Exterior Building Envelope Inspections Using

Thermal Infrared Imaging

a report to the Public Building Service of the General Services Administration

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Section 1

Summary and Table of Contents

SUMMARY

Thermographic imagery has long been used for evaluation of roof, electrical, mechanical systems and other building elements. But the technique has not been used as frequently to evaluate the exterior enclosures (envelopes) of large buildings. This has become an area of increasing interest, as the General Services Administration continues to seek the most cost-effective ways of reducing energy use, and of ensuring both the initial quality and long-term durability of federal buildings.

Purpose & Scope of the Project

To explore the potential benefits and probable limitations of thermal imaging for these purposes, the Office of the Chief Architect of the Public Buildings Service of the U.S. General Services Administration commissioned a pilot study of thermographic imaging and analysis, to be performed on five GSA owned buildings in the Denver Federal District, during the winter.

Procedures & Tasks

The procedures to use and the tasks to complete during this pilot study included:

1. Working ***entirely from the exterior*** of the target buildings, detect and quantify to the maximum extent possible the locations and/or sources of heat loss, moisture infiltration/migration, and air infiltration/exfiltration. Accomplish this by using five (5) federal buildings in Denver as examples, while they are operating under winter conditions.
2. Provide suggestions for a practical protocol for thermographic inspection of building envelopes from the exterior alone, without the ability to enter the buildings to locate and identify the sources of thermal anomalies, nor to adjust building air pressures with the HVAC system to test for air leakage, nor to use water spray racks to test for water intrusion.
3. To follow-up on issues noted during tasks 1 and 2, make a return visit to the site to take additional thermographic images or perform other forms of inspection, implementing processes recommended in item 2 above. Revise the suggested protocol and the recommended scope of work based upon this further testing.

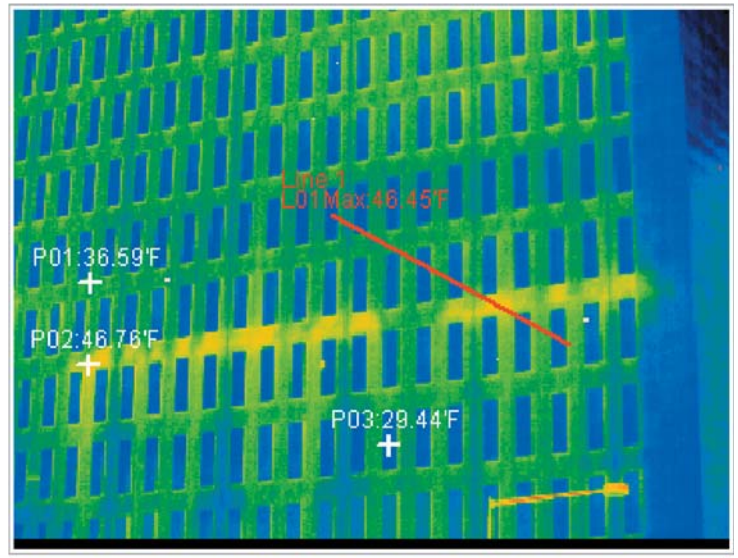
Deliverables

1. Summarize the findings from the tasks above in a 20-page white paper summary report. Present that white paper in person to the GSA project manager.

3. Develop a draft scope of work for performing relevant and useful thermal imaging inspection and analysis of exterior envelopes in other GSA buildings.

Section 2

Infrared Thermography



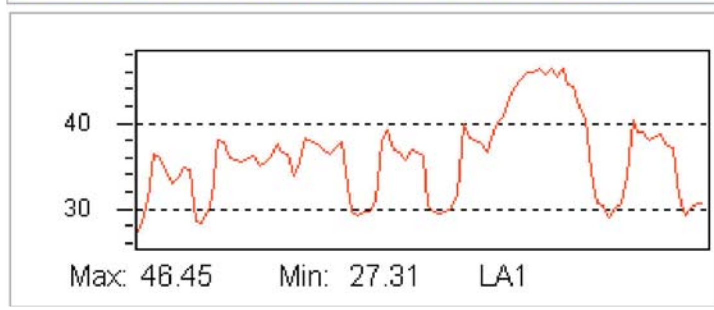


Fig. 1 Thermal Infrared Images

Images generated in grayscale can be false-colored to highlight relevant features as seen above. The patterns are the most useful information for building envelope analysis. But each pixel in the image is also radiometric. That is to say it can show the apparent surface temperature at that point in the image, allowing estimates of the severity of a problem.

THERMOGRAPHIC ANALYSIS

All objects which have a surface temperature above absolute zero (-273°C or -460°F) emit electromagnetic energy in the "thermal infrared" wave lengths–those between 7 and 14 microns. This energy can be sensed by microbolometers–instruments which measure very small amounts of heat. When a microbolometer is covered by a lens which passes infrared waves while excluding visible light waves, the instrument can measure the intensity of the incoming infrared energy. The strength of the signal from the microbolometer is proportional to the temperature of the surface that is within the line of sight and within the field of view of the lens.

This is the basic principle of the hand-held, non-contact surface temperature thermometer shown in figure 2. Such instruments measure the infrared energy being emitted from a nearby surface, and then they interpret and display that energy level as a surface temperature measurement.

A thermal infrared *camera* uses an array of thousands of these sensors not only to measure surface temperatures, but also to form a complete image based on the intensity of the infrared energy being emitted from thousands of points. The non-contact thermometer seen in figure 2 has a single sensor. The "focal plane array" contained in the infrared camera seen in figure 3 has 76,800 sensors arranged in a rectangle, with 320 sensors across and 240 sensors top to bottom. That array allows formation of the images seen in figure 1.

Fig. 2
Single-sensor Infrared Thermometer
Low-cost handheld non-contact thermometers measure the infrared emissions from a surface to make an estimate of the surface temperature. They have a single sensor, which averages all the surface temperatures within it's field of view to display a single measurement.

Fig. 3 Infrared Camera - Focal Plane Array with 76,800 Sensors
Cameras have tens of thousands of individual IR temperature sensors, allowing them to form a complete image based on the intensities measured at thousands of points on a surface.

The grayscale image seen in figure 1 is "radiometric," which means that each pixel in the image carries temperature information. This information can be accessed through software and displayed, as seen in the color image in figure 1.

That image is seen in color, even though the camera really only measures the intensity of infrared energy, which is not visible to humans and therefore has no real color at all. To generate what will become the false-color IR image seen in figure 1, the infrared intensity signals from the 76,800 sensors are divided into 256 temperature ranges. These are represented initially by 256 levels of gray. Pure white represents the warmest of the 256 temperature divisions in the image, and pure black represents the coldest. Then software can assign each of those 256 levels of gray to a different color. These color assignments are sometimes changed by the thermographer, who may prefer different false-color palettes to highlight features which might be latent, that is to say, hidden within the grayscale image.

Examples of the same image displayed with different false-color palettes are shown in figure 4. The underlying temperature data (The grayscale data) is the same in all images. Only the false-color palette has been changed.

To further assist the analysis, software can hide–or highlight –several of the 256 temperature ranges within the image. This software feature–so useful to the professional–can often be confusing and annoying to the layperson viewing the image. An example is seen in figure 5. At left is the original image, which is not especially informative to any viewer. At right is the adjusted image—the same basic image, but shown with part of its temperature range hidden, so that features latent in the image become more obvious.

This process of false-coloring and image adjustment seems at first to be a deception. And in fact, image adjustments can certainly be used to deceive or exaggerate, or to entirely hide "the truth." But in the hands of a capable and responsible thermographer–one who understands not only the camera, its software and the object being examined and who takes the time to document the thermal environment–image adjustment is a normal and essential part of the inspection and reporting process.

One can think of the image editing and reporting process as similar to editing a very wordy draft manuscript. The final document will contain fewer words, but will also convey more information in a shorter amount of time.

In the same way, editing an infrared image may remove or transform visual *data*, but those adjustments may well provide a greater amount of visual *information* which is more directly relevant to the questions being discussed in the report.

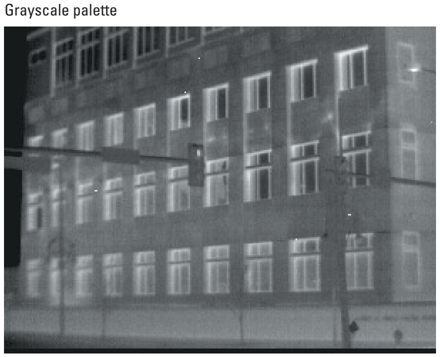
Five key facts about infrared thermography

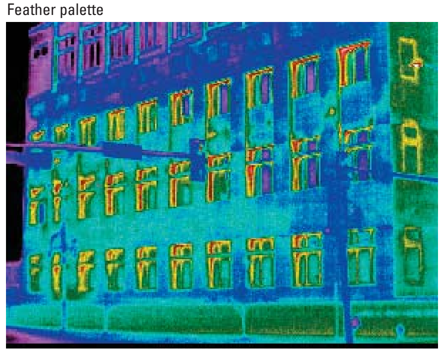
Infrared images selected to illustrate a specific point of view are usually very compelling. At the same time, randomly-selected unenhanced images from the same project may be entirely confusing. To avoid drawing false conclusions from images, it's helpful to keep five points in mind.

