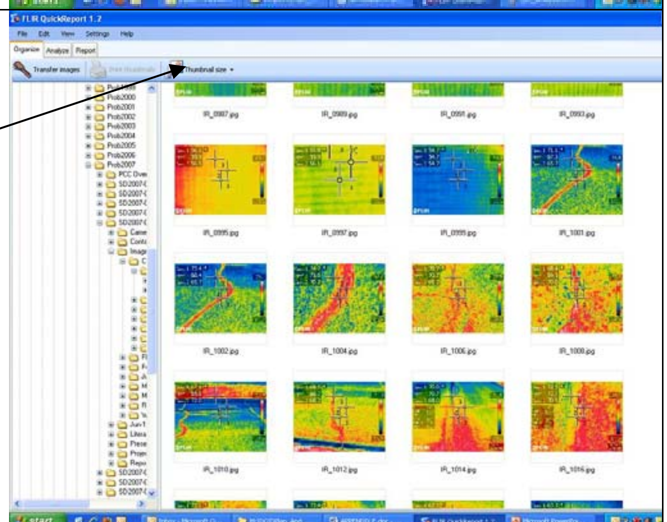
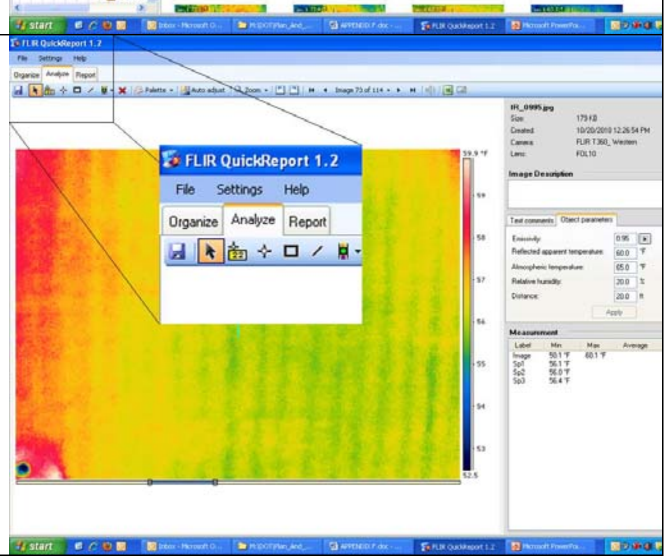
8. Place or hold at arms length a piece of tinfoil (12”x12” roughly) in between the camera lense and the object. Try to make the piece flat by attaching it to a piece of wood or cardboard.
9. Record the “average” temperature when looking at the tinfoil. This temperature is the RAT.

