User's manual
FLIR IR Monitor

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1 Legal disclaimer

1.1 Legal disclaimer

All products manufactured by FLIR Systems are warranted against defective materials and workmanship for a period of one (1) year from the delivery date of the original purchase, provided such products have been under normal storage, use and service, and in accordance with FLIR Systems instruction.

Products which are not manufactured by FLIR Systems but included in systems delivered by FLIR Systems to the original purchaser, carry the warranty, if any, of the particular supplier only. FLIR Systems has no responsibility whatsoever for such products.

The warranty extends only to the original purchaser and is not transferable. It is not applicable to any product which has been subjected to misuse, neglect, accident or abnormal conditions of operation. Expendable parts are excluded from the warranty.

In the case of a defect in a product covered by this warranty the product must not be further used in order to prevent additional damage. The purchaser shall promptly report any defect to FLIR Systems or this warranty will not apply.

FLIR Systems will, at its option, repair or replace any such defective product free of charge if, upon inspection, it proves to be defective in material or workmanship and provided that it is returned to FLIR Systems within the said one-year period.

FLIR Systems has no other obligation or liability for defects than those set forth above.

No other warranty is expressed or implied. FLIR Systems specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

FLIR Systems shall not be liable for any direct, indirect, special, incidental or consequential loss or damage, whether based on contract, tort or any other legal theory.

This warranty shall be governed by Swedish law.

Any dispute, controversy or claim arising out of or in connection with this warranty, shall be finally settled by arbitration in accordance with the Rules of the Arbitration Institute of the Stockholm Chamber of Commerce. The place of arbitration shall be Stockholm. The language to be used in the arbitral proceedings shall be English.

1.2 Usage statistics

FLIR Systems reserves the right to gather anonymous usage statistics to help maintain and improve the quality of our software and services.

1.3 Changes to registry

The registry entry HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Control\Lsa \LmCompatibilityLevel will be automatically changed to level 2 if the FLIR Camera Monitor service detects a FLIR camera connected to the computer with a USB cable. The modification will only be executed if the camera device implements a remote network service that supports network logons.

1.4 Copyright

1.5 Quality assurance

The Quality Management System under which these products are developed and manufactured has been certified in accordance with the ISO 9001 standard.

FLIR Systems is committed to a policy of continuous development; therefore we reserve the right to make changes and improvements on any of the products without prior notice.

2 Notice to user

2.1 User-to-user forums

Exchange ideas, problems, and infrared solutions with fellow thermographers around the world in our user-to-user forums. To go to the forums, visit:

http://www.infraredtraining.com/community/boards/

2.2 Training

To read about infrared training, visit:

- http://www.infraredtraining.com
- http://www.irtraining.com
- http://www.irtraining.eu

2.3 Documentation updates

Our manuals are updated several times per year, and we also issue product-critical notifications of changes on a regular basis.

To access the latest manuals and notifications, go to the Download tab at:

http://support.flir.com

It only takes a few minutes to register online. In the download area you will also find the latest releases of manuals for our other products, as well as manuals for our historical and obsolete products.

2.4 Software updates

FLIR Systems regularly issues software updates and you can update the software using this update service. Depending on your software, this update service is located at one or both of the following locations:

- *Start* > *FLIR Systems* > *[Software]* > *Check for updates*.
- *Help* > *Check for updates*.

2.5 Important note about this manual

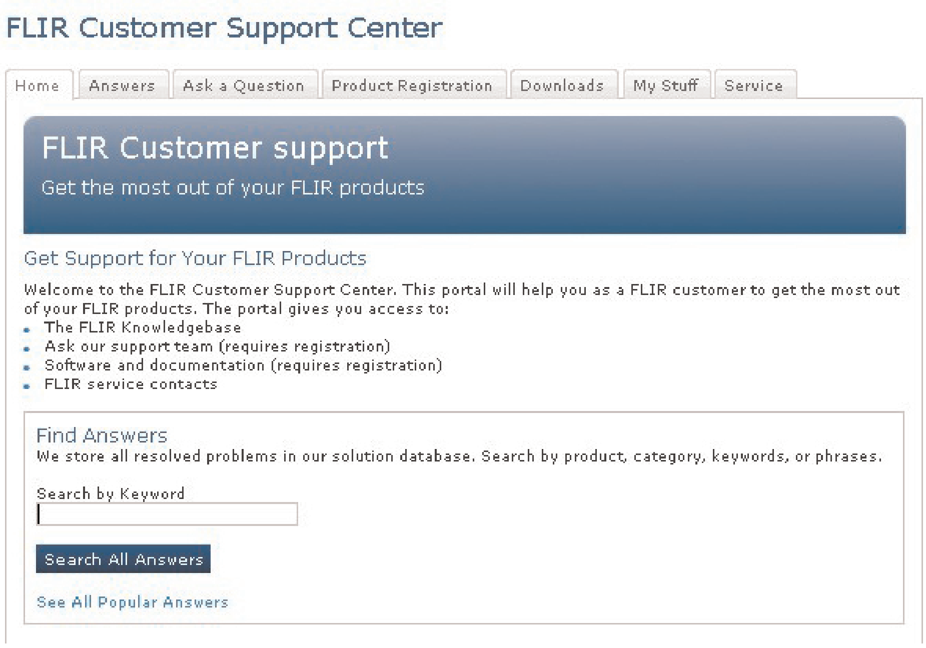
FLIR Systems issues generic manuals that cover several software variants within a software suite.

This means that this manual may contain descriptions and explanations that do not apply to your software variant.

2.6 Additional license information

For each purchased software license, the software may be installed, activated, and used on two devices, e.g., one laptop computer for on-site data acquisition, and one desktop computer for analysis in the office.

3 Customer help



3.1 General

For customer help, visit:

http://support.flir.com

3.2 Submitting a question

To submit a question to the customer help team, you must be a registered user. It only takes a few minutes to register online. If you only want to search the knowledgebase for existing questions and answers, you do not need to be a registered user.

When you want to submit a question, make sure that you have the following information to hand:

- The camera model
- The camera serial number
- The communication protocol, or method, between the camera and your device (for example, HDMI, Ethernet, USB, or FireWire)
- Device type (PC/Mac/iPhone/iPad/Android device, etc.)
- Version of any programs from FLIR Systems
- Full name, publication number, and revision number of the manual

3.3 Downloads

On the customer help site you can also download the following:

- Firmware updates for your infrared camera.
- Program updates for your PC/Mac software.
- Freeware and evaluation versions of PC/Mac software.
- User documentation for current, obsolete, and historical products.
- Mechanical drawings (in *.dxf and *.pdf format).
- Cad data models (in *.stp format).
- Application stories.
- Technical datasheets.
- Product catalogs.

4 Installation

4.1 General information

4.1.1 Explanation

The following programs are included on the ThermoVision System Tools & Utilities application CD:

- FLIR IP Config: A set-up and configuration program to detect and find FLIR automation and science cameras on a network and automatically assign or manually set IP addresses.
- FLIR IR Monitor: A program to control FLIR automation and science cameras on a network. You typically use FLIR IR Monitor to change camera settings, lay out measurement tools on the screen, set up alarms, etc.
- FLIR IR Camera Player: A PC-based remote control and video player for infrared cameras from FLIR Systems.
- A link to a web installation of FLIR Axxx Control & Image Interfaces: An installation that includes Interface Control Documents (ICDs), user documentation, and Ccode examples. We recommend that you read through the documentation.

4.1.2 Default installation paths

- C:\Program Files\FLIR Systems\FLIR IP Config
- C:\Program Files\FLIR Systems\FLIR IR Monitor
- C:\Program Files\FLIR Systems\FLIR IR Camera Player
- C:\Program Files\FLIR Systems\FLIR Axxx Control & Image Interfaces

Note
Functionality in the PC programs is dependent on the camera model.

4.2 System requirements

4.2.1 Operating system

- Microsoft Windows XP Professional, with Service Pack 2 (SP2).
- Microsoft Windows Vista Ultimate 32-bit.
- Microsoft Windows 7, 32-bit and 64-bit.

4.2.2 Hardware

- Personal computer with a 2 GHz 32-bit or 64-bit processor.
- 1 GB of RAM or more.
- 20 GB of hard disk space.
- Super VGA (1024 × 768) or higher-resolution monitor.
- Support for DirectX 9 graphics with:
  - WDDM driver
  - 128 MB of graphics memory (minimum)
  - Pixel Shader 2.0 (in hardware)
  - 32 bits per pixel.
- DVD-ROM drive.
- Audio output.
- Keyboard and Microsoft mouse, or a compatible pointing device.

4.2.3 Software

Microsoft Internet Explorer 6 or later.

4.2.4 More information

For specific information about system requirements for the operating systems mentioned above, visit http://www.microsoft.com/windows/.

4.3 Installation

4.3.1 General

Last-minute changes and other important information can be found in the read-me file on the CD-ROM. We recommend that you read this file before you install the programs.

Note

- If you experience problems during the installation, visit our Customer Help at http://support.flir.com.
- You must be an Administrator or a user with Administrative Rights to install the programs.
- A complete installation consists of several subinstallations, some of which are from third-party vendors. Do not abort these subinstallations, as they are needed for the complete installation.
- A complete installation can take up to 10 minutes to complete.

4.3.2 Procedure

Follow this procedure:

1. Close down all applications.
2. Insert the ThermoVision System Tools & Utilities CD-ROM into the CD drive on the computer. The installation should start automatically.

   Should the installation not start automatically, start Windows Explorer and double-click SETUP.HTM on the CD-ROM.
3. Click Install FLIR IR Monitor.
4. Follow the on-screen instructions.

5 Controlling the camera

> **Note**
>
> - The majority of the functions and features in FLIR IR Monitor are dependent on the camera model.
> - The first time you start FLIR IR Monitor you will need to make an active selection to use ffdshow to view images in FLIR IR Monitor. The recommendation is to select *Use ffdshow* in the dialog box that is displayed.
> - In order to view Axis camera images in FLIR IR Monitor, a specific Axis component must be installed on the computer, the *Axis Media Control*. There are two ways to obtain that component—either through the Axis camera interface or by downloading it from the Axis website (http://www.axis.com).
> - In Windows Vista, problems with displaying the image stream may occur. This problem is related to Group Policy. Please contact your IT department for support on this issue.

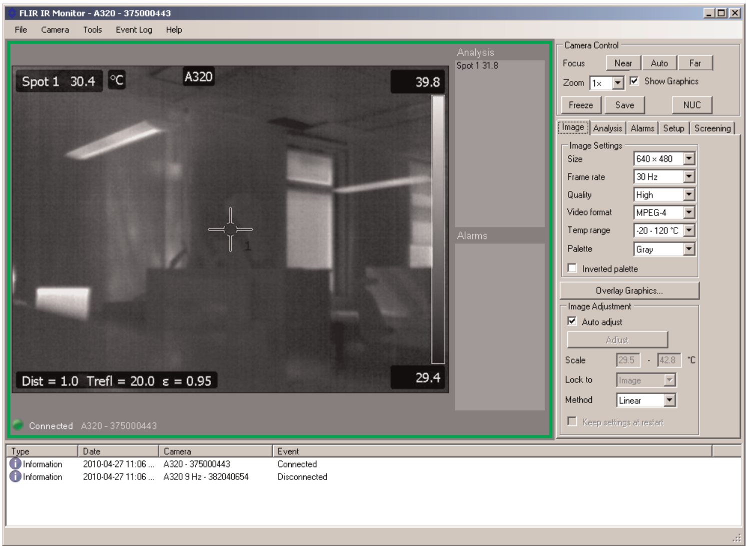
5.1 When to use FLIR IR Monitor

You typically use FLIR IR Monitor when doing one or more of the following:

- When laying out and moving analysis tools on the infrared image.
- When setting up alarms.
- When changing object parameters.
- When laying out or editing grid overlays on the infrared image.
- When scheduling when and under what circumstances images and measurement results will be distributed—by e-mail or FTP.

5.2 Figure

This figure shows a typical main window of FLIR IR Monitor.



5.3 How to start FLIR IR Monitor

To start FLIR IR Monitor, click FLIR IR Monitor on the *Start* menu (*Start* > *Programs* > FLIR Systems > FLIR IR Monitor).

5.4 Procedures related to FLIR IR Monitor

5.4.1 General

This section describes a number of typical procedures related to FLIR IR Monitor.

For detailed information on all interface elements – menus, menu commands, command buttons, list boxes, etc. – refer to section 6 *Program reference section*, page 21.

5.4.2 More information

- Section 5.4.3 *Connecting to one or more cameras*, page 8.

5.4.3 Connecting to one or more cameras

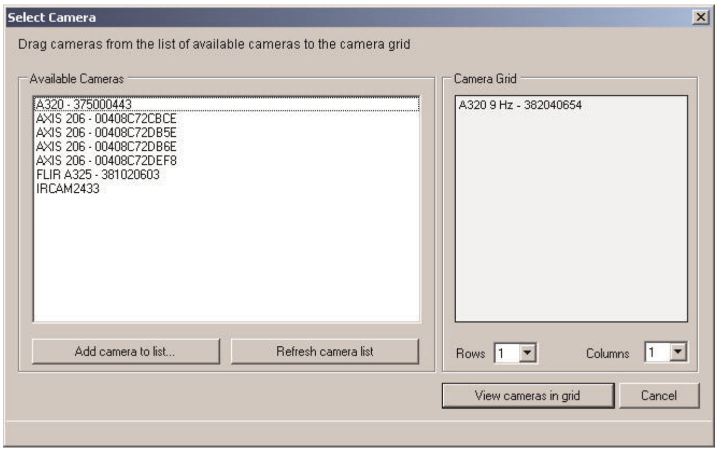
5.4.3.1 General

In FLIR IR Monitor you can display live images from one or more cameras in a network at the same time. To do this, connect the camera/cameras to FLIR IR Monitor using a *Select camera* dialog box.

5.4.3.2 Procedure

Follow this procedure:

1. On the *Camera* menu, select *Connect*. This will display a *Select Camera* dialog box:



2. In the right pane of the dialog box, create a camera grid by using the *Rows* and *Columns* list boxes.
3. In the left pane of the *Select Camera* dialog box, select the camera/cameras you want to connect to FLIR IR Monitor.
4. Drag-and-drop the selected camera/cameras into the camera grid that you created.
5. Click *View cameras in grid* to close the dialog box and go back to the main window of FLIR IR Monitor. You will now see live images from the camera/cameras you have selected.

5.4.3.3 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

5.4.4 Changing object parameters

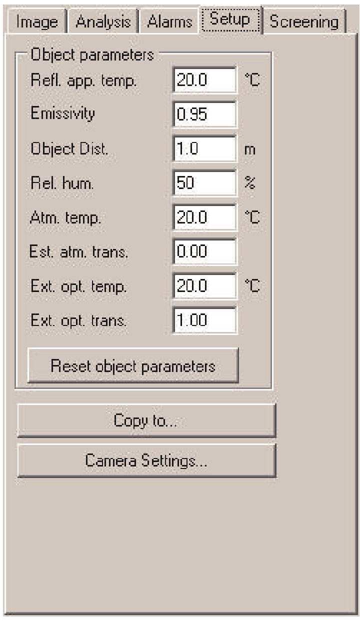
5.4.4.1 General

For accurate measurements, you must set the object parameters. This procedure describes how to change the parameters.

5.4.4.2 Procedure

Follow this procedure:

1. Click the *Setup* tab.



2. To enter new values, type the desired values in the appropriate text boxes.

Note

- If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing settings. To do this, click the window.
- You can copy one camera's object parameters to the camera that is currently displayed. To do this, click *Copy to* and select a camera.

5.4.4.3 More information

- For complete information on interface elements, refer to section 6 *Program reference section*, page 21.
- For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.

5.4.5 Changing settings related to infrared images

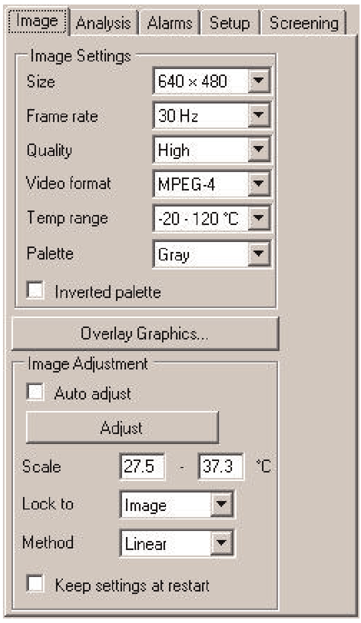
5.4.5.1 General

You change settings related to infrared images on the *Image* tab.

5.4.5.2 Procedure

Follow this procedure:

1. Click the *Image* tab.



2. Do one of the following:
   - To change an image setting, select a new value in the appropriate list box.
   - To adjust the image, do one of the following:
     - Select *Auto adjust* to make the camera automatically adjust the image.
     - Clear *Auto adjust*, enter values for the scale limits and adjustment method, and click *Adjust*.

Note

- You can also change these settings using the camera's web interface (availability dependent on the camera model).
- If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing the settings. To do this, click the window.

5.4.5.3 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

5.4.6 Laying out analysis tools

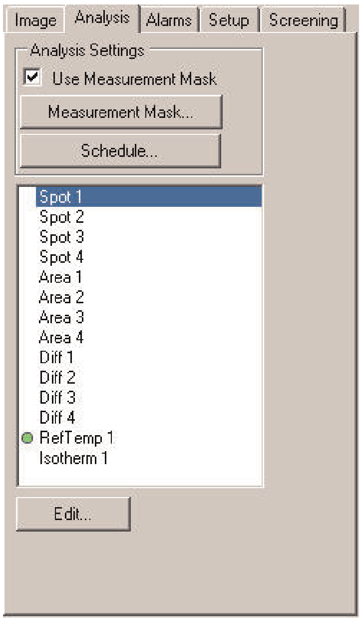
5.4.6.1 General

You lay out analysis tools using the functions on the *Analysis* tab.