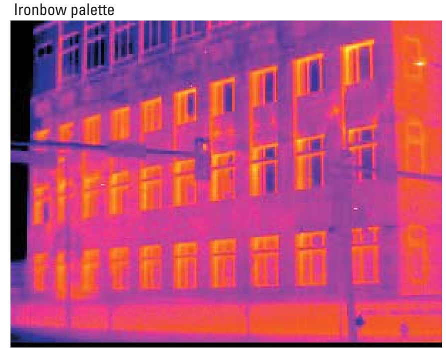
1. Infrared images show only surface temperature patterns.

Often, infrared images "look like x-ray photos." It looks like cameras can see into walls. But that's not true. They can't see into walls or into anything else. Thermal infrared cameras only show surface temperature patterns. They measure the infrared energy being emitted and reflected *from a surface*, and display that energy as an image. So there's no possibility of a more expensive camera "seeing deeper" into a wall or roof. Anything one sees in the image, no matter how much it looks like a feature buried in a wall, is only the surface temperature effect of that hidden feature. One can't really "see the studs and the missing insulation," one can only see the thermal effect that those features have on the surface temperatures of that wall.

Fig. 4
False-color palettes
The basic thermal sensor data divides all of the temperatures seen by the camera into 256 ranges. Then these temperature ranges can be represented as 256 levels of gray, or can be represented by different colors to distinguish more clearly between the different temperature ranges in the image.

Grayscale palette


Feather palette


Ironbow palette


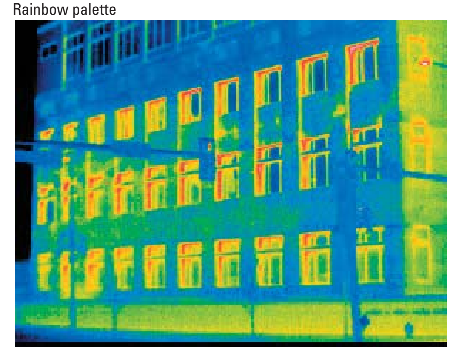
Rainbow palette


Fig. 5

Raw vs. adjusted images

The visual information latent in these image can be vast, even though it's initial appearance may not be especially informative. The thermographer adjusts the image by editing-out parts of the temperature range shown in the image, or shifts the visible image up or down in the original temperature range to highlight the features of greatest interest.

Original, raw image

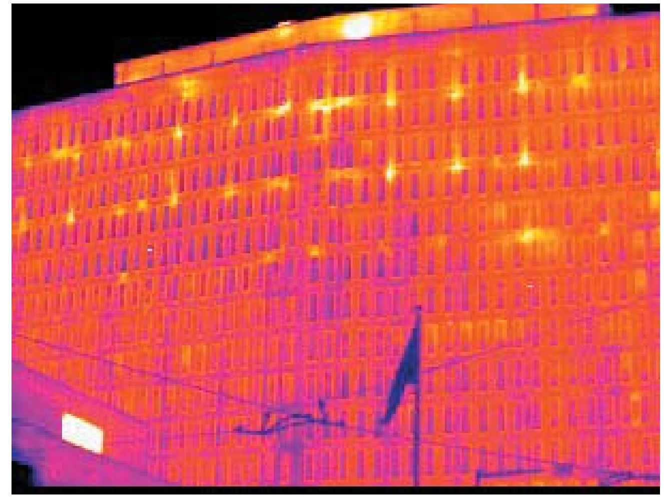


Image adjusted by the thermographer, narrowing the range of temperatures displayed.

2. Precisely accurate infrared surface temperature measurements are unlikely outside of the laboratory. But IR cameras provide a helpful " big picture" overview of the situation.

Infrared energy recorded in the image is the sum of the emitted and reflected energy from the surface. So precise temperature measurements are unlikely without precise knowledge of the emissivity of the surface and the temperatures of any objects that show up as reflected images from that surface.

Consider two examples. First, a rough asphalt street surface is an excellent emitter of infrared energy. So its surface temperatures as measured by an infrared camera are likely to be fairly close to the true values (perhaps within 3 to 5°F at normal ambient temperatures). But then consider glass, which is a *poor* emitter and at the same time an excellent *reflector* of infrared energy. The temperatures measured from glass surfaces are likely to be well below the true temperatures. The low emissivity of the glass under represents the energy in the material—not much of the energy is emitted, so the measurement underestimates the true temperature. Obtaining accurate IR temperature measurements from glass is further complicated by the reflected infrared energy from nearby sources. The energy (the temperature) being seen on a glass surface may be more indicative of the temperature of the reflected object rather than the temperature of the glass itself.

On the other hand, the infrared camera provides a very precise measurement of the temperature differences *between adjacent pixels in the image*–it can distinguish and display temperature differences of less than 0.2°F. So the image is an excellent indicator of *surface temperature differences*, but is rarely an accurate indicator of the actual, absolute temperatures. Users can rely on IR images for pattern analysis, but should not automatically assume the images are accurate for precise values of temperature.

The fact that most cameras and IR software display the surface temperatures to tenths of a degree Fahrenheit is an unfortunate and confusing factor for the non-expert in IR image analysis. The temperature measurement cannot possibly be as accurate as implied by those decimal places, except under highly-controlled laboratory situations. The viewer must keep in mind that the values shown are only that accurate as measurements of *temperature differences between* *adjacent pixels* in the same image, and then only as long as that part of the image is showing the same material (the same emissivity and reflectivity). Otherwise, at normal ambient temperatures one can assume that the temperatures shown are only within ±3 to 5°F of the true values on dark, rough, highly emissive surfaces, but highly inaccurate on smooth surfaces with low emissivity (anywhere from ±20° to ±300° or more, depending on the range of temperatures and the nature of the surface in question).

The bottom line is that on non-reflective surfaces, the viewer can rely on the patterns to be accurate, and the cameras can display very small temperature differences. So they are best used to see "the big picture" of the thermal situation—a capability that is unparalleled by any other technology.

3. Images require interpretation, and two opinions are often better than one.

The images generated by infrared cameras are very attractive and interesting and they present an impressively technical appearance. But by themselves, they are not useful.

To become useful, all the thermal factors associated with the image must be known and documented, and a person who understands both the camera and the object being analyzed must interpret the image. Before that happens the image is just data–a pretty picture–rather than valuable information.

In most cases, the thermographer–the person who understands the camera–is not an expert in the complexities of the object being examined. He or she may be able to state that the thermal pattern is anomalous–that it does not appear normal, based on his observations compared to the appearance of similar objects. A second person is usually helpful–one who understands the probable implications of that pattern, because he or she understands the normal hygrothermal behavior of the object in question. So, like detectives investigating a complex crime, two heads are often better than one in analyzing an infrared image.

4. Reliable conclusions require validation from other tools.

No matter how compelling the image, it is not conclusive evidence of anything other than surface temperature patterns. Before one takes action, it is wise to validate the suspicions created by infrared analysis using other inspection tools and techniques.

For example, excess moisture indoors usually shows moist material as darker (cooler) than dry material, because as the moisture evaporates it takes heat from that material, lowering its surface temperature. On the other hand, with air conditioning operating, cold supply air leaking out of ducts above ceilings or behind walls can cool those same surfaces, creating temperature patterns which also look like an effect of excess moisture. The only way to be certain whether moisture is excessive is to measure moisture content with a moisture meter–a different and more quantitative and conclusive tool for that purpose.

The same is true for air infiltration or air leaking outwards through a building envelope. The thermal image may suggest that air is leaking and may also suggest the locations of greatest leakage. But to be certain of the *amount* of the leakage one must either use a tracer gas test, or pressurize the building and measure the amount of air needed to maintain that pressure.

Thermal imaging can both suggest and locate a potential problem. But by itself, infrared imaging cannot conclusively confirm the nature of that problem, nor can it quantify the energy effect of that problem in absolute terms.

5. Infrared images usually provide helpful answers to initial questions. But in turn, these answers often raise more difficult and complex questions.

For example, if the outdoor face of the building envelope shows warm temperatures in cold weather, one can conclude that the envelope is leaking heat. And if the warm temperature pattern is even and consistent across the whole wall, one can further conclude that the building is not well-insulated. Or if the warm pattern is restricted to one narrow vertical panel, then one could reasonably conclude that the building is missing some insulation in that location.

But how *much* heat is leaking is a different and more difficult question, and *what to do about that heat leakage* is an even more complex question, because alternative solutions may need quantitative cost-benefit analyses. Infrared imaging analysis does not by itself answer these questions, although it can be a helpful first step in deciding whether such problems exist, and whether they are "big" problems" or "small" problems.