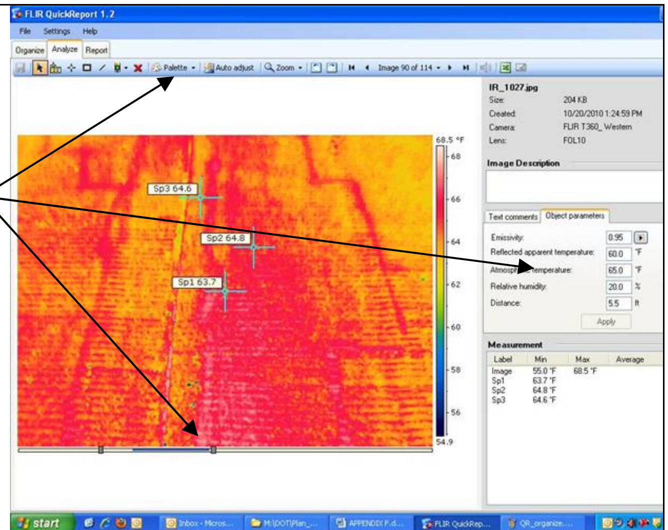
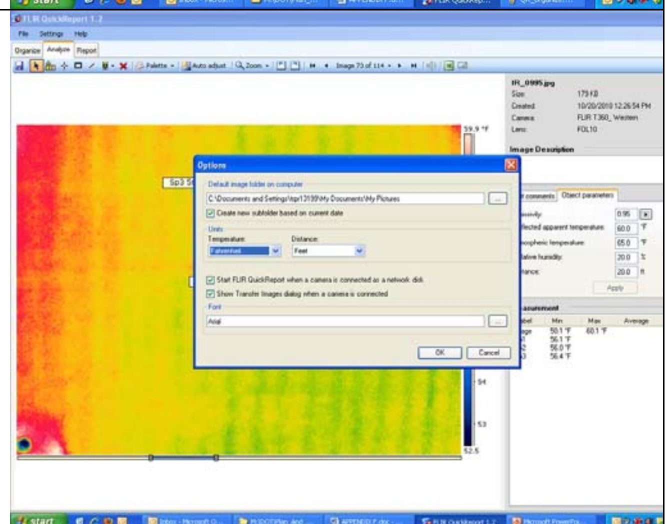
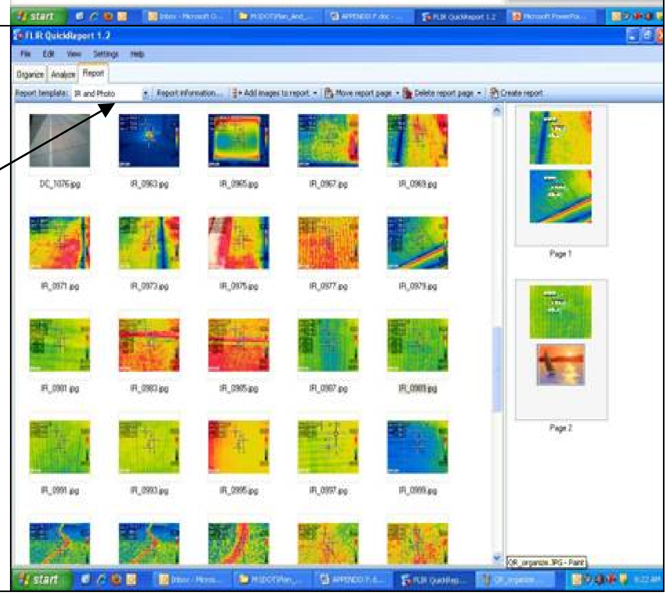
10. Now the RAT can be set within the camera. Select the “measure” button and then “parameters”. Navigate to “Refl. temp.” and select with the toggle.

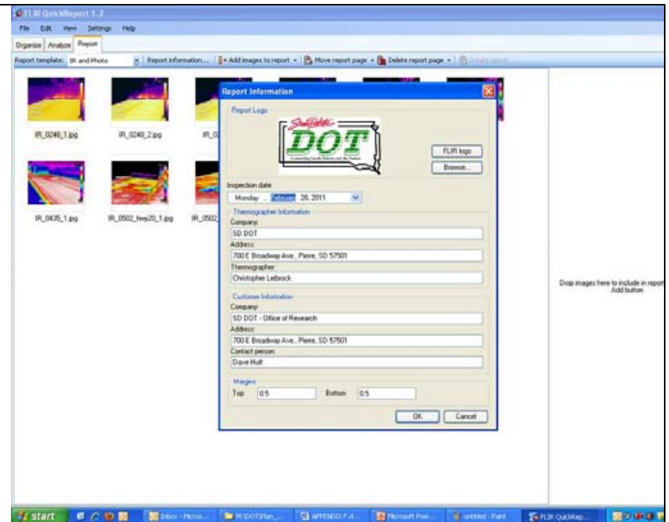
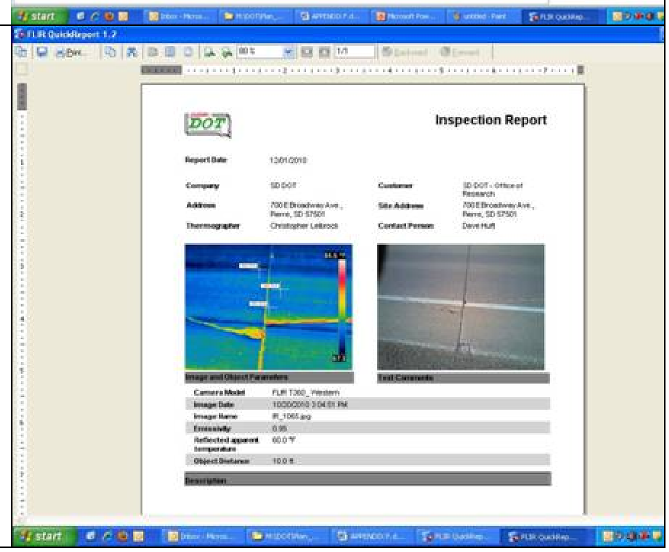