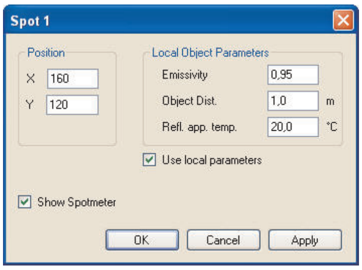
5.4.6.2 Procedure

Follow this procedure:

1. Click the *Analysis* tab.



2. In the list, select an analysis tool, e.g., a spot.
3. Click *Edit*. This will display an edit dialog box:



4. In the dialog box that is displayed, make the appropriate changes and then click *OK* or *Apply*.

Note
If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing the settings. To do this, click the window.

5.4.6.3 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

5.4.7 Working with measurement masks

5.4.7.1 General

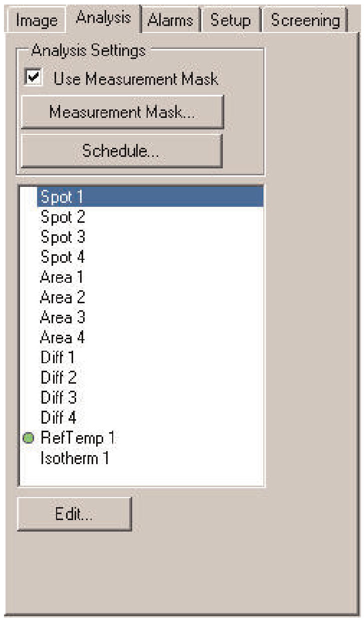
A measurement mask is a manually created free-form area within a fixed measurement area that can be used when working with alarms.

For example, if you create a rectangular area but only want an alarm to trigger if conditions are met in a smaller, irregularly shaped area inside the rectangular area, use a measurement mask to achieve this.

5.4.7.2 Procedure

Follow this procedure:

1. Click the *Analysis* tab.



2. Create a measurement area and make it active, as described in section 5.4.6 *Laying out analysis tools*, page 10.
3. Select the *Use Measurement Mask* check box.
4. Click *Measurement Mask*. This will display the *Measurement Mask* dialog box:

5. In the *Measurement Mask* dialog box, select a pen size in pixels and use the cursor to paint a free-form area within the measurement area that you previously created.
6. To leave the dialog box and apply the mask to the selected camera, click *OK*.

Note
If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing settings. To do this, click the window.

5.4.7.3 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

5.4.8 Moving and resizing analysis tools

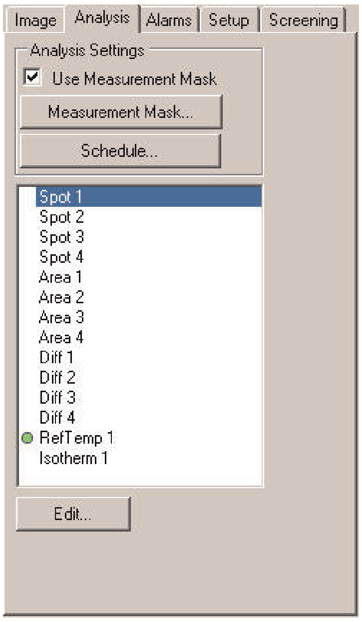
5.4.8.1 General

You move and resize analysis tools using the functions on the *Analysis* tab.

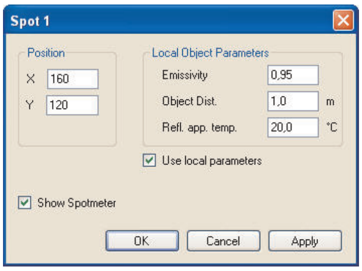
5.4.8.2 Procedure

Follow this procedure:

1. Click the *Analysis* tab.



2. In the list box, select an analysis tool.
3. Click *Edit*. This will display an edit dialog box, which will differ in appearance depending on which analysis tool was selected. The following is a spot dialog box:



4. In the dialog box, make the appropriate changes and then click *OK* or *Apply*.

Note
If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing settings. To do this, click the window.

5.4.8.3 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

5.4.9 Setting up a difference calculation

5.4.9.1 General

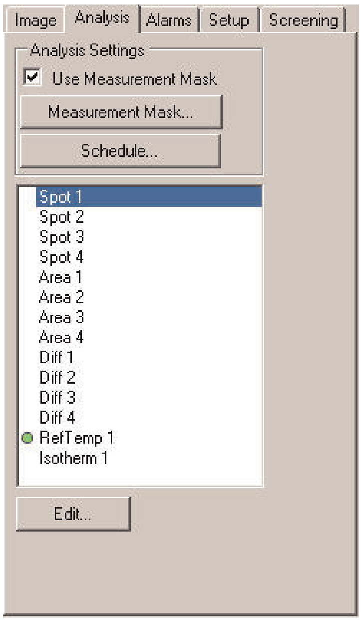
You set up difference calculations using the functions on the *Analysis* tab. A difference calculation gives the result of the subtraction between two different measurement results.

Setting up a difference calculation assumes that at least two previous analysis tools have been laid out. These analysis tools must be either two spotmeters or one spotmeter and one area.

5.4.9.2 Procedure

Follow this procedure:

1. Click the *Analysis* tab.



2. In the list box, select *Diff*.
3. Click *Edit*. This will display the *Edit* dialog box:

4. In the *Function 1* list box, select the first analysis tool to be used in the subtraction.
5. In the *Result 1* list box, select the result type that you want to use for the first analysis tool.
6. In the *Function 2* list box, select the second analysis tool to be used in the subtraction.
7. In the *Result 2* list box, select the result type that you want to use for the second analysis tool.
8. Click *OK* or *Apply*.

> **Note**
> If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing settings. To do this, click the window.

5.4.9.3 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

5.4.10 Setting up an alarm

5.4.10.1 General

You set up alarms on the *Alarms* tab.

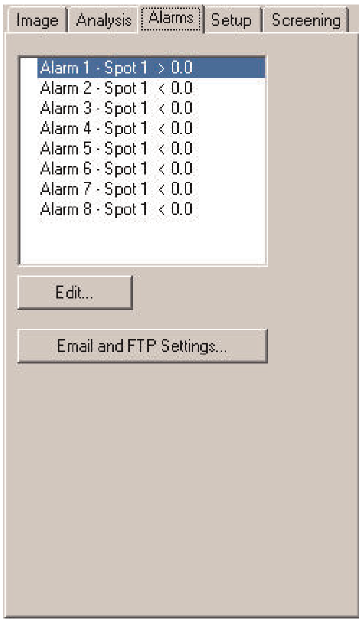
An alarm can be triggered by several different sources, such as a measurement result in the image, a digital input, or an internal temperature sensor.

When an alarm is triggered, the camera can perform one or more tasks. For example, it can e-mail the image frame for which the alarm was triggered to a mail recipient, send the image to an FTP site, or save the image to memory. The camera can also further trigger a variety of external devices, using the digital output.

5.4.10.2 Setting an alarm based on the measurement result

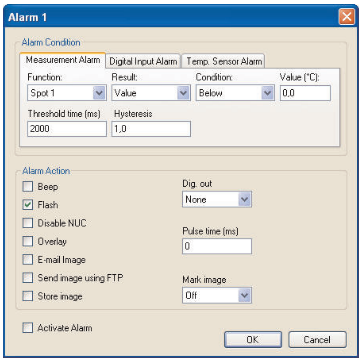
Follow this procedure:

1. Click the *Alarms* tab.



2. In the list box, select an alarm.

3. Click *Edit*. This will display the edit dialog box:



4. Click the *Measurement Alarm* tab.
5. In the *Function* list box, select the analysis tool that you want to use to trigger the alarm. The analysis tool must be one that you created in section 5.4.6 *Laying out analysis tools*, page 10.
6. In the *Result* list box, select the type of analysis result that you want to use to trigger the alarm.
7. In the *Condition* list box, select the type of alarm (*Above*, *Below*, *Match*).
8. In the *Value* text box, enter the temperature level that will be used as the trigger limit.
9. In the *Threshold time* text box, enter the duration that must be matched or exceeded in order for the alarm to be triggered.

   The duration specifies the amount of time that has to pass before an alarm is triggered. This can be used as a powerful tool to avoid false alarms.
10. In the *Hysteresis* text box, enter the hysteresis value.

    Hysteresis is the interval within which the temperature value is allowed to vary without causing a change in the trigger. If the threshold is set above, for example, 30.00°C and the hysteresis is set at 2.00°C, the trigger goes high when the temperature rises above 30.00°C and stays high until the temperature drops below 28.00°C. In contrast, if the threshold is set below 30.00°C, and the same hysteresis value is kept, the trigger goes high if the temperature drops below 30.00°C and stays high until the temperature rises above 32.00°C.
11. Under *Alarm Action*, decide which actions the camera will perform when an alarm is triggered.
12. Click *Activate Alarm*.
13. Click *OK* to leave the dialog box.

> **Note**
> If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing settings. To do this, click the window.

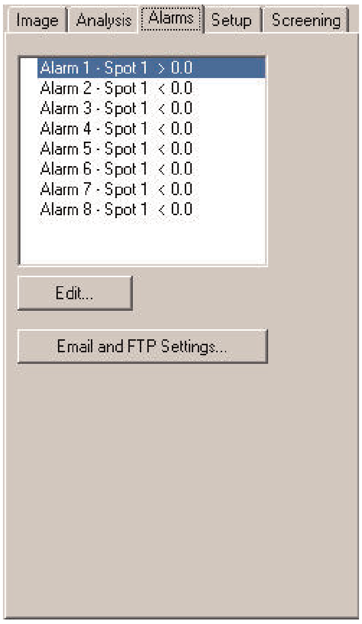
5.4.10.3 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

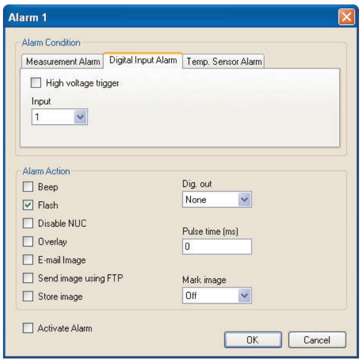
5.4.10.4 Setting an alarm based on the digital input

Follow this procedure:

1. Click the *Alarms* tab.



2. In the list box, select an alarm.
3. Click *Edit*. This will display the edit dialog box:



4. Click the *Digital Input Alarm* tab.
5. In the *Input* list box, select the digital input I/O port to use.
6. Under *Alarm Action*, decide which actions the camera will perform when an alarm is triggered.
7. Click *Activate Alarm*.
8. Click *OK* to leave the dialog box.

Note
If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing settings. To do this, click the window.

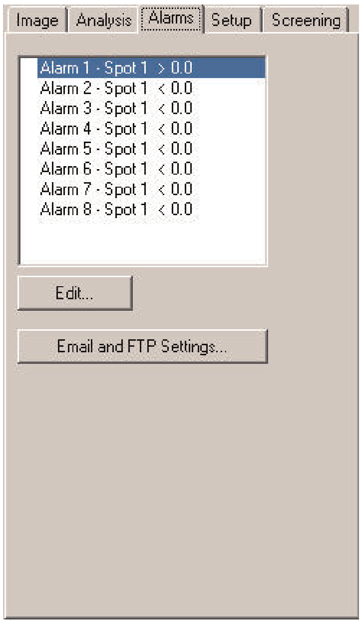
5.4.10.4.1 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

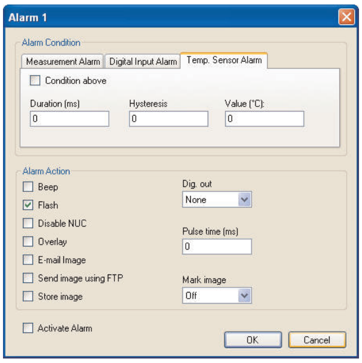
5.4.10.5 Setting an alarm based on internal temperature sensor

Follow this procedure:

1. Click the *Alarms* tab.



2. In the list box, select an alarm.
3. Click *Edit*. This will display the edit dialog box:



4. Do one of the following:
   - To trigger the alarm above a set temperature, select the *Condition above* check box.
   - To trigger the alarm below a set temperature, clear the *Condition above* check box.
5. In the *Duration* text box, enter the duration that must be matched or exceeded in order for the alarm to be triggered.

   The minimum duration identifies the amount of time that has to pass before an alarm is triggered. This can be used as a powerful tool to avoid false alarms.
6. In the *Hysteresis* text box, enter a temperature value for hysteresis.

   Hysteresis is the interval within which the temperature value is allowed to vary without causing a change in the trigger. If the threshold is set above, for example, 30.00°C and the hysteresis is set at 2.00°C, the trigger goes high when the temperature rises above 30.00°C and stays high until the temperature drops below 28.00°C. In contrast, if the threshold is set below 30.00°C, and the same hysteresis value is kept, the trigger goes high if the temperature drops below 30.00°C and stays high until the temperature rises above 32.00°C.

7. In the *Value* text box, enter a temperature level above or below which the alarm will be triggered.
8. Under *Alarm Action*, decide which actions the camera will perform when an alarm is triggered.
9. Click *Activate Alarm*.
10. Click *OK* to leave the dialog box.

Note
If you have connected several cameras to FLIR IR Monitor, you must activate the corresponding camera window before changing settings. To do this, click the window.

5.4.10.6 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

5.4.11 Screening of elevated facial temperatures

5.4.11.1 General

The *Screening* function allows you to screen a large number of persons for facial temperatures that lie above a set reference temperature.

When an elevated temperature is detected, the camera will trigger a visible and audible alarm. You can disable the audible alarm.

Note
Remove any spectacles from the person whose facial temperature you are screening.

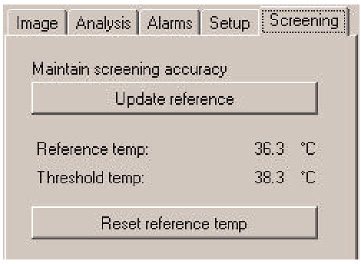
5.4.11.2 Procedure

Follow this procedure:

1. Turn on the camera, and wait at least 30 minutes before taking any measurements.
2. Start FLIR IR Monitor.
3. On the *Setup* tab, set the emissivity to 0.98.
4. On the *Screening* tab, set the alarm difference. This value is the difference between the reference temperature (described later) and the temperature at which the camera will trigger the alarm. A typical value is 2°C (3.6°F).

5. Enable/disable the audible alarm (*Beep*).
6. Click *Apply*. The camera will now be set up according to the conditions. This may take 30–60 seconds.
7. Now aim the camera at a face that has a normal temperature. Make sure that the person directly faces the camera—as in a portrait—and that the distance to the person's face is not further than that required for the face to take up at least 75% of the image width.

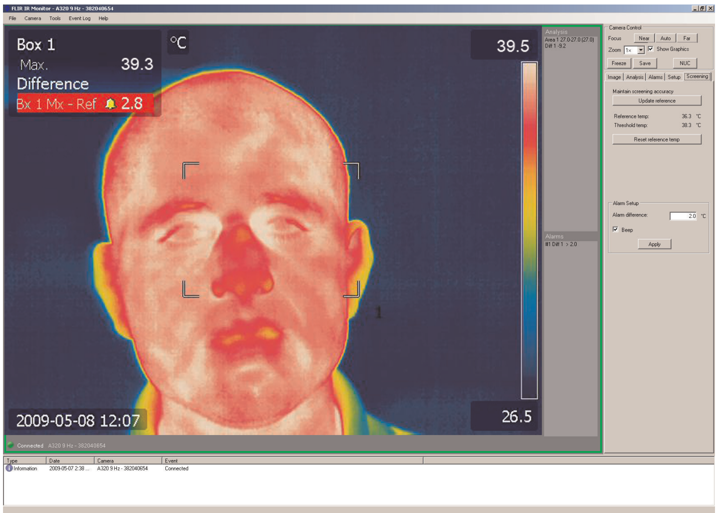
8. Click *Update reference* to store a temperature sample. Repeat this procedure on at least 10 faces with a normal temperature. *You have now set the reference temperature*.



- *Threshold temp*: Reference temperature + alarm difference, i.e., the temperature level at which the alarm will be triggered.
- *Reset reference temp*: Click this button to purge the sample memory and restart the reference temperature sampling.

9. You can now begin screening. Aim the camera at the face of the person whose facial temperature you want to screen.

   If a person's facial temperature is more than 2°C (3.6°F) above the reference temperature, an alarm will be triggered. To disable the alarm, click in the middle of the area.



10. Update the reference temperature on a regular basis (every 10–15 minutes) by clicking *Update reference* when a face that is not triggering the alarm is screened.

5.4.11.2.1 More information

For complete information on interface elements, refer to section 6 *Program reference section*, page 21.

6 Program reference section

6.1 Main menu bar

Table 6.1 The File menu

Open user settings	By clicking *Open user settings*, user settings files (*.config file extension) can be loaded.
Save user settings as	By clicking *Save user settings as*, user settings can be saved to be imported at a later time. **Note** When saving user settings, only the camera name and IP address is saved.

Table 6.2 The Camera menu

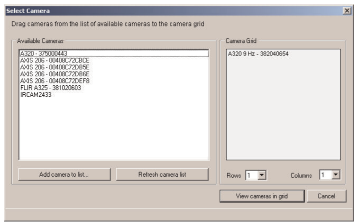
Connect	By clicking *Connect*, the *Select Camera* dialog box will be displayed.  For information, refer to section 5.4.3 *Connecting to one or more cameras*, page 8.

Table 6.3 The Tools menu

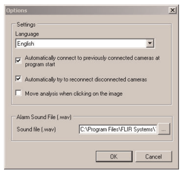
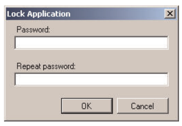
Options	By clicking *Options*, the *Options* dialog box will be displayed where the language, date and time format, measurement and temperature units, and alarm sound files can be set: 
Lock application	By clicking *Lock application*, a dialog box will appear where a password can be set to password protect the program. 

Table 6.4 The Event log menu

Save as	By clicking *Save as*, a dialog box will be displayed where the current event log can be saved as a text file (*.txt).
Clear all events	By clicking *Clear all events*, the log will be cleared.

Table 6.5 The Help menu

Manual as HTML Help	By clicking *Manual as HTML Help*, the manual will be displayed as an HTML help file.
Manual as Adobe PDF file	By clicking *Manual as Adobe PDF file*, the manual will be displayed as an Adobe PDF file.
About FLIR IR Monitor	By clicking *About FLIR IR Monitor*, a dialog box with version and copyright information about FLIR IR Monitor will be displayed.