Another example is a thermal image which simply shows a pattern on the exterior of the building which is not explained by any obvious or common problem. The pattern is simply "anomalous"–it is not consistent with the thermal circumstances in the local environment. To answer the question of *why* such a pattern exists, it will be necessary to look inside the building at the same location, understand the design and layout of the HVAC system as well as the building wiring at that location, and perhaps to drill holes into the wall or remove the interior finish. One simple answer–that the thermal behavior is not consistent with usual building behavior–raises other more complex questions which can only be answered by looking more deeply into the physical structure of the building and its systems.

Building envelope thermography

At present, there is no comprehensive, practical and definitive standard protocol for inspecting building envelopes from the exterior using thermal cameras. But there are two established international standards that deal with parts of this task: ASTM C 1060 - 90 and European Standard EN 13187:1999.

These documents are helpful in describing the fundamental variables which affect the inspection of buildings using thermal cameras, and in suggesting which variables should be recorded to ensure that the images are documented well enough that similar experts can reach similar conclusions about what the images show. But these two standards also have significant shortcomings with respect to GSA's goal of developing a practical and affordable exterior-only inspection protocol which addresses a broad variety of envelope issues for large buildings.

ASTM C 1060 - 90 (reapproved 1997)

Published by ASTM International of Philadelphia, PA, the title of this standard is helpful in understanding its strengths and limitations: "Standard Practice for Thermographic Inspections of Insulation Installations in Envelope Cavities of Frame Buildings." The document originated 20 years ago, produced by ASTM committee C-16: Thermal Insulation. The current edition was produced in 1990, and was reapproved with only editorial changes in 1997–nine years ago in May. It is:

- Focused on stud-frame walls rather than stone veneer, masonry, brick or EIFS or roofs.
- Aimed at detecting insulation voids, and silent on the subjects of moisture accumulation and air infiltration.
- Overly restrictive with respect to both the realities of GSA inspections and the capabilities of current cameras, asking for a minimum temperature difference across the wall of 10°C (18°F) for a period of four (4) hours before the test, a wind speed under 15 mph and a dry exterior surface.

On the other hand this standard makes some excellent basic points about the nature of credible documentation for thermographic inspections. In particular the need for documenting the geographic location of the building and the image with respect to climate, season and the points of the compass, the current weather and cloud cover, the indoor and outdoor temperatures, wind speed, date and time, the basic construction of the building and the camera used to capture the image. Consequently, ASTM C 1060 provides a useful introduction to the variables which can affect infrared investigations of building envelopes.

European Standard EN 13187 : 1998

Also known as DIN EN 13187 (German standard) and ISO 6781 : 1981 (modified) this document is titled: "Qualitative Detection of Thermal Irregularities in Building Envelopes - Infrared Method."

It is published by the International Organization for Standards (ISO) located in Geneva, Switzerland and is maintained by Technical Committee CEC/TC 89: "Thermal Performance of Buildings." The title of this standard and its supervising technical committee shows that its scope is much broader than ASTM document, because it includes inspection for air infiltration and moisture accumulation. The standard is also more demanding about documentation, requiring for example; recording of air pressures at each storey of the building, the amount of solar radiation during the 12 hours before the test and the air temperatures over the 24 hours preceding the test.

While this standard is much more comprehensive and therefore in many ways more helpful than the ASTM document, it is:

- Focused on Northern European conditions, in particular those of Scandinavian countries, and does not adequately address the needs of warm and mixed-climate inspections.
- Very demanding of steady state conditions before and during the test, e.g.: it asks for 12 hours without direct solar radiation on the building prior to test, no solar radiation on the building during the test and a maximum variation of 5°C in the outdoor air temperature during the period of the investigation.
- Intolerant of investigations that have not been preceded by detailed examination of construction documents and as-built drawings.
- Insistent on estimation of emissivity for all materials and on calculation of "variations in apparent radiance temperatures" across the images.
- Insistent upon generation of a known air pressure difference across the building envelope when air leakage investigation is desired.

Even with those limitations–impractical for GSA purposes–this document provides a better foundation for what GSA intends than the ASTM standard. The draft protocol has been developed with the useful aspects of the European protocol in mind.

- End of Section 2 -

Denver Federal District Thermography

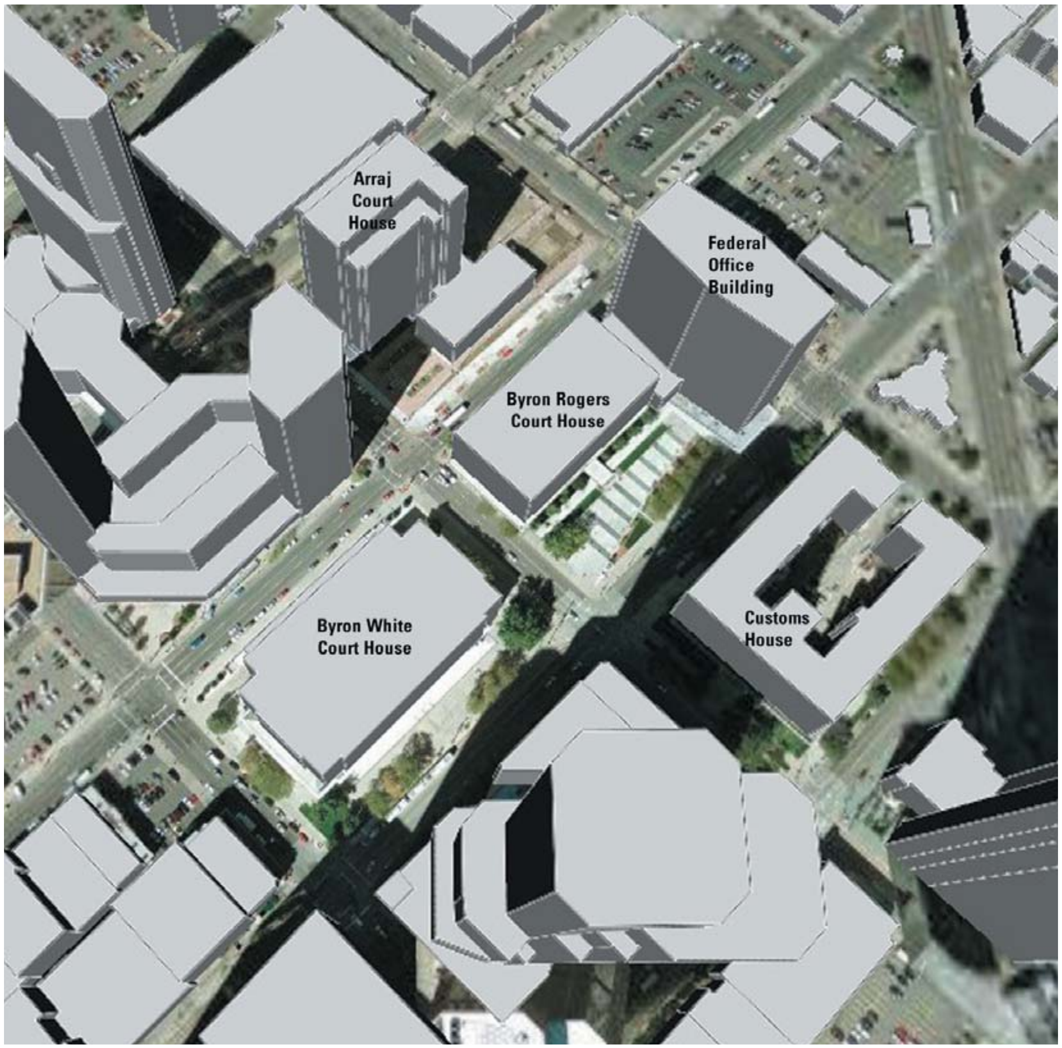


Fig. 1 Denver Federal District

Images edited from originals produced by Google Earth. Note the angle of the images has been adjusted such that north is vertical, in it's familiar position.

PILOT PROJECT

The pilot investigation was performed in Denver, Colorado between Wednesday the 8th of March and Tuesday the 14th of March, 2006. The timing–highly compressed from the perspectives of both contracting and preparation–was based on the strong desire of GSA personnel to complete the inspection during a winter month. The logic of this requirement is sound from a thermal perspective, in that cold temperatures will be most extreme during winter and therefore images will be more likely to clearly show several types of problems.

What went well

It is difficult to imagine a more ideal set of circumstances for infrared inspection than the weather, the city geography and the local support in Denver during our initial inspection. Among these ideal circumstances were:

Cold temperatures, but not bitter weather

Outdoor temperatures stayed consistently cold for nearly the entire period of the inspections, ranging between 20 and 40°F and rising above 50°F for only a brief period on the first day of the inspection. This allowed a relatively constant temperature difference between indoors and outdoors, so that images taken on one day were likely to be similar to those taken on a different day.

The fact that the temperature did not go below 20°F allowed us to work outdoors for several hours at a time. At colder temperatures, it would have been necessary to take frequent breaks to warm up batteries, equipment and personnel to the point where more productive work could be accomplished.