11. Adjust “Refl. temp.” to the average temperature recorded in step 9. Push the toggle button to exit.	
12. Select the “measure” button to exit the menu.	
The RAT has now been measured and set appropriately. ***Note****: It is recommended to measure RAT before emissivity. Once RAT has been determined, emissivity can be properly measured.*	

APPENDIX F: BASIC STEPS FOR USING QUICKREPORT SOFTWARE

1. Open the QuickReport software. 2. On the left, navigate to the folder of downloaded images or select "transfer images" if connecting directly to the camera. 3. After the folder has been selected, the images should appear on the right.	
4. Images can be viewed in multiple ways. From the pull-down menu "view", select "thumbnails" or "details". With thumbnails, the size can be adjusted by using the slider bar at the top of the screen on the toolbar.	
5. At the top left, select the "analyze" tab or double click an image you want to look at.	

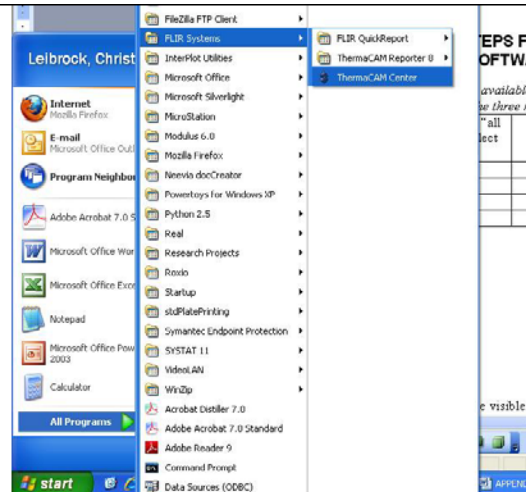
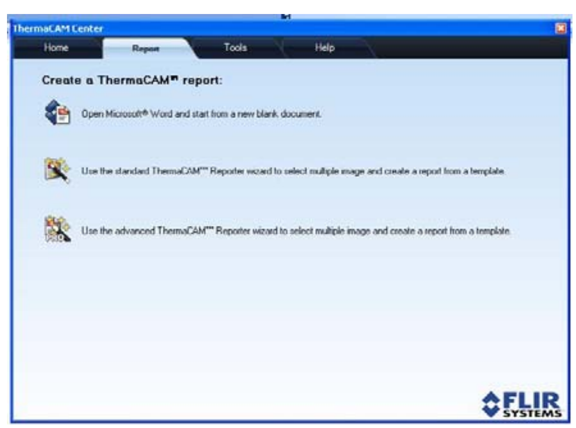
6. Within the "analyze" tab, many attributes for the image can be adjusted. The toolbar at the top of the viewing area and the tabs on the right side of the screen allow for many adjustments and additional information to be added to the image.	
7. Under the "settings" pull down menu, select "options" to change units and where images are saved. ***NOTE:*** *After an image has been modified, it is recommended to rename the file and save it somewhere else so the original is not lost.*	
8. Select the "report" tab. Within the "report" tab the images will be shown as thumbnails. Here the images can be "dragged" & "dropped" into a PDF report. Both thermal and digital images can be placed within the report by choosing under "report template" either "IR and IR" or "IR and photo".	