6.2 The Camera Control group

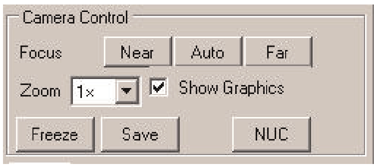


Figure 6.1 The Camera Control group

Table 6.1 The Camera control group

Near	By clicking *Near*, the camera focus is set for near objects.
Auto	By clicking *Auto*, an autofocusing sequence is performed.
Far	By clicking *Far*, the camera focus is set for distant objects.
Zoom	By selecting a zoom factor, the camera is digitally zoomed into the image.
Show Graphics	By selecting *Show Graphics*, on-screen graphics will be displayed on the image, such as measurement results, parameters, or a temperature scale.
Freeze	By clicking *Freeze*, the currently displayed image will be frozen.
Save	By clicking *Save*, the currently displayed image can be saved to disk as a *.jpg image.
NUC	By clicking *NUC*, a non-uniformity correction (NUC) is performed. The NUC function performs an internal calibration to correct for image non-uniformities that arise due to the slightly different offset characteristics occurring from detector to detector within the array.

6.3 The Image tab

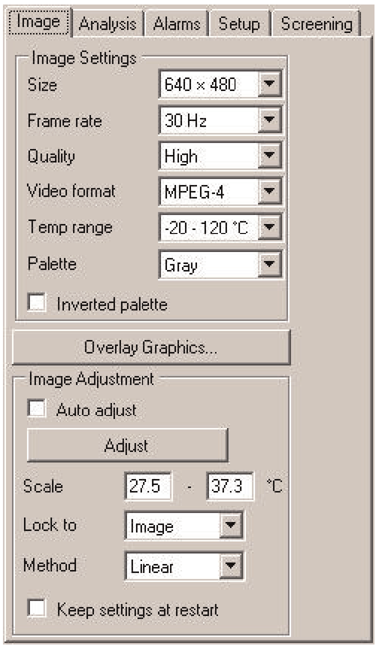


Figure 6.2 The Image tab

Table 6.1 The Image tab

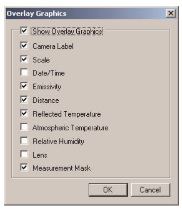
Size	By selecting an option in the *Size* box, the video stream can be up- or downsampled. The choices are *160 × 120*, *320 × 240*, and *640 × 480*.
Frame rate	By selecting an option in the *Frame rate* box, a different frame rate for the video stream can be set. The choices are *0.1*, *1*, *9*, and *30* Hz (dependent on the camera model).
Quality	By selecting an option in the *Quality* box, the compression of the video stream can be set. The choices are *High*, *Medium*, and *Low*.
Video format	By selecting an option in the *Video format* box, the format of the video stream can be changed. The choices are *MPEG-4* and *Signal*.
Temp range	By selecting an option in the *Temp range* box, the object temperature range to be used can be changed.
Palette	By selecting an option in the *Palette* box, the color palette to be used for infrared images can be changed.
Inverted palette	By selecting *Inverted palette*, the currently used color palette will be color inverted.
Overlay Graphics	By clicking *Overlay Graphics*, the *Overlay Graphics* dialog will be displayed. In this dialog box the user can select which parameters will be displayed on screen when overlay graphics are enabled. 

Table 6.1 The Image tab (continued)

Auto adjust	By selecting *Auto adjust*, the camera will be adjusted for best contrast and brightness.
Adjust	By clicking *Adjust*, the camera will be adjusted using the following settings: • *Scale* (see below for an explanation). • *Lock to* (see below for an explanation). • *Method* (see below for an explanation).
Scale	By entering high- and low-scale limit values, these values will be used as a basis for adjustments when clicking the *Adjust* button.
Lock to	Selecting an option in the *Lock to* box defines whether the temperature scale should be locked to the image or to the temperature. The choices are *Image* and *Temperature*.
Method	Selecting an option in the *Method* box defines which algorithm will be used for image adjustments. The most suitable algorithm for a particular imaging situation depends on many different factors, such as the target temperature and emissivity, reflected apparent temperature, and the distance to the target. The user will need to test the different algorithms in order to find which one suits the imaging situation the best. The choices are *Histogram* and *Linear*.
Keep settings at restart	By selecting *Keep settings at restart*, the settings are saved and used when restarting the camera.

6.4 The Analysis tab

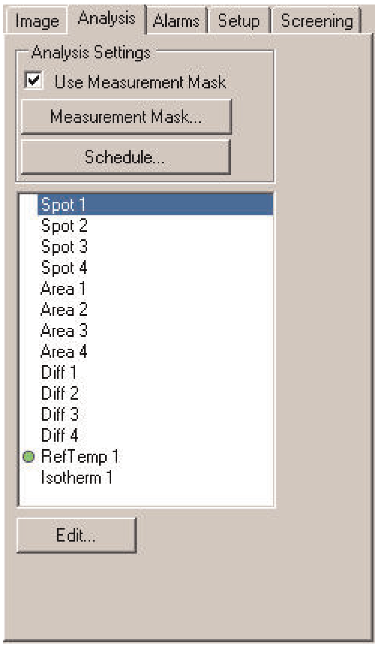
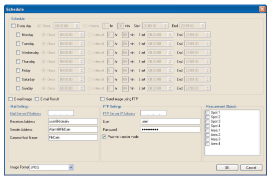


Figure 6.3 The Analysis tab

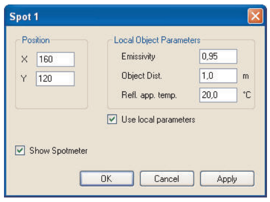
Table 6.1 The Analysis tab

<table>
<tr><td>Use Measurement Mask</td><td>By selecting Use Measurement Mask, the camera is set to use a measurement mask that the user creates. Measurement masks are created in the Measurement Mask dialog box (see below for an explanation).</td></tr>
<tr><td>Measurement Mask</td><td>By clicking Measurement Mask, the Measurement Mask dialog will be displayed.

For more information, see section 5.4.7 Working with measurement masks, page 11.</td></tr>
<tr><td>Schedule</td><td>By clicking Schedule, the Schedule dialog box will be displayed.



For more information, see section 6.4.1 Explanation of the Schedule dialog box, page 26.</td></tr>
<tr><td>Edit</td><td>By clicking Edit, the edit dialog box for the selected analysis tool will be displayed.



For more information, see section 6.4.2 Explanation of the edit dialog boxes for analysis tools, page 27.</td></tr>
</table>

6.4.1 Explanation of the Schedule dialog box

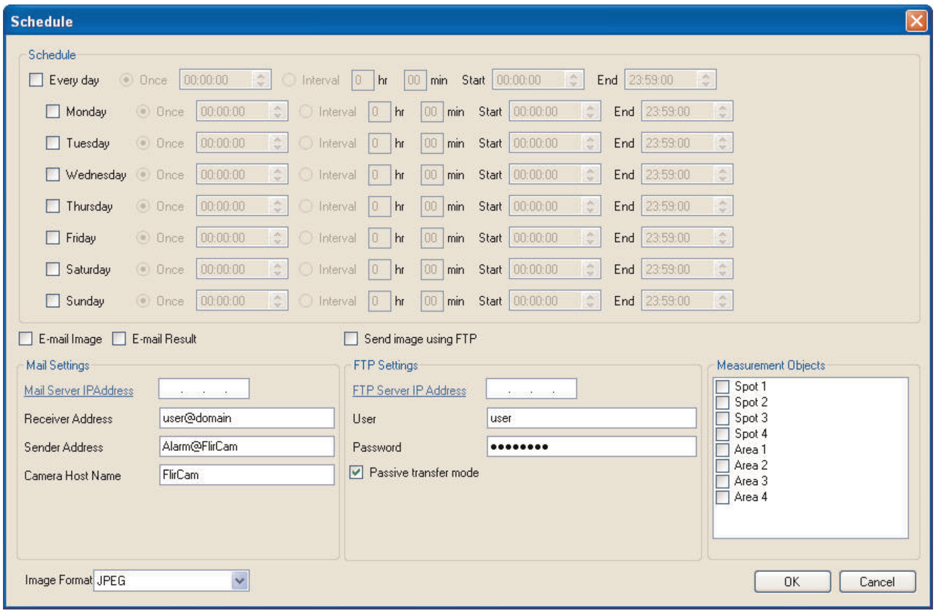


Figure 6.4 The Schedule dialog box

Table 6.1 The Schedule dialog box

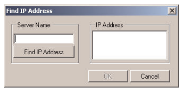
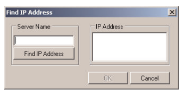
Image Format	By selecting an option in the *Image Format* box, the image format to be used when sending images will be specified. The choices are *FFF* (FLIR File Format),*FFF_JPEG*, *PNG*, *PNG JPEG* and *JPEG*.
Schedule	The *Schedule* group provides controls and settings to specify when images will be sent.
E-mail Image	By selecting *E-mail Image*, the image that was saved when an alarm was triggered will be sent by e-mail.
E-mail Result	By selecting *E-mail Result*, the result that triggered the alarm will be sent by e-mail.
Mail Server IP Address	By clicking *Mail Server IP Address*, the *Find IP Address* dialog box will be displayed. This dialog box provides a means to find the IP address for a server. 
Receiver Address	Refers to the address of the e-mail recipient.
Sender address	Refers to the address of the sender.
Send image using FTP	By selecting *Send image using FTP*, the image that was saved when an alarm was triggered will be sent by FTP.
FTP Server IP Address	By clicking *FTP Server IP Address*, the *Find IP Address* dialog box will be displayed. This dialog box provides a means to find the IP address for a server. 
User	Refers to the credentials of the FTP account.

Table 6.1 The Schedule dialog box (continued)

Password	Refers to the credentials of the FTP account.
Passive transfer mode	By selecting *Passive transfer mode*, the passive transfer mode will be used when sending an image using FTP. With passive transfers, the client asks the server for data, and the server specifies how the transfer will be done. The server chooses a port and then tells the client to connect to that port and receive the data.
Measurement Objects	By selecting one or more measurement objects the user can specify which measurement result will be sent by e-mail or FTP when an alarm is triggered.

6.4.2 Explanation of the edit dialog boxes for analysis tools

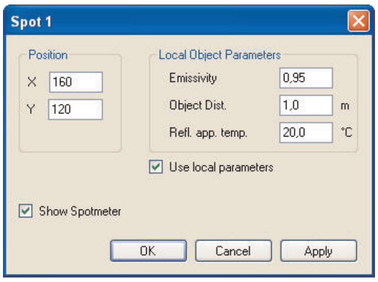


Figure 6.5 The edit dialog box for analysis tools: the Spot dialog box

Table 6.1 The edit dialog box for analysis tools: the Spot dialog box

X	Refers to the *X* position for the analysis tool, calculated from the top left corner of the image.
Y	Refers to the *Y* position for the analysis tool, calculated from the top left corner of the image.
Show Spotmeter	By selecting *Show Spotmeter*, the analysis tool will be displayed in the image.
Emissivity	Refers to how much radiation an object emits, compared with the radiation of a theoretical reference object at the same temperature (called a “blackbody”). The opposite of emissivity is reflectivity. The emissivity determines how much of the radiation originates from the object as opposed to being reflected by it. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Object Dist.	Refers to the distance between the camera and the object of interest. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Refl. app. temp.	Refers to the apparent temperature used when compensating for the radiation from the surroundings reflected by the object into the camera. This property of the object is called reflectivity. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Use local parameters	By selecting *Use local parameters*, local object parameters can be set to override global object parameters.

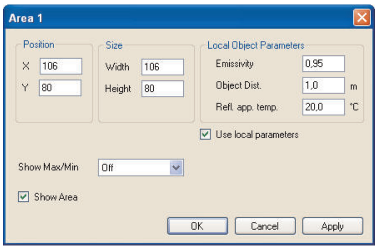


Figure 6.6 The edit dialog box for analysis tools: the Area dialog box

Table 6.2 Edit dialog box for analysis tools: the Area dialog box

X	Refers to the *X* position for the analysis tool, calculated from the top left corner of the image. **Note** Do not include the first and last pixel row and/or the first and last pixel column when setting up an area. Using these rows and columns can make the camera trigger incorrectly, due to boundary effects of the image algorithms.
Y	Refers to the *Y* position for the analysis tool, calculated from the top left corner of the image. **Note** Do not include the first and last pixel row and/or the first and last pixel column when setting up an area. Using these rows and columns can make the camera trigger incorrectly, due to boundary effects of the image algorithms.
Width	Refers to the width of the analysis tool.
Height	Refers to the height of the analysis tool.
Emissivity	Refers to how much radiation an object emits, compared with the radiation of a theoretical reference object at the same temperature (called a “blackbody”). The opposite of emissivity is reflectivity. The emissivity determines how much of the radiation originates from the object as opposed to being reflected by it. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Object Dist.	Refers to the distance between the camera and the object of interest. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Refl. app. temp.	Refers to the apparent temperature when compensating for the radiation from the surroundings reflected by the object into the camera. This property of the object is called reflectivity. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Use local parameters	By selecting *Use local parameters*, local object parameters can be set to override global object parameters.

Table 6.2 Edit dialog box for analysis tools: the Area dialog box (continued)

Show Max/Min	Refers to which temperature result will be displayed (e.g., in an area). The choices are *Off*, *Max.*, *Min.*, and *Both.*.
Show Area	By selecting *Show Area*, the analysis tool will be displayed in the image.

Figure 6.7 Edit dialog box for analysis tools: the Diff dialog box

Table 6.3 Edit dialog box for analysis tools: the Diff dialog box

Function	Refers to which analysis tool will be used in a difference calculation. The choices are *Spot*, *Box*, *RefTemp*, and *Isotherm*.
Result	Refers to which type of result from an analysis tool will be used for the difference calculation. The choices are *Average*, *Iso coverage*, *Max.*, *Min.*, *Median*, *Std. Dev.*, and *Value*.
Show Diff	By selecting *Show Diff*, the analysis result will be displayed in the image.

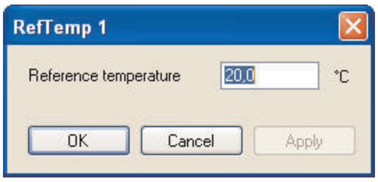


Figure 6.8 Edit dialog box for analysis tools: the RefTemp dialog box

Table 6.4 Edit dialog box for analysis tools: the RefTemp dialog box

RefTemp	Refers to the reference temperature.

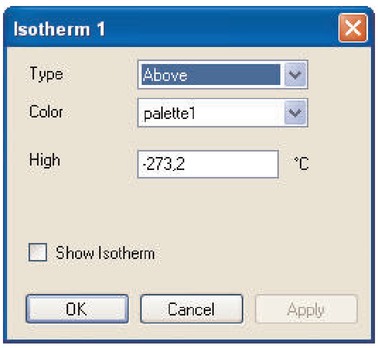


Figure 6.9 Edit dialog box for analysis tools: the Isotherm dialog box

Table 6.5 Edit dialog box for analysis tools: the Isotherm dialog box

Type	Refers to the isotherm type. The choices are *Above*, *Below*, and *Interval.*
Color	Refers to the isotherm color. The options depend on the camera configuration.
High	Refers to the higher temperature limit to be used for an isotherm.
Low	Refers to the lower temperature limit to be used for an isotherm.
Show Isotherm	By selecting *Show Isotherm*, the analysis tool will be displayed in the image.

6.5 The Alarms tab

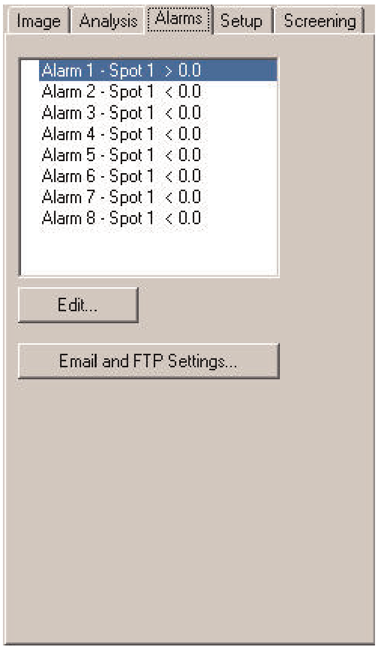
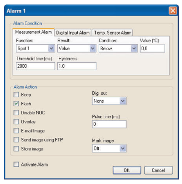
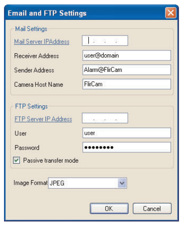


Figure 6.10 The Alarms tab

Table 6.1 The Alarms tab

Edit	By clicking *Edit*, a dialog box for a selected alarm will be displayed (typical example below).  For more information, see section 6.5.1 *Explanation of the edit dialog box for alarms*, page 31.
Email and FTP Settings	By clicking *E-mail and FTP Settings*, a dialog box where e-mail and FTP settings for the alarms can be set is displayed.  For more information, see section 6.5.2 *Explanation of the Email and FTP Settings dialog box*, page 35.

6.5.1 *Explanation of the edit dialog box for alarms*

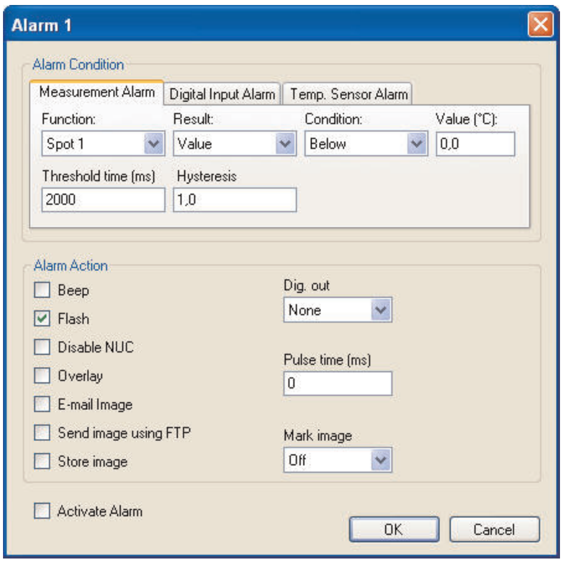


Figure 6.11 Edit dialog box for alarms: the Measurement Alarm tab

Table 6.1 Edit dialog box for alarms: the Measurement Alarm tab

Function	Refers to which type of analysis tool will be used to trigger an alarm. The choices are *Spot*, *Box*, *Diff*, *Ref. Temp.*, and *Isoherm*.
Result	Refers to which type of result from an analysis tool will be used to trigger an alarm. The choices are *Average*, *Iso coverage*, *Max.*,*Min.*, *Median*, *Std. Dev.* and *Value*.