Overcast sky, without precipitation

Although there was direct sunlight during parts of those seven days, nearly all the inspections could be carried out during the morning before dawn, the evening after sunset, or during overcast daylight conditions. At the same time, there was only light snow, and that only for a few hours during times when there was no need for inspection (Saturday and Sunday nights). This meant there was no strong sunlight or shadow preventing useful inspections, nor was there any confusing thermal effect from rainfall on the buildings.

Strong local liaison and supportive local GSA personnel

The time to prepare for the inspection was very short prior to arriving on-site. Under normal circumstances the infrared inspectors would have been provided with extensive background on the known thermal aspects of the buildings and the goals of the inspections for each building prior to scheduling the site visit. Although preparation was limited due to the urgency of the project, that fact did not measurably affect the results because of our strong local liaison, and the highly supportive local GSA personnel.

In particular, Jodi Thompson our local team liaison was, until two weeks before the inspection the construction project manager for the renovation of the Byron Rogers Court House. She was familiar with great detail concerning the buildings in the Federal District, and is on a first-name basis with many of the key people who know more about the details of buildings other than the Byron Rogers Court House. Without her support and detailed understanding of the site, the inspection and data gathering would have been much more uncertain and incomplete, and far more time-consuming.

Further, the security concerns of the Federal Marshals, the Federal Protective Service and the law enforcement personnel would have made this inspection out of the question on such short notice without the tactful and effective intervention of John Leatherman of the local GSA management staff. His efforts, together with the fact that our local liaison Jodi Thompson was well-known and trusted by the various security organizations, made it possible for us to work.

Nearby hotel accommodations

Thermographic inspection is best accomplished before dawn and after sunset. The nearby hotel accommodations (one block away from the edge of the federal district) made it practical to move to and from the site and the "office location" very quickly and easily without cars, parking and traffic, which reduced wasted time and improved the quantity and quality of the results.

Google Earth images of Federal District 3-D geography

The thermal environment of the exterior of buildings is largely controlled by sunlight, and by the shadows and reflections from the buildings and vegetation surrounding the target buildings. Setty and Associates made certain to obtain Google Earth images to gain an understanding of the buildings in and around the Denver Federal District. This made it possible to plan some of the thermography ahead of arriving on site, which saved time and made the process more certain. We knew ahead of time how the buildings were oriented with respect to each other, and with respect to north, south, east and west, and with respect to both tall and short surrounding buildings.

Google Earth images are available for many major downtown areas, but not for all locations where GSA buildings are built. The availability of these images was very fortunate, and should probably be made a standard part of planning future GSA thermographic inspections. On the other hand, where 3-D neighborhood are not available, much more pre-planning documentation will be essential before scheduling a site visit.

Clear line-of-sight to full height of target buildings

In urban environments, it is unusual to have a clear, unobstructed line of sight to all faces and to the full heights of the target buildings. The Denver Federal District is exceptionally well-suited to efficient thermographic inspection compared to most downtown environments. When buildings are obscured by others, or by trees and dense shrubbery, inspection can be difficult or entirely impractical from the exterior.

Comparing the pilot project to future inspections

The Denver circumstances were ideal–other inspections are not usually so free from complications which can increase costs and reduce the certainty of results. This fact is useful to keep in mind when developing inspection protocols, and when making assumptions about what can be achieved with exterior thermography alone.

Difficulties encountered & solutions

No significant difficulties were encountered that were not removed by ad-hoc but effective solutions. But for another time, when such ad-hoc solutions may not be available, it is worth noting the potential difficulties encountered during this inspection.

Security clearance for inspectors

This item cannot be overemphasized. The Denver Federal District contains four buildings with courts and a high-rise building containing law enforcement offices. Undocumented personnel pointing unknown apparatus at federal buildings in which judges receive daily death threats is simply not acceptable to federal law enforcement organizations, even from public streets.

From the perspective of local GSA personnel this inspection, while much-desired, was nearly impossible to accommodate. Local GSA staff does not have the "political capital" necessary to adjust–even temporarily–the security concerns of the many and overlapping security organizations which protect a federal district. This time it worked, for the reasons described above. But the ad-hoc, personnel-and-personality-dependent solution that worked in this case will not be a successful model for future infrared inspections.

As a practical matter, infrared inspectors will need badges, issued on a national level, before any future inspection is planned and scheduled. Otherwise in many cases the time and expense of travel will simply be wasted, because no actual inspection will allowed by local security procedures.

Work plans based on understanding of the thermal behavior of the target buildings

Thermographic inspections are searches for anomalies–patterns which are not "normal" for the target buildings. Understanding in advance what is likely to be normal for the buildings is usually the first step in planning a thermographic inspection. Otherwise, much time can be wasted in speculating about the origin of thermal patterns which appear to be problems to the inspector, but which are actually perfectly normal because of thermal activity inside the building, or which are already well-understood problems.

In this inspection the presence of Jodi Thompson, familiar over several years with the Byron Rogers Court House, made it possible to understand than one "problem" was in fact the location of a unit heater. Also, her understanding of the building also reinforced our suspicion that other patterns which look like problems are not, in fact explained by any aspect of building operations and construction with which she was familiar. Similarly Kevin Welch, one of Jodi's colleagues in project management was able to explain the nature of the current re-caulking operation in progress on the Federal Office Building, helping our understanding of thermal patterns around windows in that building.

The point is that without Jodi and her many colleagues, we would have wasted time speculating in the absence of factual data, and so would the viewers of our report.

Future inspections can be more effective when somebody like Jodi, or Kevin, who has a good understanding of the target building, is consulted *before* the thermography work plan is developed. In this case, we did not have a problem with the fact that little such information was available before arriving on-site. Without those personal experiences, the lack of construction documentation could have been quite a significant problem.

DENVER FEDERAL DISTRICT

The Federal District is located on four city blocks in downtown Denver which are oriented largely Northeast-Southwest. Aerial photos and 3-D sketches of the district and its buildings have been modified from Google Earth images, and are shown on earlier pages as figure 1. These provide the reader with a useful overview, which will be help in understanding both the inspection process and the thermal images which form our reports on the individual buildings.

Inspection location numbers

The reader will note that there are locations denoted by numbers on both the site plans and with the thermal images from each building. The logic of these numbers is based on the fact that a uniform "location terminology" is very important to developing a universal inspection protocol for GSA buildings.

In the northern hemisphere, the northern exposure of a building is the most free from direct solar influence. Also, navigational convention assumes that north is the beginning of the 360° of compass orientation. So our numbering system assumes eight basic locations, one on each face of a building, and one at each corner, beginning with the face or corner is most nearly facing north.

In the case of the federal district, in which the city blocks are oriented northeast and southwest, location 1 is always at a corner, the one which faces nearly north.

Because this numbering system is consistent with clockwise compass directions, the reader will always know in the future that an image taken at or near "location 1" will be the face or corner of the building which faces north, along with all the information that this fact implies, e.g.: it is mostly in shade all day long and rarely receives direct sunlight. In this way, the numbering convention itself conveys useful information about the building: how it might best be inspected, and the thermal influences inherent in the images taken from that location at different times of the day and during different seasons of the year.

Buildings Inspected

Five (5) buildings were inspected, each of which is discussed in more detail in the coming pages, along with thermal images illustrating interesting aspects of these five quite different building enclosures:

- Byron White Federal Courthouse (BWCH)
- Byron Rogers Federal Courthouse (BRCH)
- Byron Rogers Federal Office Building (FOB)
- Arraj Federal Court House (Arraj)
- Customs House Office Building (Customs)