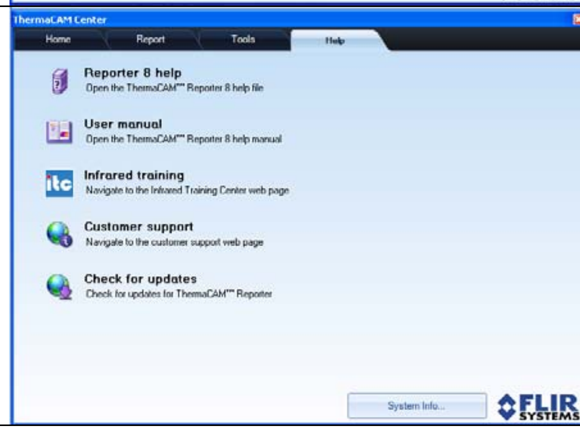
9. By selecting the button “Report Information” information can be entered to be included in the report. A specific logo can be inserted here as well.	
10. Select “create report” and a PDF will be generated. Seen to the right is a report with “IR and photo”.	

APPENDIX G: BASIC STEPS FOR USING REPORTER 8.3 SOFTWARE

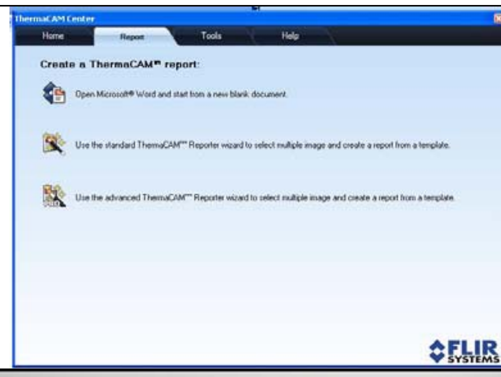
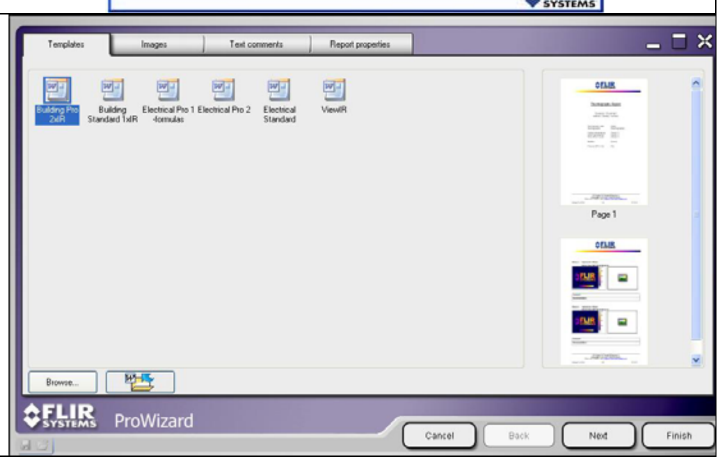
***Note**: Multiple ways to start a report are available with the Reporter 8.3 software: "wizard", "rapid report" and "blank report" are the three most likely to be used.*

To start the ThermaCAM Center:

1. Got to the "Start" menu in Windows, "All Programs", "FLIR Systems" and select "ThermaCAM Center"	
2. From within the ThermaCAM center, multiple choices can be made on how to proceed. On the "Home" page, information can be found about the camera and registration for the camera is available from here.	
3. From the "Report" tab the user can start with a blank document within Word, use the "standard" wizard to create a report or use the "advanced" wizard to create a report. The "standard" wizard is very basic and has few options much like the *QuickReport* software. The "advanced" wizard allows for much more customization and information to be integrated into a report.	

<table>
<tr><td>4. Under the “Tools” tab a report template can be made, edits to annotations and emissivity files can be made. Video is not an available option for the T360 camera.</td><td>
</td></tr>
<tr><td>5. The “Help” tab provides links to the Help file, user’s manual, ITC training website link, FLIR customer support and updates. There is also a link for system information if needed.</td><td>
</td></tr>
</table>