Table 6.1 Edit dialog box for alarms: the Measurement Alarm tab (continued)

Condition	Refers to which condition the alarm will trigger on. The choices are *Above*, *Below*, and *Match*.
Value	Refers to the temperature limit for the trigger condition.
Threshold time	Specifies the amount of time that has to pass before an alarm is triggered. This can be used as a powerful tool to avoid false alarms. **Note** The default value is 2000 ms.
Hysteresis	Hysteresis is the interval within which the temperature value is allowed to vary without causing a change in the trigger. If the threshold is set above, for example, 30.00°C and the hysteresis is set at 2.00°C, the trigger goes high when the temperature rises above 30.00°C and stays high until the temperature drops below 28.00°C. In contrast, if the threshold is set below 30.00°C, and the same hysteresis value is kept, the trigger goes high if the temperature drops below 30.00°C and stays high until the temperature rises above 32.00°C.
Beep	Sets off an audio signal when an alarm is triggered.
Flash	Displays a visible signal when an alarm is triggered.
Disable NUC	Disables the automatic non-uniformity correction (NUC) when an alarm is triggered.
Overlay	When selected, the graphical overlay is enabled when an alarm is triggered.
E-mail Image	E-mails the image frame to a mail recipient when an alarm is triggered.
Send image using FTP	Sends an image to a predefined FTP site when an alarm is triggered.
Store image	Saves the image frame to memory when an alarm is triggered.
Dig. out	Refers to the digital output I/O port. The choices are 0, 1, and 2.
Pulse time	Pulse length (in milliseconds) for the digital output. 0 = no pulse, constant high level on alarm. **Note** Negative integers are not allowed.
Mark image	Refers to which tag should be inserted in the image stream. The choices are *Start*, *Stop*, and *Tag*
Activate Alarm	When selected, the alarm is activated.

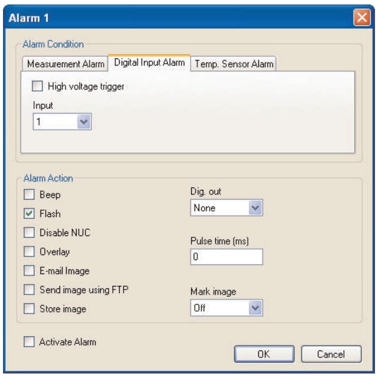


Figure 6.12 Edit dialog box for alarms: the Digital Input Alarm tab

Table 6.2 Edit dialog box for alarms: the Digital Input Alarm tab

High voltage trigger	• When selected, the camera is set to react to a high digital-in signal. • When cleared, the camera is set to react to a low digital-in signal.
Input	Refers to the digital input I/O port.
Beep	Sets off an audio signal when an alarm is triggered.
Flash	Displays a visible signal when an alarm is triggered.
Disable NUC	Disables the automatic non-uniformity correction (NUC) when an alarm is triggered.
Overlay	When selected, the graphical overlay is enabled when an alarm is triggered.
E-mail Image	E-mails the image frame to a mail recipient when an alarm is triggered.
Send image using FTP	Sends an image to a predefined FTP site when an alarm is triggered.
Store image	Saves the image frame to memory when an alarm is triggered.
Dig. out	Refers to the digital output I/O port. The choices are 0, 1, and 2.
Pulse time	Pulse length (in milliseconds) for the digital output. 0 = no pulse, constant high level on alarm.
Mark image	Refers to which tag should be inserted in the image stream. The choices are *Start*, *Stop*, and *Tag*
Activate Alarm	When selected, the alarm is activated.

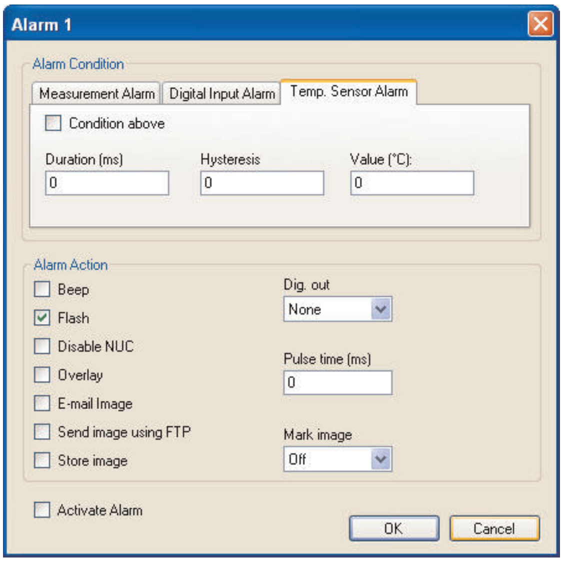


Figure 6.13 Edit dialog box for alarms: the Temp. Sensor Alarm tab

Table 6.3 Edit dialog box for alarms: the Temp. Sensor Alarm tab

Condition above	• When selected, the alarm triggers at a temperature above the set temperature. • When cleared, the alarm triggers at a temperature below the set temperature.
Duration	Specifies the amount of time that has to pass before an alarm is triggered. This can be used as a powerful tool to avoid false alarms.
Hysteresis	Hysteresis is the interval within which the temperature value is allowed to vary without causing a change in the trigger. If the threshold is set above, for example, 30.00°C and the hysteresis is set at 2.00°C, the trigger goes high when the temperature rises above 30.00°C and stays high until the temperature drops below 28.00°C. In contrast, if the threshold is set below 30.00°C, and the same hysteresis value is kept, the trigger goes high if the temperature drops below 30.00°C and stays high until the temperature rises above 32.00°C.
Value	Refers to the temperature limit for the trigger condition.
Beep	Sets off an audio signal when an alarm is triggered.
Flash	Displays a visible signal when an alarm is triggered.
Disable NUC	Disables the automatic non-uniformity correction (NUC) when an alarm is triggered.
Overlay	When selected, the graphical overlay is enabled when an alarm is triggered.
E-mail Image	E-mails the image frame to a mail recipient when an alarm is triggered.
Send image using FTP	Sends an image to a predefined FTP site when an alarm is triggered.
Store image	Saves the image frame to memory when an alarm is triggered.
Dig. out	Refers to the digital output I/O port. The choices are 0, 1, and 2.

Table 6.3 Edit dialog box for alarms: the Temp. Sensor Alarm tab (continued)

Pulse time	Pulse length (in milliseconds) for the digital output. 0 = no pulse, constant high level at alarm. **Note** Negative integers are not allowed.
Mark image	Refers to which tag should be inserted in the image stream. The choices are *Start*, *Stop*, and *Tag*
Activate Alarm	When selected, the alarm is activated.

6.5.2 *Explanation of the Email and FTP Settings dialog box*

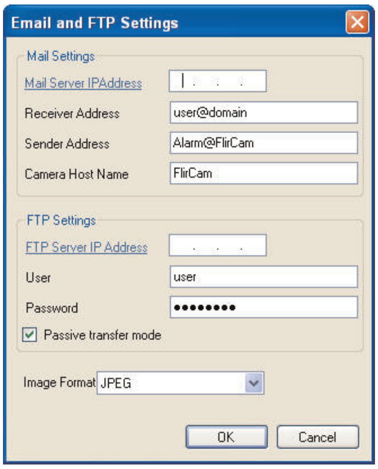


Figure 6.14 The Email and FTP Settings dialog box

For an explanation of this dialog box, see the corresponding descriptions in section 6.4.1 *Explanation of the Schedule dialog box*, page 26.

6.6 The Setup tab

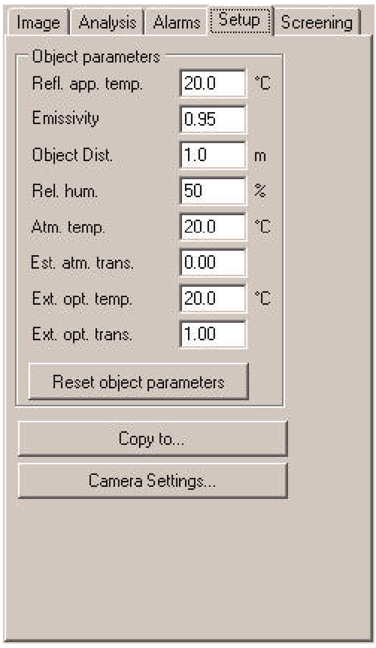


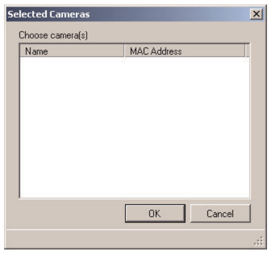
Figure 6.15 The Setup tab

Table 6.1 The Setup tab

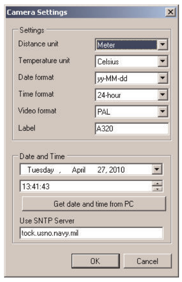
Refl. app. temp.	Refers to the apparent temperature when compensating for the radiation from the surroundings reflected by the object into the camera. This property of the object is called reflectivity.
Emissivity	For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46. Refers to how much radiation an object emits, compared with the radiation of a theoretical reference object at the same temperature (called a “blackbody”). The opposite of emissivity is reflectivity. The emissivity determines how much of the radiation originates from the object as opposed to being reflected by it.
Object Dist.	Refers to the distance between the camera and the object of interest. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Rel. hum.	Refers to the relative humidity of the air between the camera and the object of interest. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Atm. temp.	Refers to the temperature of the air between the camera and the object of interest. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Ext. atm. trans.	Refers to the external atmospheric transmission. This value is not entered by the user but calculated from other object parameters. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Ext. opt. temp.	Refers to the temperature of any protective windows, etc., that are set up between the camera and the object of interest. If no protective window or protective shield is used, this value is irrelevant. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Ext. opt. trans.	Refers to the optical transmission of any protective windows, etc., that are set up between the camera and the object of interest. For information on object parameters, refer to section 10 *Thermographic measurement techniques*, page 46.
Reset object parameters	By clicking *Reset object parameters*, all the parameters are reset to the factory defaults.

Table 6.1 The Setup tab (continued)

<table>
<tr><td>Copy to</td><td>By clicking Copy to, a dialog box in which the user can select a camera to which the current object parameters should be copied will be displayed.



</td></tr>
<tr><td>Camera Settings</td><td>By clicking Camera Settings, a dialog box in which the user can change regional settings for the camera will be displayed.



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

6.7 The Screening tab

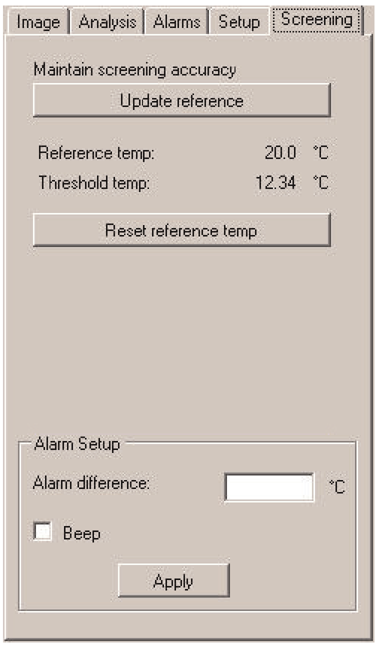


Figure 6.16 The Screening tab

Table 6.1 The Screening tab

Update reference	By clicking *Update reference*, a temperature sample is saved to the sample buffer. For more information, see section 5.4.11 *Screening of elevated facial temperatures*, page 19.
Reference temp	Refers to the temperature level based on at least 10 faces with a normal temperature. For more information, see section 5.4.11 *Screening of elevated facial temperatures*, page 19.
Threshold temp	Refers to the reference temperature + alarm difference, i.e., the temperature level at which the alarm will be triggered. For more information, see section 5.4.11 *Screening of elevated facial temperatures*, page 19.
Reset reference temp	By clicking *Reset reference temp*, the sample memory is purged and the reference temperature sampling is restarted. For more information, see section 5.4.11 *Screening of elevated facial temperatures*, page 19.
Alarm difference	Refers to the difference between the reference temperature and the temperature at which the camera will trigger the alarm. A typical value is 2° C (3.6°F). For more information, see section 5.4.11 *Screening of elevated facial temperatures*, page 19.
Beep	By selecting *Beep*, an alarm will sound when a screening alarm is triggered. For more information, see section 5.4.11 *Screening of elevated facial temperatures*, page 19.
Apply	By clicking *Apply*, the settings in the *Alarm Setup* group will be applied. For more information, see section 5.4.11 *Screening of elevated facial temperatures*, page 19.

7 Network troubleshooting

Try one of the following if you experience network problems:

- Reset the modem and unplug and replug the Ethernet cable at both ends.
- Reboot the computer with the cables connected.
- Swap your Ethernet cable with another cable that is either brand new or known to be in working condition.
- Connect your Ethernet cable to a different wall socket. If you are still not able to get online, you are probably experiencing a configuration issue.
- Verify your IP address.
- Disable network bridging.
- Disable your Wi-Fi connectivity (if you use it) to ensure that the wired Ethernet port is open.
- Renew the DHCP license.
- Make sure that the firewall is turned off when you troubleshoot.
- Make sure that your wireless adapter is switched off. If not, the search for the camera might only look for a wireless connection.
- Normally a computer will handle both crossed and uncrossed cable types automatically, but for troubleshooting purposes try both or use a switch.
- Turn off any network adapters that are not connected to the camera.
- For troubleshooting purposes, power both the camera and the computer using a mains adapter. Some laptops turn off the network card to save power when using the battery.

If none of these steps help you, contact your ISP.

8 About FLIR Systems

FLIR Systems was established in 1978 to pioneer the development of high-performance infrared imaging systems, and is the world leader in the design, manufacture, and marketing of thermal imaging systems for a wide variety of commercial, industrial, and government applications. Today, FLIR Systems embraces five major companies with outstanding achievements in infrared technology since 1958—the Swedish AGEMA Infrared Systems (formerly AGA Infrared Systems), the three United States companies Indigo Systems, FSI, and Inframetrics, and the French company Cedip. In November 2007, Extech Instruments was acquired by FLIR Systems.

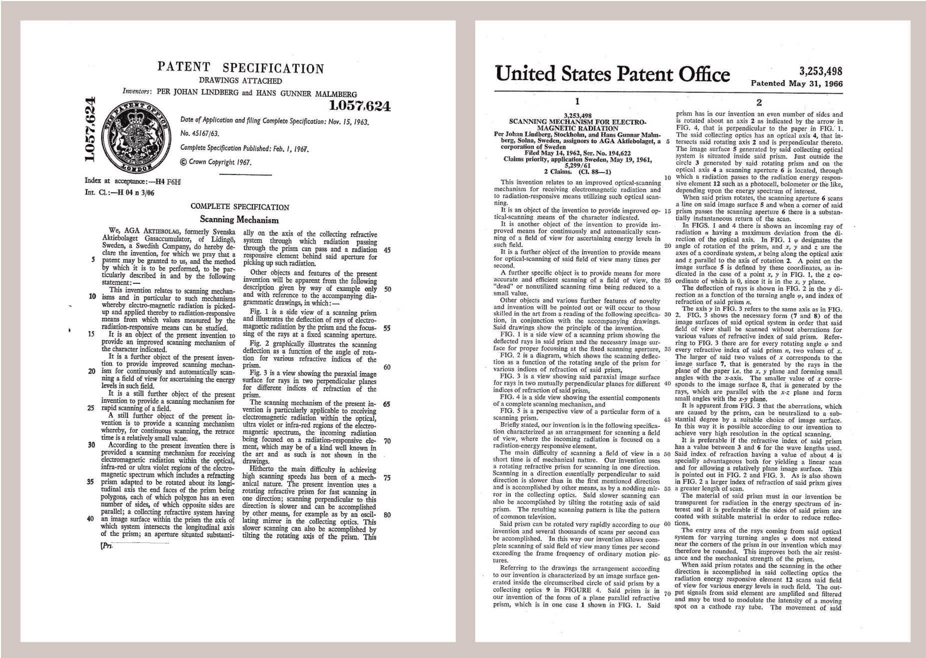


Figure 8.1 Patent documents from the early 1960s

The company has sold more than 258,000 infrared cameras worldwide for applications such as predictive maintenance, R & D, non-destructive testing, process control and automation, and machine vision, among many others.

FLIR Systems has three manufacturing plants in the United States (Portland, OR, Boston, MA, Santa Barbara, CA) and one in Sweden (Stockholm). Since 2007 there is also a manufacturing plant in Tallinn, Estonia. Direct sales offices in Belgium, Brazil, China, France, Germany, Great Britain, Hong Kong, Italy, Japan, Korea, Sweden, and the USA —together with a worldwide network of agents and distributors—support our international customer base.

FLIR Systems is at the forefront of innovation in the infrared camera industry. We anticipate market demand by constantly improving our existing cameras and developing new ones. The company has set milestones in product design and development such as the introduction of the first battery-operated portable camera for industrial inspections, and the first uncooled infrared camera, to mention just two innovations.