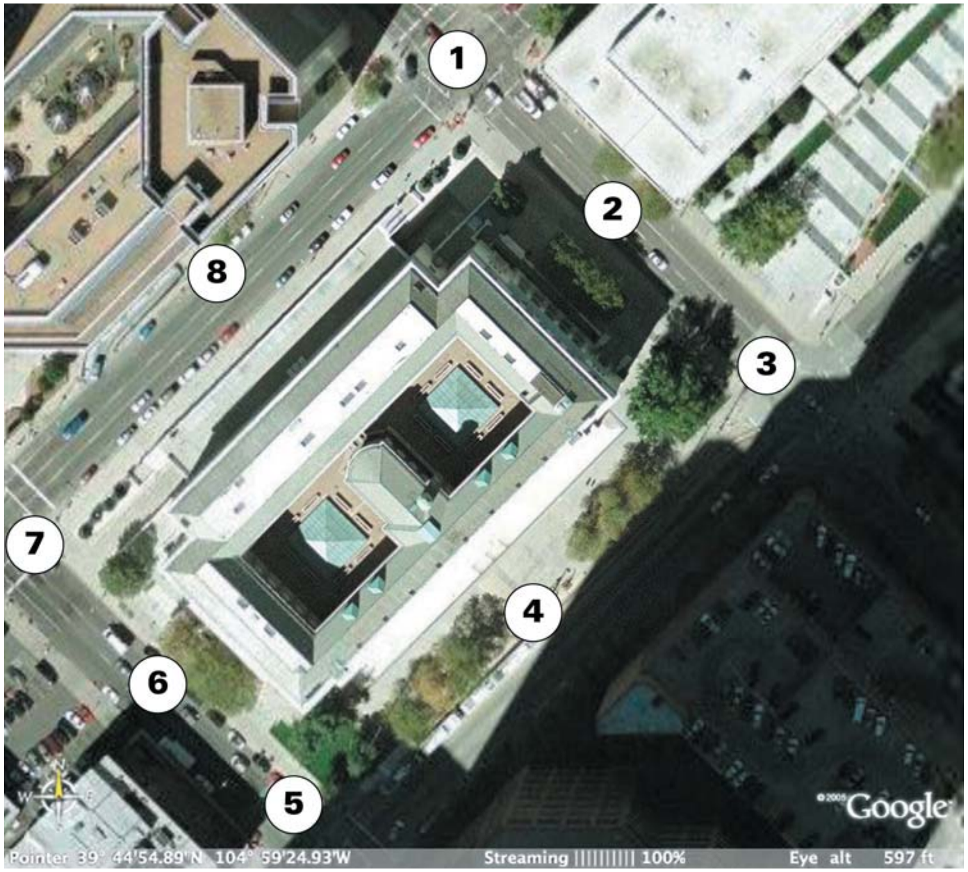


Fig. 2 Byron White Site Plan
The circled numbers indicate the basic positions from which the thermographic images were taken.

Fig. 3 Byron White Court House seen from location #5

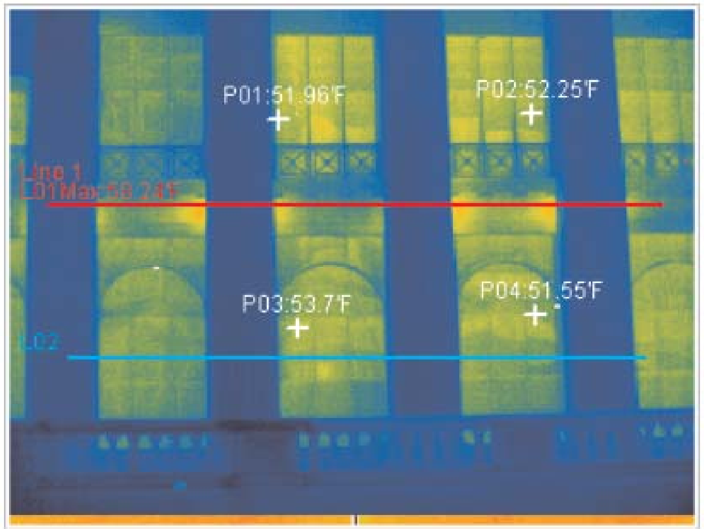
Byron White Federal Courthouse (BWCH)

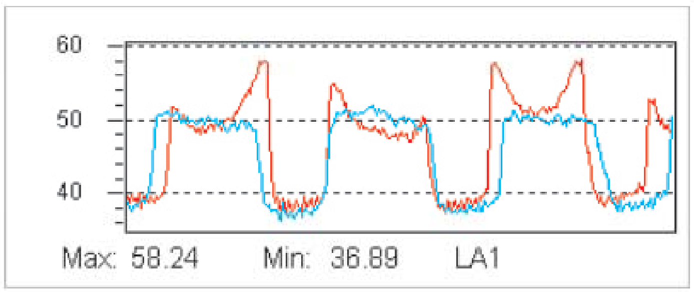
Figure 2 shows the plot plan of the BWCH, and figure 3 shows a visual image of the building taken from location 5. A basic description includes the facts that:

1. The original building was built in 1916. It is 5 stories high, and contains approximately 270,000 gross square feet of space.
2. Its envelope consists of exterior marble over red brick, with an interior finish of plaster on lath over that brick. Whether the exterior envelope includes any insulation has not been established as of the date of this report.
2. The HVAC System consists of perimeter induction units supplied from a single fan; multizone units supplying interior areas and dedicated air handling units for special areas. Boiler and water-cooled chiller plants located in the BWCH supply heating and cooling for both this building and the Customs House. The systems are controlled by a DDC building automation system.

Thermographic observations and discussion

The exterior of the BWCH shows a thermal pattern consistent with a lack of insulation, a minimum of air leakage and much more heat leakage from windows than through the exterior walls.





Project Location:	**Denver Federal District**
Building:	**Byron White Court House (BWCH)**
View:	**Location 8**
Weather:	**Partly Sunny** **54°F db / 23°F dpt** **Light Wind/ NE**
Comments:	
Thermographer:	**Bret Monroe**

Fig. 4

Byron White - Location 8

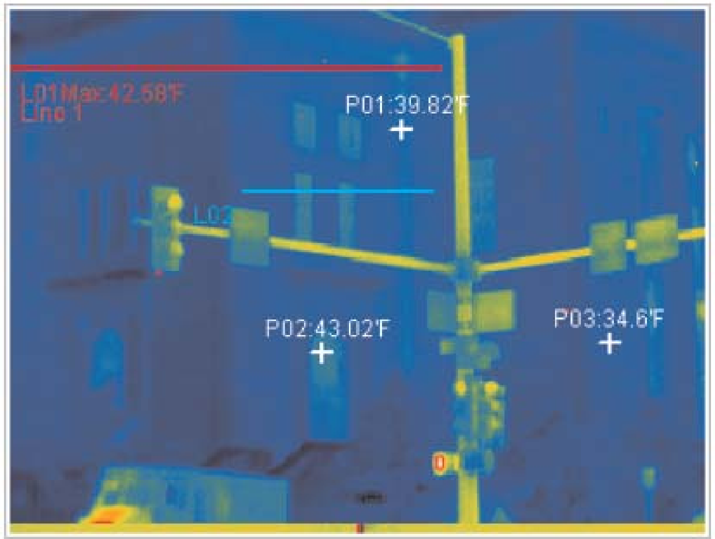
The image shows the relatively high temperatures of the exterior wall (±58°F in some locations) at a time when the columns remain well below 40°F, suggesting a significant heat loss though the walls and windows of the building.

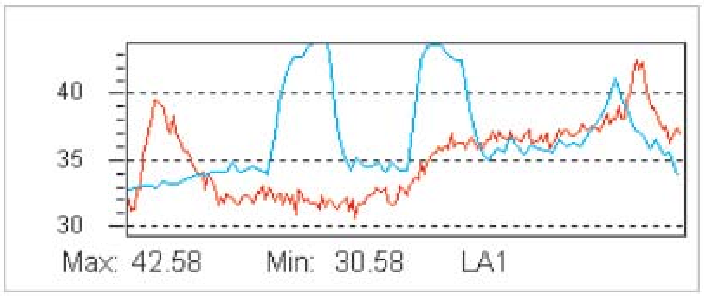
IR Info	Value
Date	2006-3-9
Time	15:43:34
Label	**Value**
P01:Temp	51.96
P01:ems	0.95
P02:Temp	52.25
P02:ems	0.95
P03:Temp	53.7
P03:ems	0.95
P04:Temp	51.55
P04:ems	0.95
L01:Max	58.24
L01:Min	36.89
L01:Avg	46.91
L02:Max	52.34
L02:Min	36.09
L02:Avg	45.53

Fig. 5

Byron White - Location 1

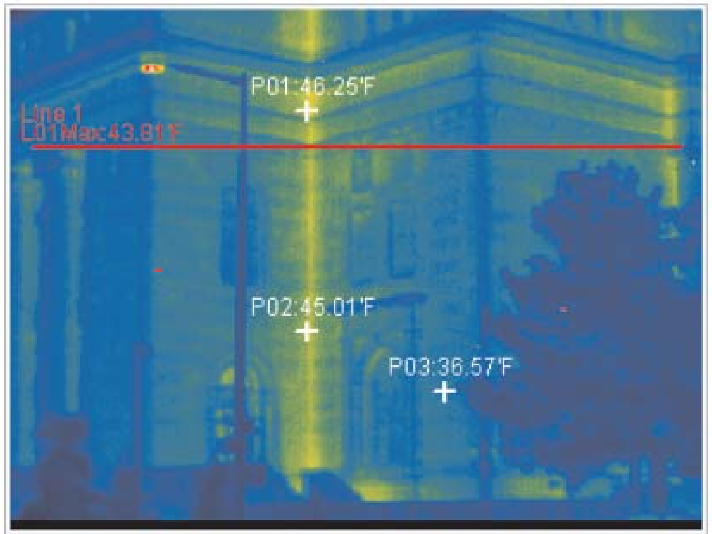
Note the warm temperature in the inside corner of the building. This pattern is repeated on all four sides of the building at all outdoor temperatures, suggesting a greater heat loss from these corners than from the balance of the exterior walls.