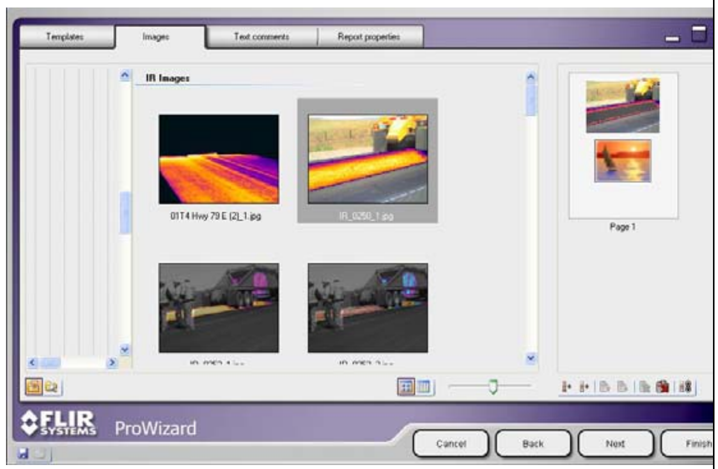
Creating a Report from the ThermaCAM Center:

<table>
<tr><td>1. Open the “ThermaCAM” center and select the “Report” tab. Choose the “advanced” wizard option.</td><td>
</td></tr>
<tr><td>2. The screen to the right should load. From here premade templates are available including templates that have been custom made. On the right, examples of the templates are shown. Select a template style and then hit the “Next” button.</td><td>
</td></tr>
</table>

<table>
<tr>
<td>

3. From the “Images” tab, navigate on the left to the folder where the thermal images are kept. Once found, thumbnails should appear. From this screen, drag and drop images onto the right side of the screen. If digital images are associated with the image they will automatically be added. If digital images were taken with another camera, they can be added by navigating to their location and adding them just like the IR images. Once all the images have been added select “Next”.

</td>
<td>

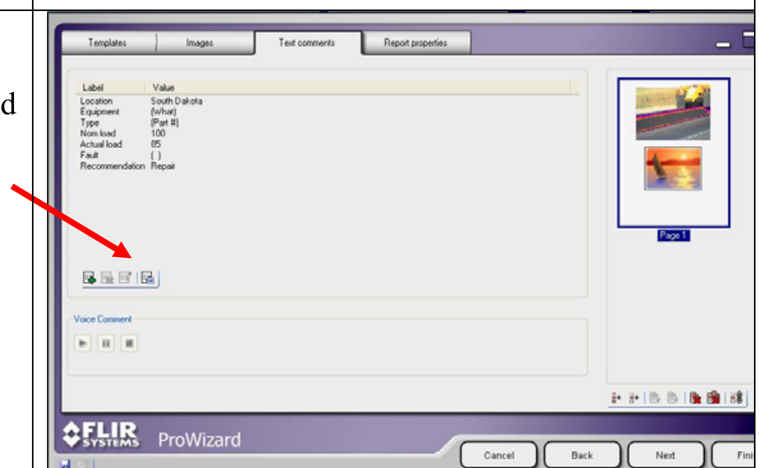


</td>
</tr>
<tr>
<td>

4. Within the “Text comments” tabs, attributes can be added to the images. Select the “add text comment” button or use premade templates. Once finished, hit “Next”.

Note*: These annotations should only be specific attributes and note detailed notes.*