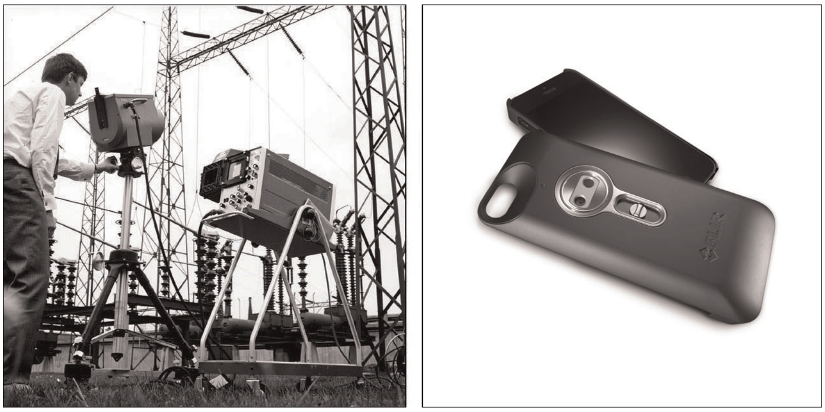


Figure 8.2 LEFT: Thermovision Model 661 from 1969. The camera weighed approximately 25 kg (55 lb.), the oscilloscope 20 kg (44 lb.), and the tripod 15 kg (33 lb.). The operator also needed a 220 VAC generator set, and a 10 L (2.6 US gallon) jar with liquid nitrogen. To the left of the oscilloscope the Polaroid attachment (6 kg/13 lb.) can be seen. RIGHT: FLIR One, which was launched in January 2014, is a slide-on attachment that gives iPhones thermal imaging capabilities. Weight: 90 g (3.2 oz.).

FLIR Systems manufactures all vital mechanical and electronic components of the camera systems itself. From detector design and manufacturing, to lenses and system electronics, to final testing and calibration, all production steps are carried out and supervised by our own engineers. The in-depth expertise of these infrared specialists ensures the accuracy and reliability of all vital components that are assembled into your infrared camera.

8.1 More than just an infrared camera

At FLIR Systems we recognize that our job is to go beyond just producing the best infrared camera systems. We are committed to enabling all users of our infrared camera systems to work more productively by providing them with the most powerful camera–software combination. Especially tailored software for predictive maintenance, R & D, and process monitoring is developed in-house. Most software is available in a wide variety of languages.

We support all our infrared cameras with a wide variety of accessories to adapt your equipment to the most demanding infrared applications.

8.2 Sharing our knowledge

Although our cameras are designed to be very user-friendly, there is a lot more to thermography than just knowing how to handle a camera. Therefore, FLIR Systems has founded the Infrared Training Center (ITC), a separate business unit, that provides certified training courses. Attending one of the ITC courses will give you a truly hands-on learning experience.

The staff of the ITC are also there to provide you with any application support you may need in putting infrared theory into practice.

8.3 Supporting our customers

FLIR Systems operates a worldwide service network to keep your camera running at all times. If you discover a problem with your camera, local service centers have all the equipment and expertise to solve it within the shortest possible time. Therefore, there is no need to send your camera to the other side of the world or to talk to someone who does not speak your language.

8.4 A few images from our facilities

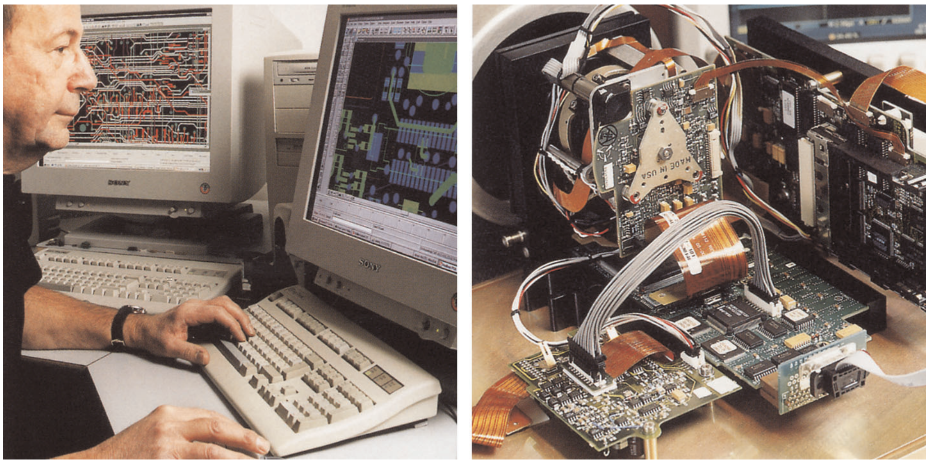


Figure 8.3 LEFT: Development of system electronics; RIGHT: Testing of an FPA detector

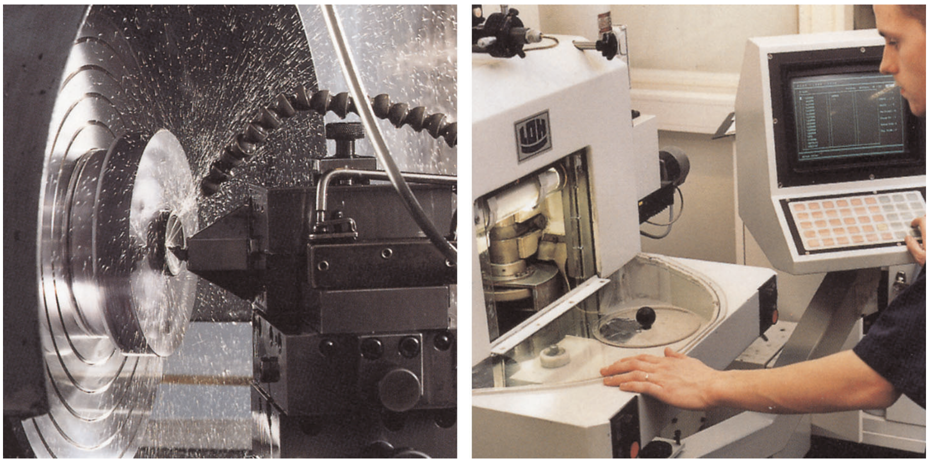


Figure 8.4 LEFT: Diamond turning machine; RIGHT: Lens polishing

9 Glossary

absorption (absorption factor)	The amount of radiation absorbed by an object relative to the received radiation. A number between 0 and 1.
atmosphere	The gases between the object being measured and the camera, normally air.
autoadjust	A function making a camera perform an internal image correction.
autopalette	The IR image is shown with an uneven spread of colors, displaying cold objects as well as hot ones at the same time.
blackbody	Totally non-reflective object. All its radiation is due to its own temperature.
blackbody radiator	An IR radiating equipment with blackbody properties used to calibrate IR cameras.
calculated atmospheric transmission	A transmission value computed from the temperature, the relative humidity of air and the distance to the object.
cavity radiator	A bottle shaped radiator with an absorbing inside, viewed through the bottleneck.
color temperature	The temperature for which the color of a blackbody matches a specific color.
conduction	The process that makes heat diffuse into a material.
continuous adjust	A function that adjusts the image. The function works all the time, continuously adjusting brightness and contrast according to the image content.
convection	Convection is a heat transfer mode where a fluid is brought into motion, either by gravity or another force, thereby transferring heat from one place to another.
dual isotherm	An isotherm with two color bands, instead of one.
emissivity (emissivity factor)	The amount of radiation coming from an object, compared to that of a blackbody. A number between 0 and 1.
emittance	Amount of energy emitted from an object per unit of time and area (W/m^2)
environment	Objects and gases that emit radiation towards the object being measured.
estimated atmospheric transmission	A transmission value, supplied by a user, replacing a calculated one
external optics	Extra lenses, filters, heat shields etc. that can be put between the camera and the object being measured.
filter	A material transparent only to some of the infrared wavelengths.
FOV	Field of view: The horizontal angle that can be viewed through an IR lens.
FPA	Focal plane array: A type of IR detector.
graybody	An object that emits a fixed fraction of the amount of energy of a blackbody for each wavelength.
IFOV	Instantaneous field of view: A measure of the geometrical resolution of an IR camera.

image correction (internal or external)	A way of compensating for sensitivity differences in various parts of live images and also of stabilizing the camera.
infrared	Non-visible radiation, having a wavelength from about 2–13 μm.
IR	infrared
isotherm	A function highlighting those parts of an image that fall above, below or between one or more temperature intervals.
isothermal cavity	A bottle-shaped radiator with a uniform temperature viewed through the bottleneck.
Laser LocatIR	An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera.
laser pointer	An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera.
level	The center value of the temperature scale, usually expressed as a signal value.
manual adjust	A way to adjust the image by manually changing certain parameters.
NETD	Noise equivalent temperature difference. A measure of the image noise level of an IR camera.
noise	Undesired small disturbance in the infrared image
object parameters	A set of values describing the circumstances under which the measurement of an object was made, and the object itself (such as emissivity, reflected apparent temperature, distance etc.)
object signal	A non-calibrated value related to the amount of radiation received by the camera from the object.
palette	The set of colors used to display an IR image.
pixel	Stands for *picture element*. One single spot in an image.
radiance	Amount of energy emitted from an object per unit of time, area and angle ($W/m^2/sr$)
radiant power	Amount of energy emitted from an object per unit of time (W)
radiation	The process by which electromagnetic energy, is emitted by an object or a gas.
radiator	A piece of IR radiating equipment.
range	The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration.
reference temperature	A temperature which the ordinary measured values can be compared with.
reflection	The amount of radiation reflected by an object relative to the received radiation. A number between 0 and 1.
relative humidity	Relative humidity represents the ratio between the current water vapour mass in the air and the maximum it may contain in saturation conditions.
saturation color	The areas that contain temperatures outside the present level/span settings are colored with the saturation colors. The saturation colors contain an ‘overflow’ color and an ‘underflow’ color. There is also a third red saturation color that marks everything saturated by the detector indicating that the range should probably be changed.

span	The interval of the temperature scale, usually expressed as a signal value.
spectral (radiant) emittance	Amount of energy emitted from an object per unit of time, area and wavelength ($W/m^2/\mu m$)
temperature difference, or difference of temperature.	A value which is the result of a subtraction between two temperature values.
temperature range	The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration.
temperature scale	The way in which an IR image currently is displayed. Expressed as two temperature values limiting the colors.
thermogram	infrared image
transmission (or transmittance) factor	Gases and materials can be more or less transparent. Transmission is the amount of IR radiation passing through them. A number between 0 and 1.
transparent isotherm	An isotherm showing a linear spread of colors, instead of covering the highlighted parts of the image.
visual	Refers to the video mode of a IR camera, as opposed to the normal, thermographic mode. When a camera is in video mode it captures ordinary video images, while thermographic images are captured when the camera is in IR mode.

10 Thermographic measurement techniques

10.1 Introduction

An infrared camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display this temperature.

However, the radiation measured by the camera does not only depend on the temperature of the object but is also a function of the emissivity. Radiation also originates from the surroundings and is reflected in the object. The radiation from the object and the reflected radiation will also be influenced by the absorption of the atmosphere.

To measure temperature accurately, it is therefore necessary to compensate for the effects of a number of different radiation sources. This is done on-line automatically by the camera. The following object parameters must, however, be supplied for the camera:

- The emissivity of the object
- The reflected apparent temperature
- The distance between the object and the camera
- The relative humidity
- Temperature of the atmosphere

10.2 Emissivity

The most important object parameter to set correctly is the emissivity which, in short, is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature.

Normally, object materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a higher emissivity. Oil-based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity 0.97 to 0.98.

Non-oxidized metals represent an extreme case of perfect opacity and high reflexivity, which does not vary greatly with wavelength. Consequently, the emissivity of metals is low – only increasing with temperature. For non-metals, emissivity tends to be high, and decreases with temperature.

10.2.1 Finding the emissivity of a sample

10.2.1.1 Step 1: Determining reflected apparent temperature

Use one of the following two methods to determine reflected apparent temperature:

10.2.1.1.1 Method 1: Direct method

Follow this procedure:

1. Look for possible reflection sources, considering that the incident angle = reflection angle (a = b).

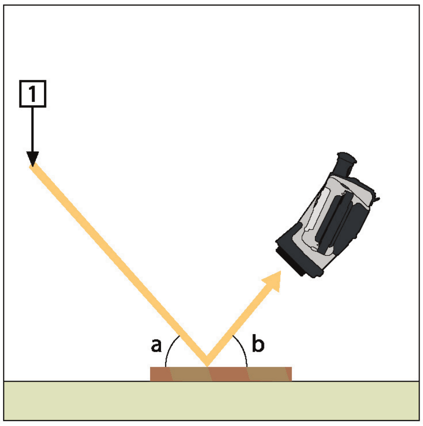


Figure 10.1 1 = Reflection source

2. If the reflection source is a spot source, modify the source by obstructing it using a piece if cardboard.

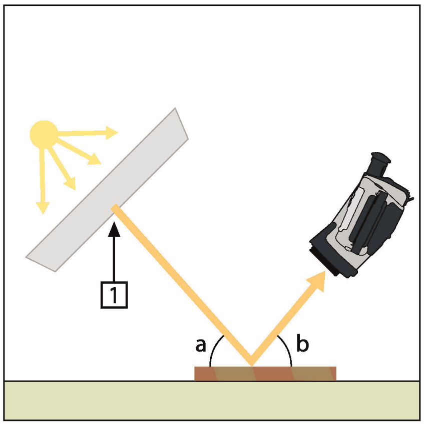


Figure 10.2 1 = Reflection source

3. Measure the radiation intensity (= apparent temperature) from the reflecting source using the following settings:
    - Emissivity: 1.0
    - D_{obj}: 0

    You can measure the radiation intensity using one of the following two methods:

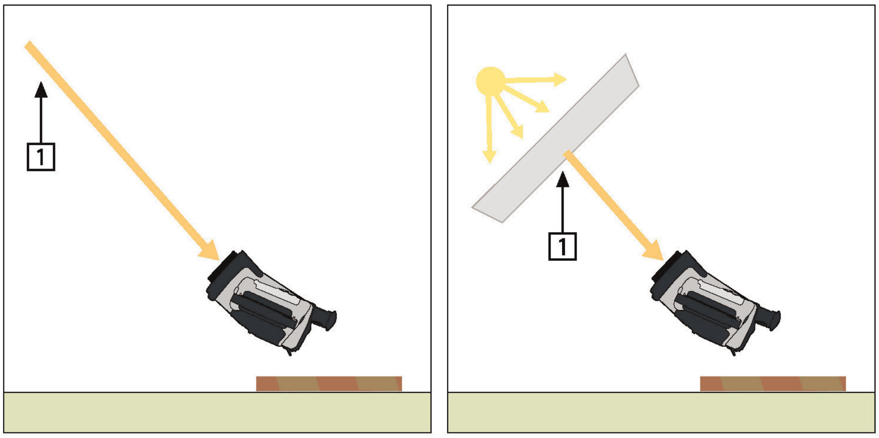


Figure 10.3 1 = Reflection source

Note
Using a thermocouple to measure reflected apparent temperature is not recommended for two important reasons:

- A thermocouple does not measure radiation intensity
- A thermocouple requires a very good thermal contact to the surface, usually by gluing and covering the sensor by a thermal isolator.

10.2.1.1.2 Method 2: Reflector method

Follow this procedure:

1. Crumble up a large piece of aluminum foil.
2. Uncrumble the aluminum foil and attach it to a piece of cardboard of the same size.
3. Put the piece of cardboard in front of the object you want to measure. Make sure that the side with aluminum foil points to the camera.
4. Set the emissivity to 1.0.
5. Measure the apparent temperature of the aluminum foil and write it down.

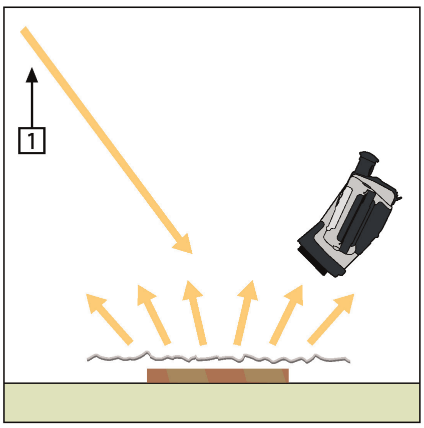


Figure 10.4 Measuring the apparent temperature of the aluminum foil.

10.2.1.2 Step 2: Determining the emissivity

Follow this procedure:

1. Select a place to put the sample.
2. Determine and set reflected apparent temperature according to the previous procedure.
3. Put a piece of electrical tape with known high emissivity on the sample.
4. Heat the sample at least 20 K above room temperature. Heating must be reasonably even.
5. Focus and auto-adjust the camera, and freeze the image.
6. Adjust *Level* and *Span* for best image brightness and contrast.
7. Set emissivity to that of the tape (usually 0.97).
8. Measure the temperature of the tape using one of the following measurement functions:
   - *Isotherm* (helps you to determine both the temperature and how evenly you have heated the sample)
   - *Spot* (simpler)
   - *Box Avg* (good for surfaces with varying emissivity).
9. Write down the temperature.
10. Move your measurement function to the sample surface.
11. Change the emissivity setting until you read the same temperature as your previous measurement.
12. Write down the emissivity.

Note

- Avoid forced convection
- Look for a thermally stable surrounding that will not generate spot reflections
- Use high quality tape that you know is not transparent, and has a high emissivity you are certain of
- This method assumes that the temperature of your tape and the sample surface are the same. If they are not, your emissivity measurement will be wrong.

10.3 Reflected apparent temperature

This parameter is used to compensate for the radiation reflected in the object. If the emissivity is low and the object temperature relatively far from that of the reflected it will be important to set and compensate for the reflected apparent temperature correctly.

10.4 Distance

The distance is the distance between the object and the front lens of the camera. This parameter is used to compensate for the following two facts:

- That radiation from the target is absorbed by the atmosphere between the object and the camera.
- That radiation from the atmosphere itself is detected by the camera.

10.5 Relative humidity

The camera can also compensate for the fact that the transmittance is also dependent on the relative humidity of the atmosphere. To do this set the relative humidity to the correct value. For short distances and normal humidity the relative humidity can normally be left at a default value of 50%.

10.6 Other parameters

In addition, some cameras and analysis programs from FLIR Systems allow you to compensate for the following parameters:

- Atmospheric temperature – *i.e.* the temperature of the atmosphere between the camera and the target
- External optics temperature – *i.e.* the temperature of any external lenses or windows used in front of the camera

- External optics transmittance – *i.e.* the transmission of any external lenses or windows used in front of the camera

11 History of infrared technology

Before the year 1800, the existence of the infrared portion of the electromagnetic spectrum wasn't even suspected. The original significance of the infrared spectrum, or simply 'the infrared' as it is often called, as a form of heat radiation is perhaps less obvious today than it was at the time of its discovery by Herschel in 1800.