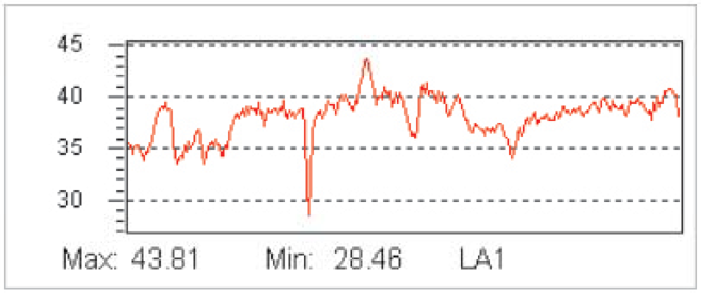




Project Location:	**Denver Federal District**
Building:	**Byron White Court House (BWCH)**
View:	**Location 1**
Weather:	**Partly Sunny** **54°F db / 23°F dpt** **Light Wind/ NE**
Comments:	
Thermographer:	**Bret Monroe**

IR Info	Value
Date	2006-3-9
Time	15:33:32
Label	**Value**
P01:Temp	39.82
P01:ems	0.95
P02:Temp	43.02
P02:ems	0.95
P03:Temp	34.6
P03:ems	0.95
L01:Max	42.58
L01:Min	30.58
L01:Avg	35.17
L02:Max	44.59
L02:Min	32.86
L02:Avg	36.92





Project Location:	**Denver Federal District**
Building:	**Byron White Court House (BWCH)**
View:	**Location 7**
Weather:	**Overcast** **32°F db / 16°F dpt** **Light Wind/ NE**
Comments:	
Thermographer:	**Bret Monroe**

IR Info	Value
Date	2006-3-10
Time	7:55:13
Label	**Value**
P01:Temp	46.25
P01:ems	0.95
P02:Temp	45.01
P02:ems	0.95
P03:Temp	36.57
P03:ems	0.95
L01:Max	43.81
L01:Min	28.46
L01:Avg	38.11

Fig. 6

Byron White - Location 7

Again note the warm temperature in the inside corner of the building, as seen under warmer outdoor conditions in figure 5.

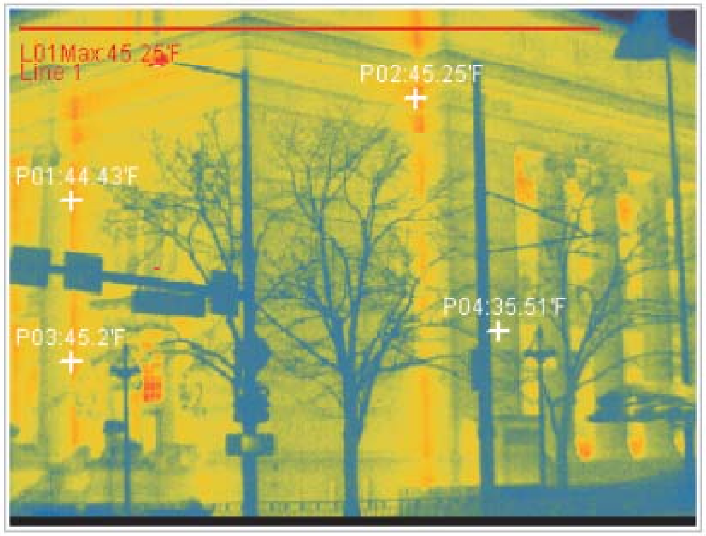
In this case, the corner temperature is 46°F before dawn, when the outdoor temperature is 32°F. The rest of the walls are at roughly 36°, as seen at point 3.

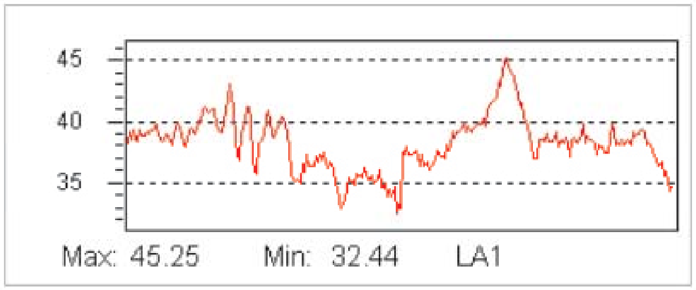
Fig. 7

Byron White - Location 6

In this case, the visual image does not match the angle of the infrared image because the actual visual image was taken too long before dawn to see clearly. This is the view from location 5.

But the infrared image again shows a consistently high heat loss at the inside corners seen from location 6. The corner temperature is ±45° when the wall temperature is ±35°F.





IR Info	Value
Date	2006-3-10
Time	8:8:58
Label	**Value**
P01:Temp	44.43
P01:ems	0.95
P02:Temp	45.25
P02:ems	0.95
P03:Temp	45.2
P03:ems	0.95
P04:Temp	35.51
P04:ems	0.95
L01:Max	45.25
L01:Min	32.44
L01:Avg	38.19

Project Location:	Denver Federal District
Building:	Byron White Court House (BWCH)
View:	Location 5
Weather:	Partly Sunny 34°F db / 15°F dpt Light Wind/ NE
Comments:	
Thermographer:	Bret Monroe

Byron Rogers Federal Court House (BRCH)

Figure 8 shows the plot plan of the BRCH, and figure 9 shows a visual image of the building taken from location 5. A basic description includes the facts that:

1. The building was built in 1965. In May 2003 the building nderwent a major renovation, with substantial completion in December 2005. It is 6 stories high including its mechanical penthouse, and contains approximately 215,000 gross square feet of space.
2. The envelope system consists of precast stone panels with a variety of finishes, over airspace/structural support followed by concrete masonry units with concrete-filled cores and plaster, gypsum board or wood paneling interior.
2. The HVAC System consists of central air handling units serving variable air volume terminal units for overhead air distribution and under-window hot water convection units. Chilled and hot water are supplied from the federal office building. The systems are controlled by a DDC building automation system.

This building presents many thermal patterns which remain puzzling, in spite of the fact that the project manager for the renovation–Jodi Thompson–was very helpful in providing details of the recent renovation. Two points would seem to be significant and worth keeping in mind during further investigation of this building, and which we suggest amy be useful in understanding the patterns seen in the images on the following pages. These facts are:

1. The renovation added winter humidification to the HVAC system, but no changes were made to the exterior wall insulation, nor was any interior vapor barrier added to keep humid air out of the exterior wall.
2. The budget did not allow for window replacement.

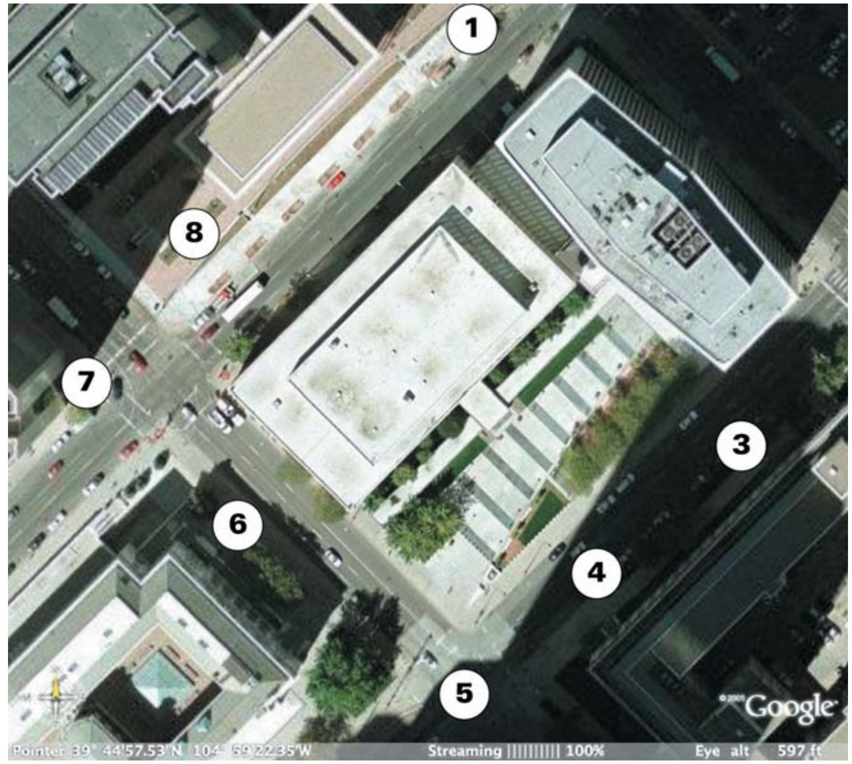


Fig. 9
Byron Rogers site plan

Fig. 9
Byron Rogers - Location 5

Fig. 10

Byron Rogers - Location 6

The striking thermal pattern seen in this image has no obvious cause, but is certainly not normal.