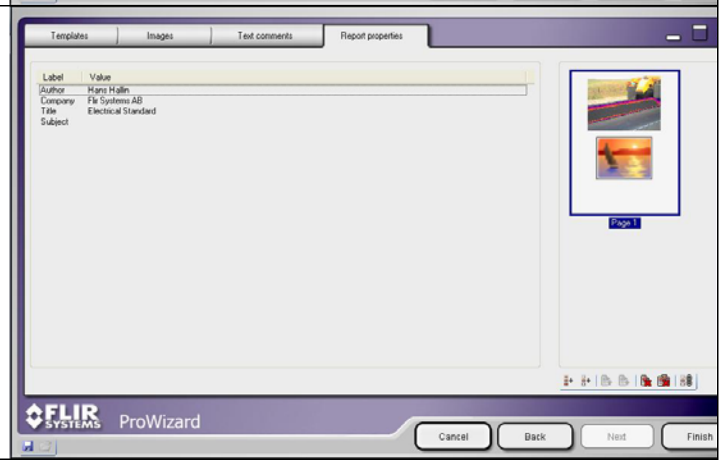
</td>
<td>



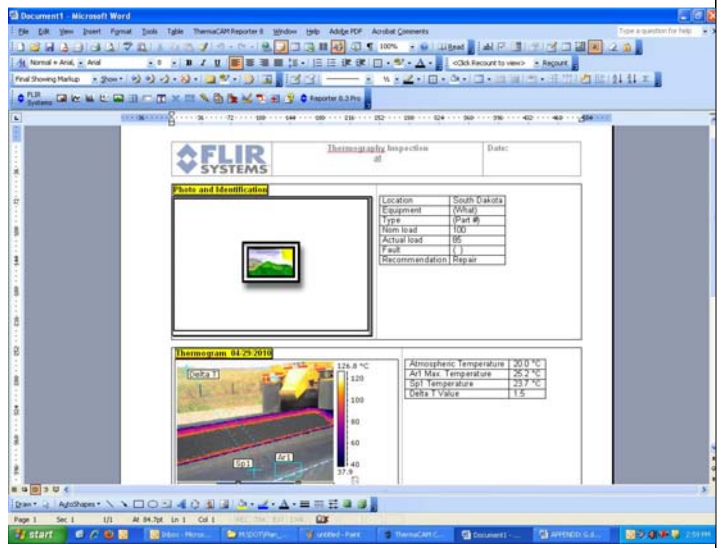
</td>
</tr>
<tr>
<td>

5. From the “Report Properties” tab information regarding the report can be added and modified as necessary. Once completed hit the “Finish” button.

</td>
<td>

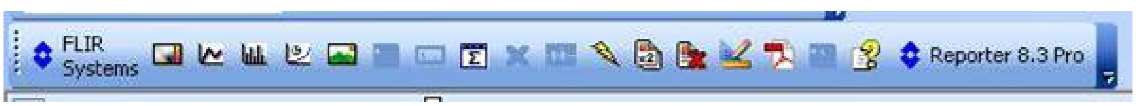


</td>
</tr>
</table>

6. The Report should now be created and *Word* should have opened with the results. From here final modifications can be made. Adjustments can now be made to the images, measurement tools can be added, etc. The tables can also be modified, but do not modify them as normal Word tables as they may lose connection to the image attributes. To make changes to the table information, right click and select "contents". Once changes are finished, save the document.	

When in Microsoft Word:

1. The Reporter 8.3 toolbar should be visible. If not, select "view", "toolbars" and select the "ThermaCAM Reporter 8" toolbar. If this is not available, the software needs to be reinstalled.
2. From this toolbar multiple tools are available for creating or modifying reports.



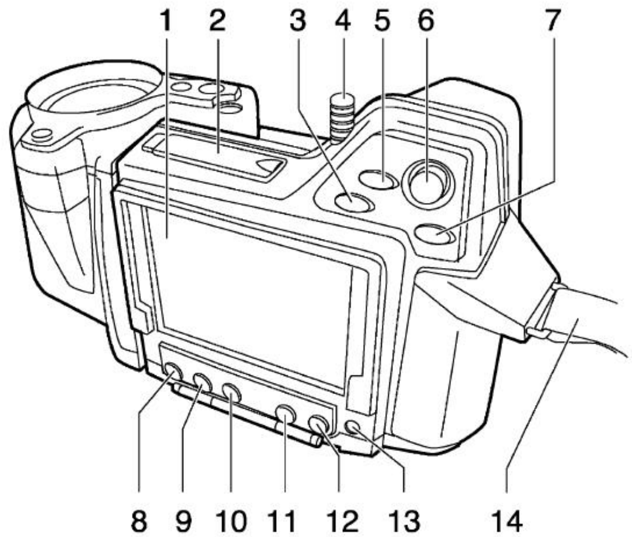
3. The tools available are listed below from left to right on the toolbar:

FLIR Systems	Link to FLIR website
Insert IR Viewer	Select the location to insert a viewing pane within the report. Click on the toolbar icon for "Insert IR viewer" and a viewer will appear. Right click within the viewer to open an IR image. Left click within the image to bring up the toolbar for the viewer that allows adjustments and modifications to the image.
Insert IR Profile	Select the location to insert a Profile pane within the report. Double click or right click to bring up the settings for the profile viewer.
Insert IR Histogram	Select the location to insert a Histogram pane within the report. Double click or right click and select to bring up the settings for the histogram viewer.
Insert IR Trending	Select the location to insert a Trending pane within the report. Double click or right click and select to bring up the settings for the trending chart.
Insert Digital Photos	Select the location to insert a Digital Photo pane within the report. Double click or right click and select to bring up the settings for the digital photo.

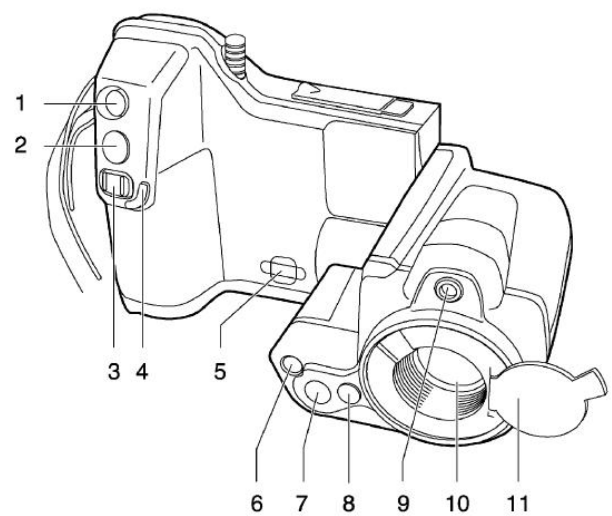
Insert Table	Once an IR image has been inserted into a report, a table of values can then be inserted. These values are dependant upon the user to decide. Right click and select contents to change the contents of the table.
Insert Field	Select this tool to generate a field within a report that will list specific data about the inserted image. When selected a window will open and display available data to be displayed in the field. The table can be modified after insertion by simply right clicking and selecting contents.
Insert Summary Table	Once an IR image is inserted into a report, a summary table may be generated displaying calculated data about the image. When selected a window will be displayed with available options to be presented in the table. The table can be modified after insertion by simply right clicking and selecting contents.
Delete	Use this tool to delete objects. Normal methods of deleting within *WORD* are not available with the FLIR add-on.
Connect	When inserting charts, histograms or tables it may be necessary to "link" the charts and images together. Select this tool and then select the two objects to connect together. The objects must be on the same page in order for them to connect.
Quick Insert	This allows multiple items to be inserted at one time.
Duplicate Page	Select this tool to create a separate, but identical copy of the current page.
Delete Page	Select to completely delete and remove the current page.
Design Mode	Selecting this tool will display another toolbar. This toolbar is for advanced users wanting to generate new reports with automated features, such as macros. Further information about using these tools can be found in the FLIR user manual.
Create PDF Documents	Select this tool to generate a PDF file of the current document.
View FLIR Task Pane	Opens the FLIR Task Pane on the right hand side of the screen.
Help	Opens the help file for the FLIR Reporter 8.3 software.
About	Displays information about the FLIR Reporter 8.3 software.

APPENDIX H: FUNCTIONS OF THE T360 CAMERA

1. Touch screen LCD
2. Cover for SD memory card slot
3. Zoom button
4. Stylus pen
5. Camera button
6. Joystick
7. Auto/Manual button
8. Measure button
9. Info display button
10. Setup menu button
11. Archive button
12. Mode button
13. On/off button
14. Hand strap



1. Laser pointer button
2. Save/preview button
3. Focus button
4. Protective edge for focus button
5. Attachment for neck strap
6. Video lamp
7. Digital camera lense
8. Release button for add-on IR lense
9. Laser pointer
10. Infrared lense
11. Lens cap for IR lense



1. Tripod mount ¼" -20
2. Release button for connector bay
3. Cover for connector bay
4. Release button for battery compartment cover
5. Cover for battery compartment