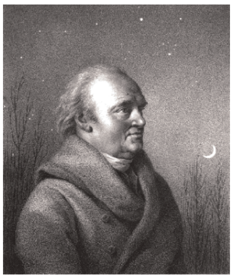


Figure 11.1 Sir William Herschel (1738–1822)

The discovery was made accidentally during the search for a new optical material. Sir William Herschel – Royal Astronomer to King George III of England, and already famous for his discovery of the planet Uranus – was searching for an optical filter material to reduce the brightness of the sun's image in telescopes during solar observations. While testing different samples of colored glass which gave similar reductions in brightness he was intrigued to find that some of the samples passed very little of the sun's heat, while others passed so much heat that he risked eye damage after only a few seconds' observation.

Herschel was soon convinced of the necessity of setting up a systematic experiment, with the objective of finding a single material that would give the desired reduction in brightness as well as the maximum reduction in heat. He began the experiment by actually repeating Newton's prism experiment, but looking for the heating effect rather than the visual distribution of intensity in the spectrum. He first blackened the bulb of a sensitive mercury-in-glass thermometer with ink, and with this as his radiation detector he proceeded to test the heating effect of the various colors of the spectrum formed on the top of a table by passing sunlight through a glass prism. Other thermometers, placed outside the sun's rays, served as controls.

As the blackened thermometer was moved slowly along the colors of the spectrum, the temperature readings showed a steady increase from the violet end to the red end. This was not entirely unexpected, since the Italian researcher, Landriani, in a similar experiment in 1777 had observed much the same effect. It was Herschel, however, who was the first to recognize that there must be a point where the heating effect reaches a maximum, and that measurements confined to the visible portion of the spectrum failed to locate this point.

Figure 11.2 Marsilio Landriani (1746–1815)

Moving the thermometer into the dark region beyond the red end of the spectrum, Herschel confirmed that the heating continued to increase. The maximum point, when he found it, lay well beyond the red end – in what is known today as the 'infrared wavelengths'.

When Herschel revealed his discovery, he referred to this new portion of the electromagnetic spectrum as the ‘thermometrical spectrum’. The radiation itself he sometimes referred to as ‘dark heat’, or simply ‘the invisible rays’. Ironically, and contrary to popular opinion, it wasn't Herschel who originated the term ‘infrared’. The word only began to appear in print around 75 years later, and it is still unclear who should receive credit as the originator.

Herschel’s use of glass in the prism of his original experiment led to some early controversies with his contemporaries about the actual existence of the infrared wavelengths. Different investigators, in attempting to confirm his work, used various types of glass indiscriminately, having different transparencies in the infrared. Through his later experiments, Herschel was aware of the limited transparency of glass to the newly-discovered thermal radiation, and he was forced to conclude that optics for the infrared would probably be doomed to the use of reflective elements exclusively (i.e. plane and curved mirrors). Fortunately, this proved to be true only until 1830, when the Italian investigator, Melloni, made his great discovery that naturally occurring rock salt (NaCl) – which was available in large enough natural crystals to be made into lenses and prisms – is remarkably transparent to the infrared. The result was that rock salt became the principal infrared optical material, and remained so for the next hundred years, until the art of synthetic crystal growing was mastered in the 1930’s.

Figure 11.3 Macedonio Melloni (1798–1854)

Thermometers, as radiation detectors, remained unchallenged until 1829, the year Nobili invented the thermocouple. (Herschel’s own thermometer could be read to 0.2 °C (0.036 °F), and later models were able to be read to 0.05 °C (0.09 °F)). Then a breakthrough occurred; Melloni connected a number of thermocouples in series to form the first thermopile. The new device was at least 40 times as sensitive as the best thermometer of the day for detecting heat radiation – capable of detecting the heat from a person standing three meters away.

The first so-called ‘heat-picture’ became possible in 1840, the result of work by Sir John Herschel, son of the discoverer of the infrared and a famous astronomer in his own right. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light where the interference effects of the oil film made the image visible to the eye. Sir John also managed to obtain a primitive record of the thermal image on paper, which he called a ‘thermograph’.

Figure 11.4 Samuel P. Langley (1834–1906)

The improvement of infrared-detector sensitivity progressed slowly. Another major breakthrough, made by Langley in 1880, was the invention of the bolometer. This consisted of a thin blackened strip of platinum connected in one arm of a Wheatstone bridge circuit upon which the infrared radiation was focused and to which a sensitive galvanometer responded. This instrument is said to have been able to detect the heat from a cow at a distance of 400 meters.

An English scientist, Sir James Dewar, first introduced the use of liquefied gases as cooling agents (such as liquid nitrogen with a temperature of -196 °C (-320.8 °F)) in low temperature research. In 1892 he invented a unique vacuum insulating container in which it is possible to store liquefied gases for entire days. The common ‘thermos bottle’, used for storing hot and cold drinks, is based upon his invention.

Between the years 1900 and 1920, the inventors of the world ‘discovered’ the infrared. Many patents were issued for devices to detect personnel, artillery, aircraft, ships – and even icebergs. The first operating systems, in the modern sense, began to be developed during the 1914–18 war, when both sides had research programs devoted to the military exploitation of the infrared. These programs included experimental systems for enemy intrusion/detection, remote temperature sensing, secure communications, and ‘flying torpedo’ guidance. An infrared search system tested during this period was able to detect an approaching airplane at a distance of 1.5 km (0.94 miles), or a person more than 300 meters (984 ft.) away.

The most sensitive systems up to this time were all based upon variations of the bolometer idea, but the period between the two wars saw the development of two revolutionary new infrared detectors: the image converter and the photon detector. At first, the image converter received the greatest attention by the military, because it enabled an observer for the first time in history to literally ‘see in the dark’. However, the sensitivity of the image converter was limited to the near infrared wavelengths, and the most interesting military targets (i.e. enemy soldiers) had to be illuminated by infrared search beams. Since this involved the risk of giving away the observer’s position to a similarly-equipped enemy observer, it is understandable that military interest in the image converter eventually faded.

The tactical military disadvantages of so-called 'active’ (i.e. search beam-equipped) thermal imaging systems provided impetus following the 1939–45 war for extensive secret military infrared-research programs into the possibilities of developing ‘passive’ (no search beam) systems around the extremely sensitive photon detector. During this period, military secrecy regulations completely prevented disclosure of the status of infrared-imaging technology. This secrecy only began to be lifted in the middle of the 1950’s, and from that time adequate thermal-imaging devices finally began to be available to civilian science and industry.

12 Theory of thermography

12.1 Introduction

The subjects of infrared radiation and the related technique of thermography are still new to many who will use an infrared camera. In this section the theory behind thermography will be given.

12.2 The electromagnetic spectrum

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called *bands*, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength.

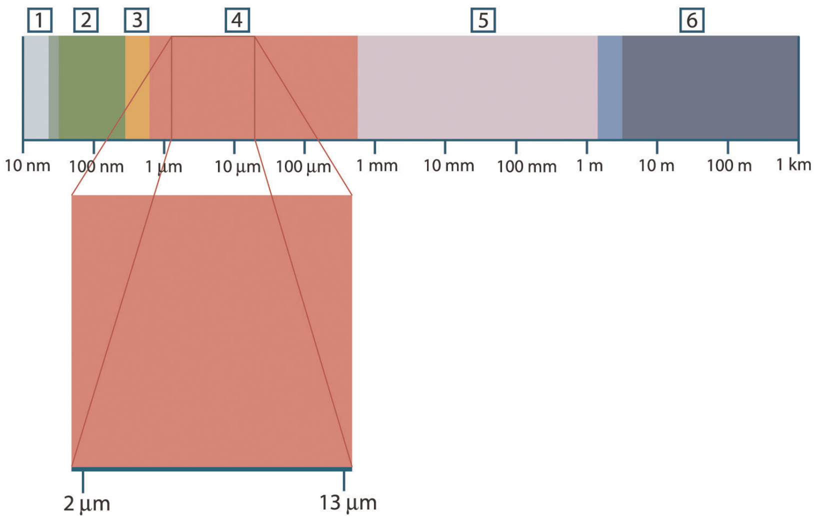


Figure 12.1 The electromagnetic spectrum. 1: X-ray; 2: UV; 3: Visible; 4: IR; 5: Microwaves; 6: Radiowaves.

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths, in the millimeter range.

The infrared band is often further subdivided into four smaller bands, the boundaries of which are also arbitrarily chosen. They include: the *near infrared* (0.75–3 µm), the *middle infrared* (3–6 µm), the *far infrared* (6–15 µm) and the *extreme infrared* (15–100 µm). Although the wavelengths are given in µm (micrometers), other units are often still used to measure wavelength in this spectral region, *e.g.* nanometer (nm) and Ångström (Å).

The relationships between the different wavelength measurements is:

$$10\ 000\ \text{Å} = 1\ 000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$$

12.3 Blackbody radiation

A blackbody is defined as an object which absorbs all radiation that impinges on it at any wavelength. The apparent misnomer *black* relating to an object emitting radiation is explained by Kirchhoff's Law (after *Gustav Robert Kirchhoff*, 1824–1887), which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.

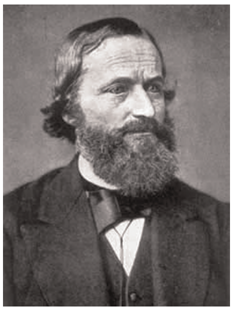


Figure 12.2 Gustav Robert Kirchhoff (1824–1887)

The construction of a blackbody source is, in principle, very simple. The radiation characteristics of an aperture in an isotherm cavity made of an opaque absorbing material represents almost exactly the properties of a blackbody. A practical application of the principle to the construction of a perfect absorber of radiation consists of a box that is light tight except for an aperture in one of the sides. Any radiation which then enters the hole is scattered and absorbed by repeated reflections so only an infinitesimal fraction can possibly escape. The blackness which is obtained at the aperture is nearly equal to a blackbody and almost perfect for all wavelengths.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a *cavity radiator*. An isothermal cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are determined solely by the temperature of the cavity. Such cavity radiators are commonly used as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as a FLIR Systems camera for example.

If the temperature of blackbody radiation increases to more than 525°C (977°F), the source begins to be visible so that it appears to the eye no longer black. This is the incipient red heat temperature of the radiator, which then becomes orange or yellow as the temperature increases further. In fact, the definition of the so-called *color temperature* of an object is the temperature to which a blackbody would have to be heated to have the same appearance.

Now consider three expressions that describe the radiation emitted from a blackbody.

12.3.1 Planck's law

Figure 12.3 Max Planck (1858–1947)

Max Planck (1858–1947) was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W_{\lambda b} = \frac{2\pi hc^2}{\lambda^5 \left(e^{hc/\lambda kT} - 1\right)} \times 10^{-6} [Watt\,/\,m^2, \mu m]$$

where:

$W_{\lambda b}$	Blackbody spectral radiant emittance at wavelength λ.
c	Velocity of light = 3×10^8 m/s
h	Planck's constant = 6.6×10^{-34} Joule sec.
k	Boltzmann's constant = 1.4×10^{-23} Joule/K.
T	Absolute temperature (K) of a blackbody.
λ	Wavelength (μm).

Note
The factor 10^{-6} is used since spectral emittance in the curves is expressed in Watt/m^2, μm.

Planck's formula, when plotted graphically for various temperatures, produces a family of curves. Following any particular Planck curve, the spectral emittance is zero at λ = 0, then increases rapidly to a maximum at a wavelength λ_{max} and after passing it approaches zero again at very long wavelengths. The higher the temperature, the shorter the wavelength at which maximum occurs.

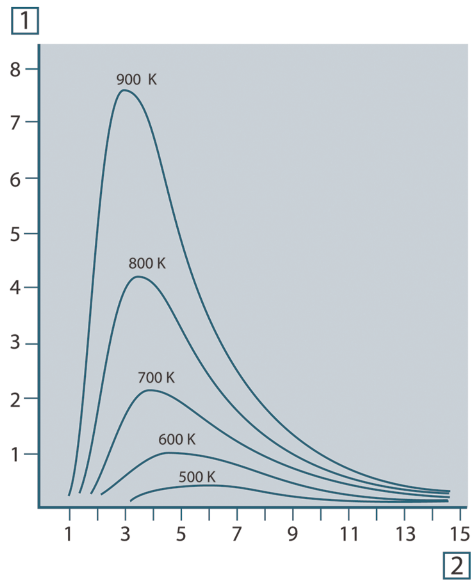


Figure 12.4 Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. 1: Spectral radiant emittance (W/cm^2 × 10^3(μm)); 2: Wavelength (μm)

12.3.2 Wien's displacement law

By differentiating Planck's formula with respect to λ, and finding the maximum, we have:

$$\lambda_{\max} = \frac{2898}{T}[\mu m]$$

This is Wien's formula (after *Wilhelm Wien*, 1864–1928), which expresses mathematically the common observation that colors vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the color is the same as the wavelength calculated for λ_{max}. A good approximation of the value of λ_{max} for a given blackbody temperature is obtained by applying the rule-of-thumb 3 000/T μm. Thus, a very hot star such as Sirius (11 000 K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength 0.27 μm.

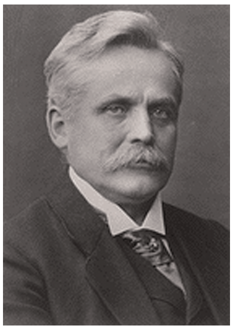


Figure 12.5 Wilhelm Wien (1864–1928)

The sun (approx. 6 000 K) emits yellow light, peaking at about 0.5 µm in the middle of the visible light spectrum.

At room temperature (300 K) the peak of radiant emittance lies at 9.7 µm, in the far infrared, while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant amount of radiant emittance occurs at 38 µm, in the extreme infrared wavelengths.

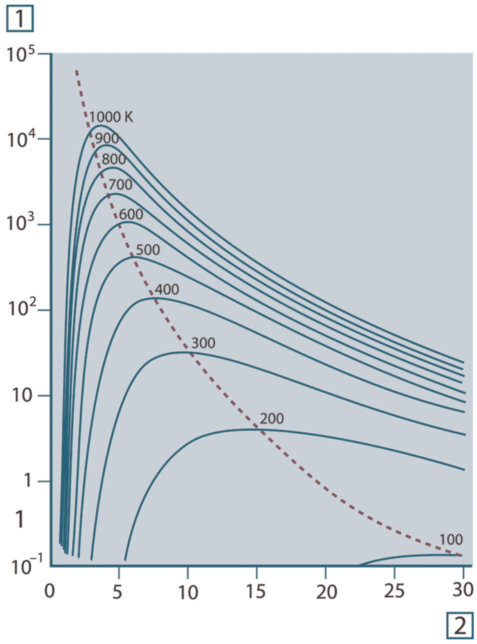


Figure 12.6 Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. 1: Spectral radiant emittance (W/cm² (µm)); 2: Wavelength (µm).

12.3.3 Stefan-Boltzmann's law

By integrating Planck's formula from λ = 0 to λ = ∞, we obtain the total radiant emittance (W_b) of a blackbody:

$$W_b = \sigma T^4 \ [\mathrm{Watt/m^2}]$$

This is the Stefan-Boltzmann formula (after *Josef Stefan*, 1835–1893, and *Ludwig Boltzmann*, 1844–1906), which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature. Graphically, W_b represents the area below the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval λ = 0 to λ_{max} is only 25% of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.

Figure 12.7 Josef Stefan (1835–1893), and Ludwig Boltzmann (1844–1906)

Using the Stefan-Boltzmann formula to calculate the power radiated by the human body, at a temperature of 300 K and an external surface area of approx. 2 m^2, we obtain 1 kW. This power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

12.3.4 Non-blackbody emitters

So far, only blackbody radiators and blackbody radiation have been discussed. However, real objects almost never comply with these laws over an extended wavelength region – although they may approach the blackbody behavior in certain spectral intervals. For example, a certain type of white paint may appear perfectly *white* in the visible light spectrum, but becomes distinctly *gray* at about 2 µm, and beyond 3 µm it is almost *black*.

There are three processes which can occur that prevent a real object from acting like a blackbody: a fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted. Since all of these factors are more or less wavelength dependent, the subscript λ is used to imply the spectral dependence of their definitions. Thus:

- The spectral absorptance α_λ= the ratio of the spectral radiant power absorbed by an object to that incident upon it.
- The spectral reflectance ρ_λ = the ratio of the spectral radiant power reflected by an object to that incident upon it.
- The spectral transmittance τ_λ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

The sum of these three factors must always add up to the whole at any wavelength, so we have the relation:

$$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$$

For opaque materials $\tau_\lambda = 0$ and the relation simplifies to:

$$\varepsilon_\lambda + \rho_\lambda = 1$$

Another factor, called the emissivity, is required to describe the fraction ε of the radiant emittance of a blackbody produced by an object at a specific temperature. Thus, we have the definition:

The spectral emissivity ε_λ= the ratio of the spectral radiant power from an object to that from a blackbody at the same temperature and wavelength.

Expressed mathematically, this can be written as the ratio of the spectral emittance of the object to that of a blackbody as follows:

$$\varepsilon_\lambda = \frac{W_{\lambda o}}{W_{\lambda b}}$$

Generally speaking, there are three types of radiation source, distinguished by the ways in which the spectral emittance of each varies with wavelength.

- A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$
- A graybody, for which $\varepsilon_\lambda = \varepsilon$ = constant less than 1

- A selective radiator, for which ε varies with wavelength

According to Kirchhoff's law, for any material the spectral emissivity and spectral absorptance of a body are equal at any specified temperature and wavelength. That is:

$$\varepsilon_\lambda = \alpha_\lambda$$

From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_\lambda = 1$):

$$\varepsilon_\lambda + \rho_\lambda = 1$$

For highly polished materials ε_λ approaches zero, so that for a perfectly reflecting material (*i.e.* a perfect mirror) we have:

$$\rho_\lambda = 1$$

For a graybody radiator, the Stefan-Boltzmann formula becomes:

$$W = \varepsilon \sigma T^4 \text{ [Watt/m}^2\text{]}$$

This states that the total emissive power of a graybody is the same as a blackbody at the same temperature reduced in proportion to the value of ε from the graybody.