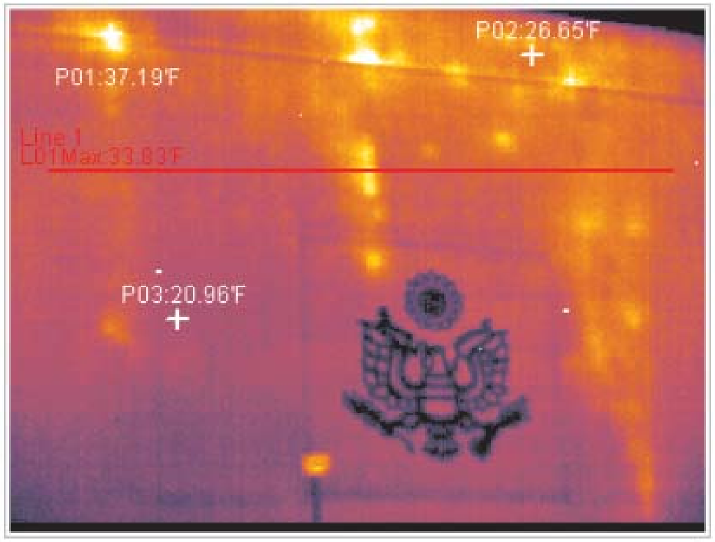
Heat is leaking at a greater rate from light areas, which are considerably warmer than the balance of the wall. Note that point one, in a warm area, shows a temperature of 37° which is 17 degrees warmer than was typical at that time for the rest of the walls, as indicated by the reading at point 3.

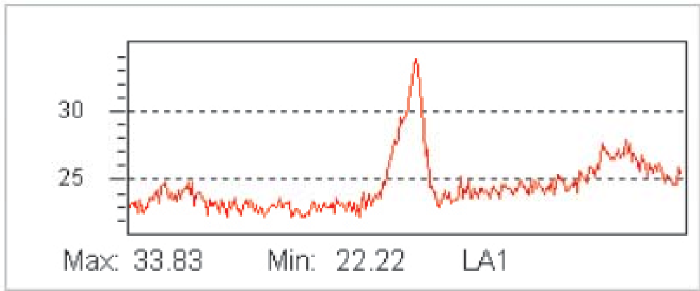
Comments After June 6th, 2006 Inspection

In June, 2006 our team revisited the building and took additional thermal images of this section and others which appeared puzzling under winter conditions.

This pattern was not better-understood after imaging under warm weather conditions. Exterior images taken un June 2006 showed faint traces of these patterns. Unfortunately, in spite of excellent interior access, no internal imaging was possible in this spot, because the interior finish consists of wood paneling. The extra layer formed by the interior paneling made it impossible to gather useful information to explain this pattern from indoors.

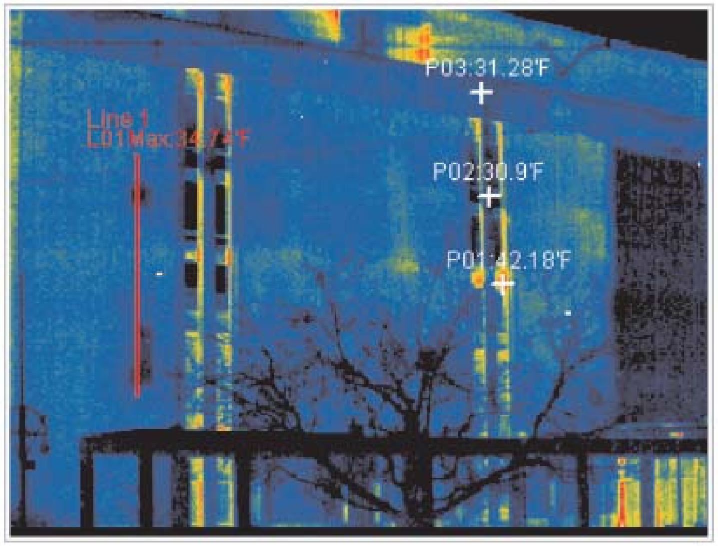
This pattern remains an unexplained anomaly.

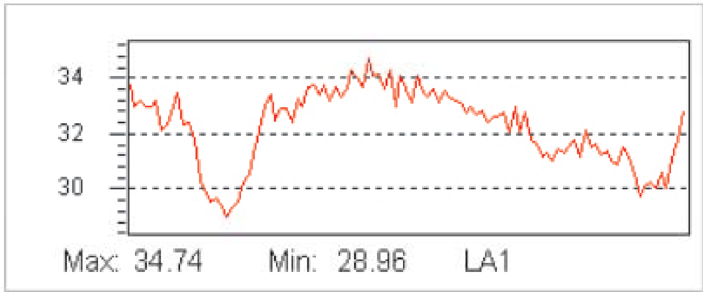




Project Location:	Denver Federal District
Building:	Byron Rogers Court House (BRCH)
View:	Location 6
Weather:	Overcast 26°F db / 22°F dpt Light Wind/ NE
Comments:	
Thermographer:	Bret Monroe

IR Info	Value
Date	2006-3-13
Time	8:10:18
Label	**Value**
P01:Temp	37.19
P01:ems	0.95
P02:Temp	26.65
P02:ems	0.95
P03:Temp	20.96
P03:ems	0.95
L01:Max	33.83
L01:Min	22.22
L01:Avg	24.54





Project Location:	Denver Federal District
Building:	Byron Rogers Court House (BRCH)
View:	Location 4
Weather:	Clear 34°F db / 15°F dpt Light Wind/ NE
Comments:	
Thermographer:	Bret Monroe

IR Info	Value
Date	2006-3-10
Time	8:25:30
Label	**Value**
P01:Temp	42.18
P01:ems	0.95
P02:Temp	30.9
P02:ems	0.95
P03:Temp	31.28
P03:ems	0.95
L01:Max	34.74
L01:Min	28.96
L01:Avg	32.25

Fig. 12

Byron Rogers - Location 5

Around the corner from figure 11 is this similarly unusual thermal pattern.

Heat leaking from the old windows is obvious. But the dark (cool) patterns at the left of the image do not correlate with either panel joints or indoor features known to Jodi Thompson, the renovation project manager.

Comments After June 6th, 2006 Inspection

In the case of this pattern, our inspection in June, performed from the interior, was conclusive. This pattern results from the presence of fire extinguisher boxes set into the wall at locations which correspond exactly to the pattern seen here. Similar patterns are seen in images taken during hot weather conditions.

For reasons not entirely understood, the wall temperature in these loactions lags the thermal change—remaining colder in the winter, and warmer in the summer than the rest of the wall after sunrise and after sundown.

Fig. 13

Byron Rogers - Location 4

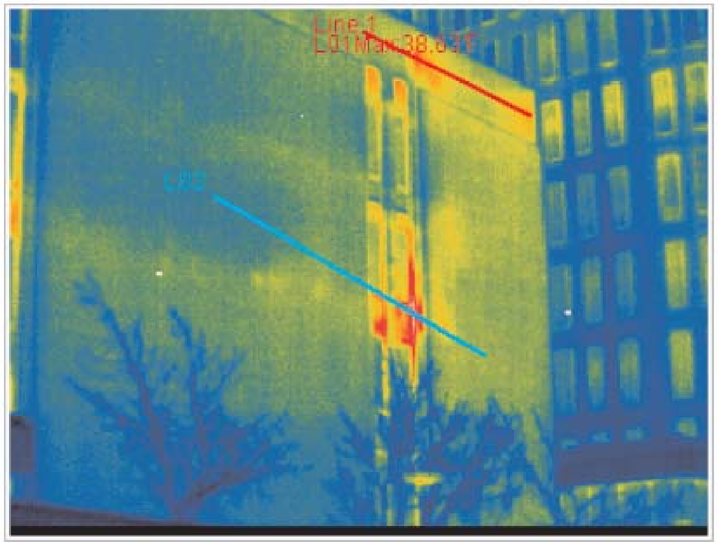
The thermal pattern shown under line 2 may be explained by the fact that at roughly this point in the wall indoors is a unit heater, according to Jodi Thompson.

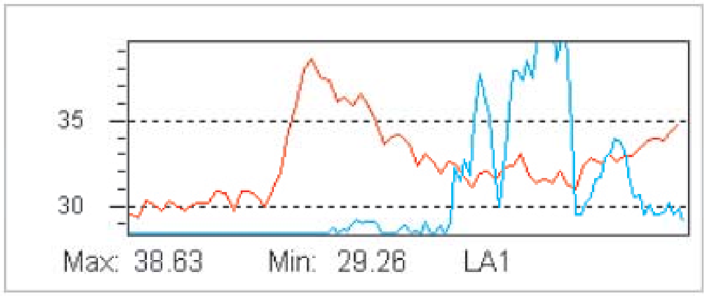
But the heat loss shown under line 1 near the roof line does not have any similarly plausible explanation.

Comments After June 6th, 2006 Inspection

Interior inspection at this location showed that Jodi Thompson's explanation is the most likely cause of the anomaly across line 02. There is indeed a unit heater in that location, and it blows air torads that window, which is covered by an rigid foam insulation panel. That panel was not quite fully pushed into the window cavity, which could and most probably did allow heat to leak out in that location, generating the pattern seen in the winter image.