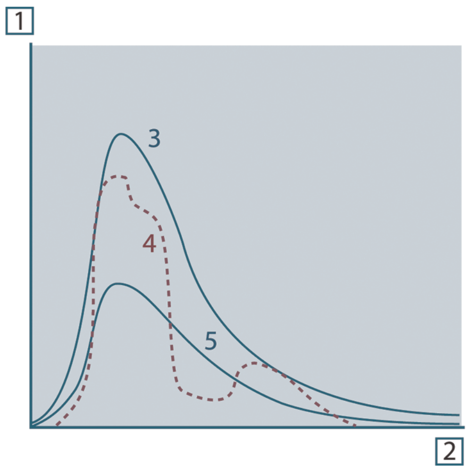


Figure 12.8 Spectral radiant emittance of three types of radiators. 1: Spectral radiant emittance; 2: Wavelength; 3: Blackbody; 4: Selective radiator; 5: Graybody.

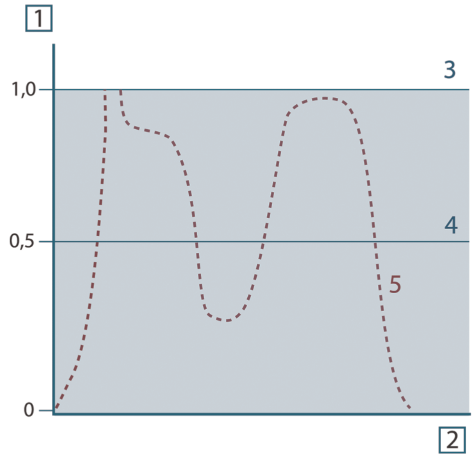


Figure 12.9 Spectral emissivity of three types of radiators. 1: Spectral emissivity; 2: Wavelength; 3: Blackbody; 4: Graybody; 5: Selective radiator.

12.4 Infrared semi-transparent materials

Consider now a non-metallic, semi-transparent body – let us say, in the form of a thick flat plate of plastic material. When the plate is heated, radiation generated within its volume must work its way toward the surfaces through the material in which it is partially absorbed. Moreover, when it arrives at the surface, some of it is reflected back into the interior. The back-reflected radiation is again partially absorbed, but some of it arrives at the other surface, through which most of it escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker they must all be added up when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as:

$$\varepsilon_\lambda = \frac{(1-\rho_\lambda)(1-\tau_\lambda)}{1-\rho_\lambda\tau_\lambda}$$

When the plate becomes opaque this formula is reduced to the single formula:

$$\varepsilon_\lambda = 1-\rho_\lambda$$

This last relation is a particularly convenient one, because it is often easier to measure reflectance than to measure emissivity directly.

13 The measurement formula

As already mentioned, when viewing an object, the camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. To this comes a third radiation contribution from the atmosphere itself.

This description of the measurement situation, as illustrated in the figure below, is so far a fairly true description of the real conditions. What has been neglected could for instance be sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify, however, in most cases they are fortunately small enough to be neglected. In case they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, shielding off intense radiation sources etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

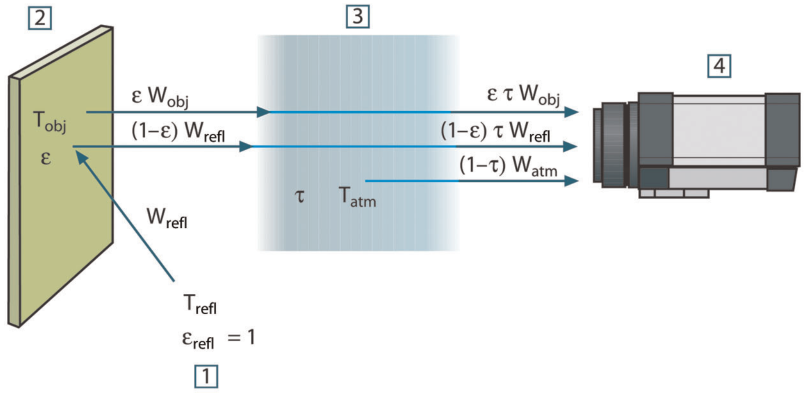


Figure 13.1 A schematic representation of the general thermographic measurement situation.1: Surroundings; 2: Object; 3: Atmosphere; 4: Camera

Assume that the received radiation power W from a blackbody source of temperature T_{source} on short distance generates a camera output signal U_{source} that is proportional to the power input (power linear camera). We can then write (Equation 1):

$$U_{source} = CW(T_{source})$$

or, with simplified notation:

$$U_{source} = CW_{source}$$

where C is a constant.

Should the source be a graybody with emittance ε, the received radiation would consequently be εW_{source}.

We are now ready to write the three collected radiation power terms:

1. *Emission from the object* = $\varepsilon\tau W_{obj}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is T_{obj}.

2. *Reflected emission from ambient sources* = $(1 - \varepsilon)\tau W_{refl}$, where $(1 - \varepsilon)$ is the reflectance of the object. The ambient sources have the temperature T_{refl}.
It has here been assumed that the temperature T_{refl} is the same for all emitting surfaces within the halfsphere seen from a point on the object surface. This is of course sometimes a simplification of the true situation. It is, however, a necessary simplification in order to derive a workable formula, and T_{refl} can – at least theoretically – be given a value that represents an efficient temperature of a complex surrounding.

   Note also that we have assumed that the emittance for the surroundings = 1. This is correct in accordance with Kirchhoff's law: All radiation impinging on the surrounding surfaces will eventually be absorbed by the same surfaces. Thus the emittance = 1. (Note though that the latest discussion requires the complete sphere around the object to be considered.)
3. *Emission from the atmosphere* = $(1 - \tau)\tau W_{atm}$, where $(1 - \tau)$ is the emittance of the atmosphere. The temperature of the atmosphere is T_{atm}.

The total received radiation power can now be written (Equation 2):

$$W_{tot} = \varepsilon\tau W_{obj} + (1-\varepsilon)\tau W_{refl} + (1-\tau)W_{atm}$$

We multiply each term by the constant C of Equation 1 and replace the CW products by the corresponding U according to the same equation, and get (Equation 3):

$$U_{tot} = \varepsilon\tau U_{obj} + (1-\varepsilon)\tau U_{refl} + (1-\tau)U_{atm}$$

Solve Equation 3 for U_{obj} (Equation 4):

$$U_{obj} = \frac{1}{\varepsilon\tau}U_{tot} - \frac{1-\varepsilon}{\varepsilon}U_{refl} - \frac{1-\tau}{\varepsilon\tau}U_{atm}$$

This is the general measurement formula used in all the FLIR Systems thermographic equipment. The voltages of the formula are:

Table 13.1 Voltages

U_{obj}	Calculated camera output voltage for a blackbody of temperature T_{obj} i.e. a voltage that can be directly converted into true requested object temperature.
U_{tot}	Measured camera output voltage for the actual case.
U_{refl}	Theoretical camera output voltage for a blackbody of temperature T_{refl} according to the calibration.
U_{atm}	Theoretical camera output voltage for a blackbody of temperature T_{atm} according to the calibration.

The operator has to supply a number of parameter values for the calculation:

- the object emittance ε,
- the relative humidity,
- T_{atm}
- object distance (D_{obj})
- the (effective) temperature of the object surroundings, or the reflected ambient temperature T_{refl}, and
- the temperature of the atmosphere T_{atm}

This task could sometimes be a heavy burden for the operator since there are normally no easy ways to find accurate values of emittance and atmospheric transmittance for the actual case. The two temperatures are normally less of a problem provided the surroundings do not contain large and intense radiation sources.

A natural question in this connection is: How important is it to know the right values of these parameters? It could though be of interest to get a feeling for this problem already here by looking into some different measurement cases and compare the relative magnitudes of the three radiation terms. This will give indications about when it is important to use correct values of which parameters.

The figures below illustrates the relative magnitudes of the three radiation contributions for three different object temperatures, two emittances, and two spectral ranges: SW and LW. Remaining parameters have the following fixed values:

- $\tau = 0.88$
- T_{refl} = +20°C (+68°F)
- T_{atm} = +20°C (+68°F)

It is obvious that measurement of low object temperatures are more critical than measuring high temperatures since the 'disturbing' radiation sources are relatively much stronger in the first case. Should also the object emittance be low, the situation would be still more difficult.

We have finally to answer a question about the importance of being allowed to use the calibration curve above the highest calibration point, what we call extrapolation. Imagine that we in a certain case measure U_{tot} = 4.5 volts. The highest calibration point for the camera was in the order of 4.1 volts, a value unknown to the operator. Thus, even if the object happened to be a blackbody, i.e. $U_{obj} = U_{tot}$, we are actually performing extrapolation of the calibration curve when converting 4.5 volts into temperature.

Let us now assume that the object is not black, it has an emittance of 0.75, and the transmittance is 0.92. We also assume that the two second terms of Equation 4 amount to 0.5 volts together. Computation of U_{obj} by means of Equation 4 then results in U_{obj} = 4.5 / 0.75 / 0.92 – 0.5 = 6.0. This is a rather extreme extrapolation, particularly when considering that the video amplifier might limit the output to 5 volts! Note, though, that the application of the calibration curve is a theoretical procedure where no electronic or other limitations exist. We trust that if there had been no signal limitations in the camera, and if it had been calibrated far beyond 5 volts, the resulting curve would have been very much the same as our real curve extrapolated beyond 4.1 volts, provided the calibration algorithm is based on radiation physics, like the FLIR Systems algorithm. Of course there must be a limit to such extrapolations.

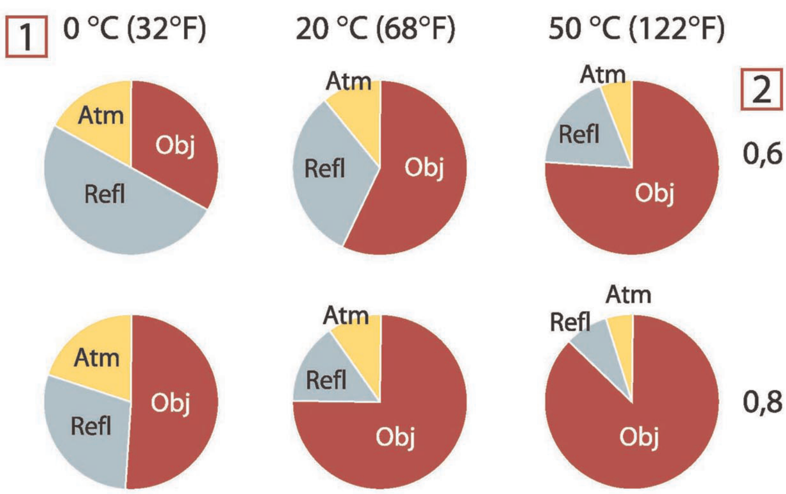


Figure 13.2 Relative magnitudes of radiation sources under varying measurement conditions (SW camera). 1: Object temperature; 2: Emittance; Obj: Object radiation; Refl: Reflected radiation; Atm: atmosphere radiation. Fixed parameters: $\tau = 0.88$; T_{refl} = 20°C (+68°F); T_{atm} = 20°C (+68°F).

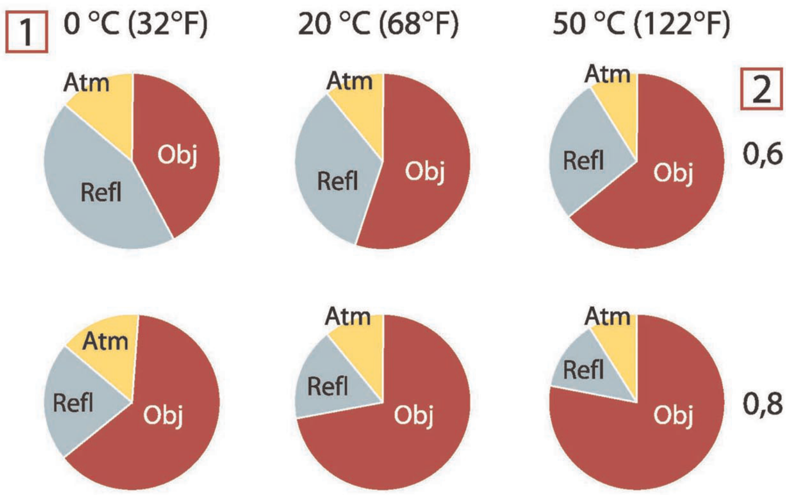


Figure 13.3 Relative magnitudes of radiation sources under varying measurement conditions (LW camera). 1: Object temperature; 2: Emittance; Obj: Object radiation; Refl: Reflected radiation; Atm: atmosphere radiation. Fixed parameters: τ = 0.88; T_{refl} = 20°C (+68°F); T_{atm} = 20°C (+68°F).

14 Emissivity tables

This section presents a compilation of emissivity data from the infrared literature and measurements made by FLIR Systems.

14.1 References

1. Mikaél A. Bramson: *Infrared Radiation, A Handbook for Applications*, Plenum press, N.Y.
2. William L. Wolfe, George J. Zissis: *The Infrared Handbook*, Office of Naval Research, Department of Navy, Washington, D.C.
3. Madding, R. P.: *Thermographic Instruments and systems*. Madison, Wisconsin: University of Wisconsin – Extension, Department of Engineering and Applied Science.
4. William L. Wolfe: *Handbook of Military Infrared Technology*, Office of Naval Research, Department of Navy, Washington, D.C.
5. Jones, Smith, Probert: *External thermography of buildings...,* Proc. of the Society of Photo-Optical Instrumentation Engineers, vol.110, Industrial and Civil Applications of Infrared Technology, June 1977 London.
6. Paljak, Pettersson: *Thermography of Buildings*, Swedish Building Research Institute, Stockholm 1972.
7. Vlcek, J: *Determination of emissivity with imaging radiometers and some emissivities at λ = 5 µm.* Photogrammetric Engineering and Remote Sensing.
8. Kern: *Evaluation of infrared emission of clouds and ground as measured by weather satellites*, Defence Documentation Center, AD 617 417.
9. Öhman, Claes: *Emittansmätningar med AGEMA E-Box*. Teknisk rapport, AGEMA 1999. (Emittance measurements using AGEMA E-Box. Technical report, AGEMA 1999.)
10. Matteï, S., Tang-Kwor, E: *Emissivity measurements for Nextel Velvet coating 811-21 between –36°C AND 82°C.*
11. Lohrengel & Todtenhaupt (1996)
12. ITC Technical publication 32.
13. ITC Technical publication 29.

Note
The emissivity values in the table below are recorded using a shortwave (SW) camera. The values should be regarded as recommendations only and used with caution.

14.2 Tables

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference

1	2	3	4	5	6
3M type 35	Vinyl electrical tape (several colors)	< 80	LW	≈ 0.96	13
3M type 88	Black vinyl electrical tape	< 105	LW	≈ 0.96	13
3M type 88	Black vinyl electrical tape	< 105	MW	< 0.96	13
3M type Super 33 +	Black vinyl electrical tape	< 80	LW	≈ 0.96	13
Aluminum	anodized sheet	100	T	0.55	2
Aluminum	anodized, black, dull	70	SW	0.67	9
Aluminum	anodized, black, dull	70	LW	0.95	9
Aluminum	anodized, light gray, dull	70	SW	0.61	9
Aluminum	anodized, light gray, dull	70	LW	0.97	9

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Aluminum	as received, plate	100	T	0.09	4
Aluminum	as received, sheet	100	T	0.09	2
Aluminum	cast, blast cleaned	70	SW	0.47	9
Aluminum	cast, blast cleaned	70	LW	0.46	9
Aluminum	dipped in HNO_3, plate	100	T	0.05	4
Aluminum	foil	27	10 µm	0.04	3
Aluminum	foil	27	3 µm	0.09	3
Aluminum	oxidized, strongly	50–500	T	0.2–0.3	1
Aluminum	polished	50–100	T	0.04–0.06	1
Aluminum	polished plate	100	T	0.05	4
Aluminum	polished, sheet	100	T	0.05	2
Aluminum	rough surface	20–50	T	0.06–0.07	1
Aluminum	roughened	27	10 µm	0.18	3
Aluminum	roughened	27	3 µm	0.28	3
Aluminum	sheet, 4 samples differently scratched	70	SW	0.05–0.08	9
Aluminum	sheet, 4 samples differently scratched	70	LW	0.03–0.06	9
Aluminum	vacuum deposited	20	T	0.04	2
Aluminum	weathered, heavily	17	SW	0.83–0.94	5
Aluminum bronze		20	T	0.60	1
Aluminum hydroxide	powder		T	0.28	1
Aluminum oxide	activated, powder		T	0.46	1
Aluminum oxide	pure, powder (alumina)		T	0.16	1
Asbestos	board	20	T	0.96	1
Asbestos	fabric		T	0.78	1
Asbestos	floor tile	35	SW	0.94	7
Asbestos	paper	40–400	T	0.93–0.95	1
Asbestos	powder		T	0.40–0.60	1
Asbestos	slate	20	T	0.96	1
Asphalt paving		4	LLW	0.967	8
Brass	dull, tarnished	20–350	T	0.22	1
Brass	oxidized	100	T	0.61	2
Brass	oxidized	70	SW	0.04–0.09	9
Brass	oxidized	70	LW	0.03–0.07	9
Brass	oxidized at 600°C	200–600	T	0.59–0.61	1
Brass	polished	200	T	0.03	1

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Brass	polished, highly	100	T	0.03	2
Brass	rubbed with 80-grit emery	20	T	0.20	2
Brass	sheet, rolled	20	T	0.06	1
Brass	sheet, worked with emery	20	T	0.2	1
Brick	alumina	17	SW	0.68	5
Brick	common	17	SW	0.86–0.81	5
Brick	Dinas silica, glazed, rough	1100	T	0.85	1
Brick	Dinas silica, refractory	1000	T	0.66	1
Brick	Dinas silica, unglazed, rough	1000	T	0.80	1
Brick	firebrick	17	SW	0.68	5
Brick	fireclay	1000	T	0.75	1
Brick	fireclay	1200	T	0.59	1
Brick	fireclay	20	T	0.85	1
Brick	masonry	35	SW	0.94	7
Brick	masonry, plastered	20	T	0.94	1
Brick	red, common	20	T	0.93	2
Brick	red, rough	20	T	0.88–0.93	1
Brick	refractory, corundum	1000	T	0.46	1
Brick	refractory, magnesite	1000–1300	T	0.38	1
Brick	refractory, strongly radiating	500–1000	T	0.8–0.9	1
Brick	refractory, weakly radiating	500–1000	T	0.65–0.75	1
Brick	silica, 95% SiO_2	1230	T	0.66	1
Brick	sillimanite, 33% SiO_2, 64% Al_2O_3	1500	T	0.29	1
Brick	waterproof	17	SW	0.87	5
Bronze	phosphor bronze	70	SW	0.08	9
Bronze	phosphor bronze	70	LW	0.06	9
Bronze	polished	50	T	0.1	1
Bronze	porous, rough	50–150	T	0.55	1
Bronze	powder		T	0.76–0.80	1
Carbon	candle soot	20	T	0.95	2
Carbon	charcoal powder		T	0.96	1
Carbon	graphite powder		T	0.97	1
Carbon	graphite, filed surface	20	T	0.98	2
Carbon	lampblack	20–400	T	0.95–0.97	1
Chipboard	untreated	20	SW	0.90	6

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Chromium	polished	50	T	0.10	1
Chromium	polished	500–1000	T	0.28–0.38	1
Clay	fired	70	T	0.91	1
Cloth	black	20	T	0.98	1
Concrete		20	T	0.92	2
Concrete	dry	36	SW	0.95	7
Concrete	rough	17	SW	0.97	5
Concrete	walkway	5	LLW	0.974	8
Copper	commercial, burnished	20	T	0.07	1
Copper	electrolytic, carefully polished	80	T	0.018	1
Copper	electrolytic, polished	–34	T	0.006	4
Copper	molten	1100–1300	T	0.13–0.15	1
Copper	oxidized	50	T	0.6–0.7	1
Copper	oxidized to blackness		T	0.88	1
Copper	oxidized, black	27	T	0.78	4
Copper	oxidized, heavily	20	T	0.78	2
Copper	polished	50–100	T	0.02	1
Copper	polished	100	T	0.03	2
Copper	polished, commercial	27	T	0.03	4
Copper	polished, mechanical	22	T	0.015	4
Copper	pure, carefully prepared surface	22	T	0.008	4
Copper	scraped	27	T	0.07	4
Copper dioxide	powder		T	0.84	1
Copper oxide	red, powder		T	0.70	1
Ebonite			T	0.89	1
Emery	coarse	80	T	0.85	1
Enamel		20	T	0.9	1
Enamel	lacquer	20	T	0.85–0.95	1
Fiber board	hard, untreated	20	SW	0.85	6
Fiber board	masonite	70	SW	0.75	9
Fiber board	masonite	70	LW	0.88	9
Fiber board	particle board	70	SW	0.77	9
Fiber board	particle board	70	LW	0.89	9
Fiber board	porous, untreated	20	SW	0.85	6
Gold	polished	130	T	0.018	1
Gold	polished, carefully	200–600	T	0.02–0.03	1
Gold	polished, highly	100	T	0.02	2
Granite	polished	20	LLW	0.849	8

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Granite	rough	21	LLW	0.879	8
Granite	rough, 4 different samples	70	SW	0.95–0.97	9
Granite	rough, 4 different samples	70	LW	0.77–0.87	9
Gypsum		20	T	0.8–0.9	1
Ice: See Water					
Iron and steel	cold rolled	70	SW	0.20	9
Iron and steel	cold rolled	70	LW	0.09	9
Iron and steel	covered with red rust	20	T	0.61–0.85	1
Iron and steel	electrolytic	100	T	0.05	4
Iron and steel	electrolytic	22	T	0.05	4
Iron and steel	electrolytic	260	T	0.07	4
Iron and steel	electrolytic, carefully polished	175–225	T	0.05–0.06	1
Iron and steel	freshly worked with emery	20	T	0.24	1
Iron and steel	ground sheet	950–1100	T	0.55–0.61	1
Iron and steel	heavily rusted sheet	20	T	0.69	2
Iron and steel	hot rolled	130	T	0.60	1
Iron and steel	hot rolled	20	T	0.77	1
Iron and steel	oxidized	100	T	0.74	4
Iron and steel	oxidized	100	T	0.74	1
Iron and steel	oxidized	1227	T	0.89	4
Iron and steel	oxidized	125–525	T	0.78–0.82	1
Iron and steel	oxidized	200	T	0.79	2
Iron and steel	oxidized	200–600	T	0.80	1
Iron and steel	oxidized strongly	50	T	0.88	1
Iron and steel	oxidized strongly	500	T	0.98	1
Iron and steel	polished	100	T	0.07	2
Iron and steel	polished	400–1000	T	0.14–0.38	1
Iron and steel	polished sheet	750–1050	T	0.52–0.56	1
Iron and steel	rolled sheet	50	T	0.56	1
Iron and steel	rolled, freshly	20	T	0.24	1
Iron and steel	rough, plane surface	50	T	0.95–0.98	1
Iron and steel	rusted red, sheet	22	T	0.69	4
Iron and steel	rusted, heavily	17	SW	0.96	5
Iron and steel	rusty, red	20	T	0.69	1
Iron and steel	shiny oxide layer, sheet,	20	T	0.82	1
Iron and steel	shiny, etched	150	T	0.16	1
Iron and steel	wrought, carefully polished	40–250	T	0.28	1

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Iron galvanized	heavily oxidized	70	SW	0.64	9
Iron galvanized	heavily oxidized	70	LW	0.85	9
Iron galvanized	sheet	92	T	0.07	4
Iron galvanized	sheet, burnished	30	T	0.23	1
Iron galvanized	sheet, oxidized	20	T	0.28	1
Iron tinned	sheet	24	T	0.064	4
Iron, cast	casting	50	T	0.81	1
Iron, cast	ingots	1000	T	0.95	1
Iron, cast	liquid	1300	T	0.28	1
Iron, cast	machined	800–1000	T	0.60–0.70	1
Iron, cast	oxidized	100	T	0.64	2
Iron, cast	oxidized	260	T	0.66	4
Iron, cast	oxidized	38	T	0.63	4
Iron, cast	oxidized	538	T	0.76	4
Iron, cast	oxidized at 600°C	200–600	T	0.64–0.78	1
Iron, cast	polished	200	T	0.21	1
Iron, cast	polished	38	T	0.21	4
Iron, cast	polished	40	T	0.21	2
Iron, cast	unworked	900–1100	T	0.87–0.95	1
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	LW	≈ 0.96	12
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	MW	≈ 0.97	12
Lacquer	3 colors sprayed on Aluminum	70	SW	0.50–0.53	9
Lacquer	3 colors sprayed on Aluminum	70	LW	0.92–0.94	9
Lacquer	Aluminum on rough surface	20	T	0.4	1
Lacquer	bakelite	80	T	0.83	1
Lacquer	black, dull	40–100	T	0.96–0.98	1
Lacquer	black, matte	100	T	0.97	2
Lacquer	black, shiny, sprayed on iron	20	T	0.87	1
Lacquer	heat–resistant	100	T	0.92	1
Lacquer	white	100	T	0.92	2
Lacquer	white	40–100	T	0.8–0.95	1
Lead	oxidized at 200°C	200	T	0.63	1
Lead	oxidized, gray	20	T	0.28	1
Lead	oxidized, gray	22	T	0.28	4
Lead	shiny	250	T	0.08	1
Lead	unoxidized, polished	100	T	0.05	4
Lead red		100	T	0.93	4
Lead red, powder		100	T	0.93	1

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Leather	tanned		T	0.75–0.80	1
Lime			T	0.3–0.4	1
Magnesium		22	T	0.07	4
Magnesium		260	T	0.13	4
Magnesium		538	T	0.18	4
Magnesium	polished	20	T	0.07	2
Magnesium powder			T	0.86	1
Molybdenum		1500–2200	T	0.19–0.26	1
Molybdenum		600–1000	T	0.08–0.13	1
Molybdenum	filament	700–2500	T	0.1–0.3	1
Mortar		17	SW	0.87	5
Mortar	dry	36	SW	0.94	7
Nextel Velvet 811-21 Black	Flat black	–60–150	LW	> 0.97	10 and 11
Nichrome	rolled	700	T	0.25	1
Nichrome	sandblasted	700	T	0.70	1
Nichrome	wire, clean	50	T	0.65	1
Nichrome	wire, clean	500–1000	T	0.71–0.79	1
Nichrome	wire, oxidized	50–500	T	0.95–0.98	1
Nickel	bright matte	122	T	0.041	4
Nickel	commercially pure, polished	100	T	0.045	1
Nickel	commercially pure, polished	200–400	T	0.07–0.09	1
Nickel	electrolytic	22	T	0.04	4
Nickel	electrolytic	260	T	0.07	4
Nickel	electrolytic	38	T	0.06	4
Nickel	electrolytic	538	T	0.10	4
Nickel	electroplated on iron, polished	22	T	0.045	4
Nickel	electroplated on iron, unpolished	20	T	0.11–0.40	1
Nickel	electroplated on iron, unpolished	22	T	0.11	4
Nickel	electroplated, polished	20	T	0.05	2
Nickel	oxidized	1227	T	0.85	4
Nickel	oxidized	200	T	0.37	2
Nickel	oxidized	227	T	0.37	4
Nickel	oxidized at 600°C	200–600	T	0.37–0.48	1
Nickel	polished	122	T	0.045	4
Nickel	wire	200–1000	T	0.1–0.2	1
Nickel oxide		1000–1250	T	0.75–0.86	1
Nickel oxide		500–650	T	0.52–0.59	1
Oil, lubricating	0.025 mm film	20	T	0.27	2

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Oil, lubricating	0.050 mm film	20	T	0.46	2
Oil, lubricating	0.125 mm film	20	T	0.72	2
Oil, lubricating	film on Ni base: Ni base only	20	T	0.05	2
Oil, lubricating	thick coating	20	T	0.82	2
Paint	8 different colors and qualities	70	SW	0.88–0.96	9
Paint	8 different colors and qualities	70	LW	0.92–0.94	9
Paint	Aluminum, various ages	50–100	T	0.27–0.67	1
Paint	cadmium yellow		T	0.28–0.33	1
Paint	chrome green		T	0.65–0.70	1
Paint	cobalt blue		T	0.7–0.8	1
Paint	oil	17	SW	0.87	5
Paint	oil based, average of 16 colors	100	T	0.94	2
Paint	oil, black flat	20	SW	0.94	6
Paint	oil, black gloss	20	SW	0.92	6
Paint	oil, gray flat	20	SW	0.97	6
Paint	oil, gray gloss	20	SW	0.96	6
Paint	oil, various colors	100	T	0.92–0.96	1
Paint	plastic, black	20	SW	0.95	6
Paint	plastic, white	20	SW	0.84	6
Paper	4 different colors	70	SW	0.68–0.74	9
Paper	4 different colors	70	LW	0.92–0.94	9
Paper	black		T	0.90	1
Paper	black, dull		T	0.94	1
Paper	black, dull	70	SW	0.86	9
Paper	black, dull	70	LW	0.89	9
Paper	blue, dark		T	0.84	1
Paper	coated with black lacquer		T	0.93	1
Paper	green		T	0.85	1
Paper	red		T	0.76	1
Paper	white	20	T	0.7–0.9	1
Paper	white bond	20	T	0.93	2
Paper	white, 3 different glosses	70	SW	0.76–0.78	9
Paper	white, 3 different glosses	70	LW	0.88–0.90	9
Paper	yellow		T	0.72	1
Plaster		17	SW	0.86	5
Plaster	plasterboard, untreated	20	SW	0.90	6

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Plaster	rough coat	20	T	0.91	2
Plastic	glass fibre laminate (printed circ. board)	70	SW	0.94	9
Plastic	glass fibre laminate (printed circ. board)	70	LW	0.91	9
Plastic	polyurethane isolation board	70	LW	0.55	9
Plastic	polyurethane isolation board	70	SW	0.29	9
Plastic	PVC, plastic floor, dull, structured	70	SW	0.94	9
Plastic	PVC, plastic floor, dull, structured	70	LW	0.93	9
Platinum		100	T	0.05	4
Platinum		1000–1500	T	0.14–0.18	1
Platinum		1094	T	0.18	4
Platinum		17	T	0.016	4
Platinum		22	T	0.03	4
Platinum		260	T	0.06	4
Platinum		538	T	0.10	4
Platinum	pure, polished	200–600	T	0.05–0.10	1
Platinum	ribbon	900–1100	T	0.12–0.17	1
Platinum	wire	1400	T	0.18	1
Platinum	wire	500–1000	T	0.10–0.16	1
Platinum	wire	50–200	T	0.06–0.07	1
Porcelain	glazed	20	T	0.92	1
Porcelain	white, shiny		T	0.70–0.75	1
Rubber	hard	20	T	0.95	1
Rubber	soft, gray, rough	20	T	0.95	1
Sand			T	0.60	1
Sand		20	T	0.90	2
Sandstone	polished	19	LLW	0.909	8
Sandstone	rough	19	LLW	0.935	8
Silver	polished	100	T	0.03	2
Silver	pure, polished	200–600	T	0.02–0.03	1
Skin	human	32	T	0.98	2
Slag	boiler	0–100	T	0.97–0.93	1
Slag	boiler	1400–1800	T	0.69–0.67	1
Slag	boiler	200–500	T	0.89–0.78	1
Slag	boiler	600–1200	T	0.76–0.70	1
Snow: See Water					
Soil	dry	20	T	0.92	2
Soil	saturated with water	20	T	0.95	2

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Stainless steel	alloy, 8% Ni, 18% Cr	500	T	0.35	1
Stainless steel	rolled	700	T	0.45	1
Stainless steel	sandblasted	700	T	0.70	1
Stainless steel	sheet, polished	70	SW	0.18	9
Stainless steel	sheet, polished	70	LW	0.14	9
Stainless steel	sheet, untreated, somewhat scratched	70	SW	0.30	9
Stainless steel	sheet, untreated, somewhat scratched	70	LW	0.28	9
Stainless steel	type 18-8, buffed	20	T	0.16	2
Stainless steel	type 18-8, oxi-dized at 800°C	60	T	0.85	2
Stucco	rough, lime	10–90	T	0.91	1
Styrofoam	insulation	37	SW	0.60	7
Tar			T	0.79–0.84	1
Tar	paper	20	T	0.91–0.93	1
Tile	glazed	17	SW	0.94	5
Tin	burnished	20–50	T	0.04–0.06	1
Tin	tin–plated sheet iron	100	T	0.07	2
Titanium	oxidized at 540°C	1000	T	0.60	1
Titanium	oxidized at 540°C	200	T	0.40	1
Titanium	oxidized at 540°C	500	T	0.50	1
Titanium	polished	1000	T	0.36	1
Titanium	polished	200	T	0.15	1
Titanium	polished	500	T	0.20	1
Tungsten		1500–2200	T	0.24–0.31	1
Tungsten		200	T	0.05	1
Tungsten		600–1000	T	0.1–0.16	1
Tungsten	filament	3300	T	0.39	1
Varnish	flat	20	SW	0.93	6
Varnish	on oak parquet floor	70	SW	0.90	9
Varnish	on oak parquet floor	70	LW	0.90–0.93	9
Wallpaper	slight pattern, light gray	20	SW	0.85	6
Wallpaper	slight pattern, red	20	SW	0.90	6
Water	distilled	20	T	0.96	2
Water	frost crystals	–10	T	0.98	2
Water	ice, covered with heavy frost	0	T	0.98	1
Water	ice, smooth	0	T	0.97	1
Water	ice, smooth	–10	T	0.96	2

Table 14.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Water	layer >0.1 mm thick	0–100	T	0.95–0.98	1
Water	snow		T	0.8	1
Water	snow	–10	T	0.85	2
Wood		17	SW	0.98	5
Wood		19	LLW	0.962	8
Wood	ground		T	0.5–0.7	1
Wood	pine, 4 different samples	70	SW	0.67–0.75	9
Wood	pine, 4 different samples	70	LW	0.81–0.89	9
Wood	planed	20	T	0.8–0.9	1
Wood	planed oak	20	T	0.90	2
Wood	planed oak	70	SW	0.77	9
Wood	planed oak	70	LW	0.88	9
Wood	plywood, smooth, dry	36	SW	0.82	7
Wood	plywood, untreated	20	SW	0.83	6
Wood	white, damp	20	T	0.7–0.8	1
Zinc	oxidized at 400°C	400	T	0.11	1
Zinc	oxidized surface	1000–1200	T	0.50–0.60	1
Zinc	polished	200–300	T	0.04–0.05	1
Zinc	sheet	50	T	0.20	1

A note on the technical production of this publication

This publication was produced using XML — the eXtensible Markup Language. For more information about XML, please visit http://www.w3.org/XML/

A note on the typeface used in this publication

This publication was typeset using Linotype Helvetica™ World. Helvetica™ was designed by Max Miedinger (1910–1980)

LOEF (List Of Effective Files)

T501089.xml; en-US; AA; 15613; 2014-07-01
T505473.xml; en-US; 15553; 2014-06-30
T505474.xml; en-US; 15553; 2014-06-30
T505013.xml; en-US; 9229; 2013-10-03
T505007.xml; en-US; 12154; 2014-03-06
T505004.xml; en-US; 12154; 2014-03-06
T505000.xml; en-US; 12154; 2014-03-06
T505005.xml; en-US; 12154; 2014-03-06
T505001.xml; en-US; 12154; 2014-03-06
T505006.xml; en-US; 12154; 2014-03-06
T505002.xml; en-US; 13591; 2014-04-28

Corporate Headquarters
FLIR Systems, Inc.
27700 SW Parkway Ave.
Wilsonville, OR 97070
USA
Telephone: +1-503-498-3547

Website
http://www.flir.com

Customer support
http://support.flir.com

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Publ. No.:	T559495
Release:	AA
Commit:	15613
Head:	15680
Language:	en-US
Modified:	2014-07-01
Formatted:	2014-07-03