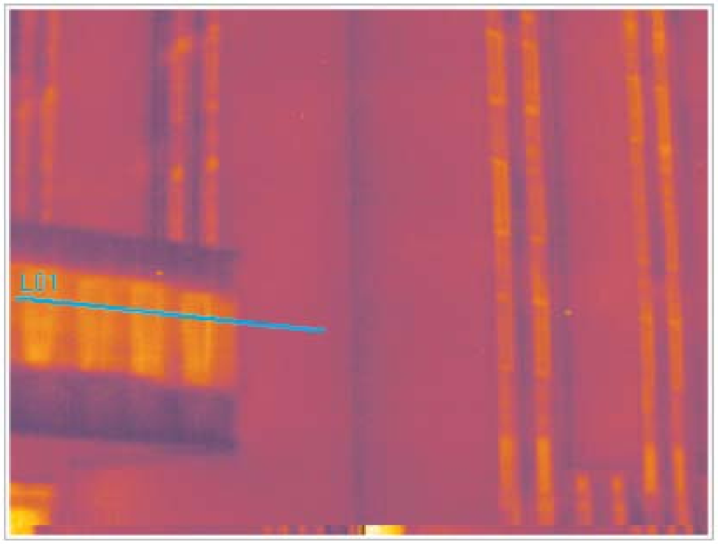
The pattern seen across line 1 was not explained by any condition visible from indoors, nor was that pattern visible from the exterior during June. That pattern remains unexplained.

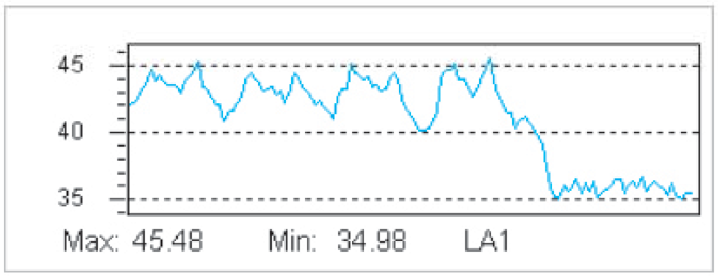


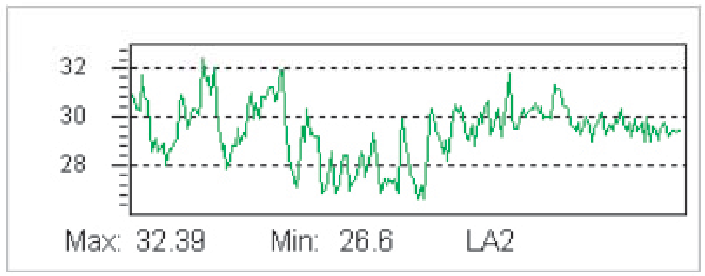


Project Location:	Denver Federal District
Building:	Byron Rogers Court House (BRCH)
View:	Location 4
Weather:	Overcast 26°F db / 22°F dpt Light Wind/ Various
Comments:	
Thermographer:	Bret Monroe

IR Info	Value
Date	2006-3-13
Time	8:33:15
Label	**Value**
L01:Max	38.63
L01:Min	29.26
L01:Avg	32.59
L02:Max	44.53
L02:Min	25.54
L02:Avg	29.97







Project Location:	Denver Federal District	
Building:	Byron Rogers Court House (BRCH)	
View:	Location 1	
Weather:	IR 1= Overcast, 32°F db / 16°F dpt	IR 2= Clear 39°F db/
10° dpt	Light Wind/ NE	No wind
Date/Time:	Fri 3/10/06	Mon
3/13/06	4:15 PM	8:55 PM
Thermographer:	Lew Harriman	

Fig. 14

Byron Rogers - Location 1

The image at left was taken in the afternoon just before the close of the business day, and shows considerable heat loss from the windows of the pedestrian bridge which connects the court house to the office building.

The image at right was taken at about 9:00pm on Monday night, long after the building occupants have left and the HVAC system is being operated in unoccupied mode.

The difference between these two thermal images suggests further examination of the HVAC system effects on heat leakage.

Comments After June 6th, 2006 Inspection

This area was not inspected during the June visit. But Joe Baker, GSA contract employee, noted that offices in the courthouse near this location have been notorious for cold air infiltration during the winter. Reportedly, papers can be lifted off of desk by incoming cold air rushing into the bridge area on its way upwards into the adjoining Federal Office Building.

Such a problem would be consistent with the apparent stack-effect air leakage seen in figures 18 and 19. It would also explain why the bridge area leaks heat during the daytime during winter, but less so after the systems are turned off, after the bridge area cools down via air infiltration.

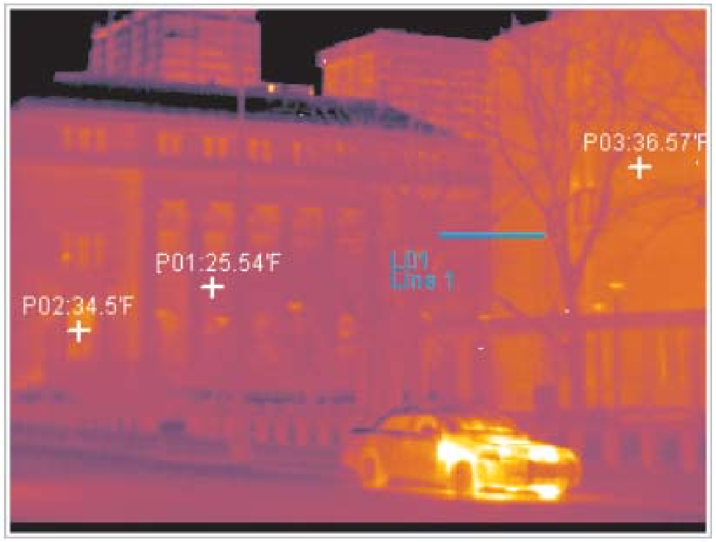
That theory fits the observed data, but further winter investigation from the interior would be required to conclude this is a complete explanation for the patterns seen in these images.

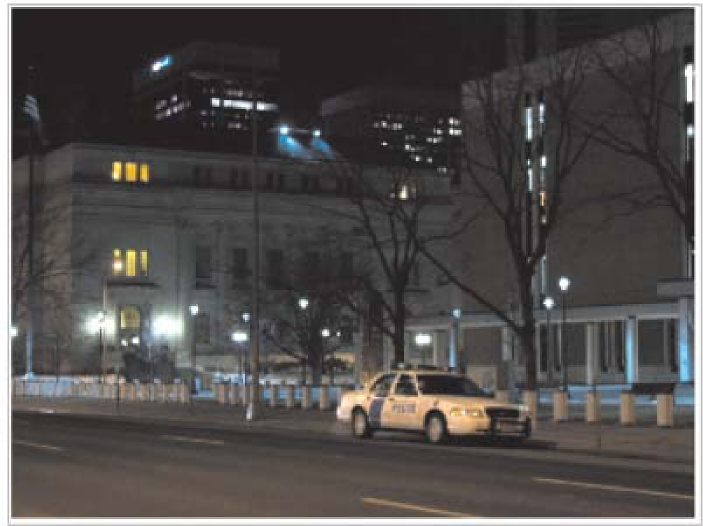
Fig. 15

Byron Rogers - Location 4

This image compares the surface temperatures of the Byron Rogers Court House to those of the neighboring Byron White Court House.

In short, the newer building leaks considerably more heat than the much older building. Compare the temperatures of both buildings by noting the position of line one, and the corresponding temperature graph below the thermal image.





IR Info	Value
Date	2006-3-13
Time	22:46:59
Label	**Value**
P01:Temp	25.54
P01:ems	0.95
P02:Temp	34.5
P02:ems	0.95
P03:Temp	36.57
P03:ems	0.95
L01:Max	34.17
L01:Min	25.44
L01:Avg	29.46

Project Location:	Denver Federal District
Building:	Byron Rogers -vs- Byron White
View:	Location 4
Weather:	Clear 39°F db / 10°F dpt No Wind
Comments:	
Thermographer:	Lew Harriman

Byron Rogers Federal Office Building (FOB)

Figure 16 shows the plot plan of the FOB, and figure 17 shows a visual image of the building taken from location 5. A basic description includes the facts that:

1. The building was built in 1965, at the same time as the adjoining Byron Rogers Court House. It is 18 stories high, and contains approximately 280,000 gross square feet of space. It is scheduled for major renovation in the near term.
2. Its envelope system consists of marble facing over airspace and 18-inches of concrete with plaster interior.
3. The HVAC System consists of perimeter induction units located throughout the perimeter of the building, which use hot water to provide heat to office spaces. Constant volume dual duct mixing boxes served from air handling units located in both the penthouse and the sub-basement also provide heat to office spaces. Additionally, unit heaters provide additional heat at various locations throughout the building. The principal systems are controlled by a DDC building automation system.

The building shows thermal patterns consistent with air leakage due to stack effect, but also shows patterns that will need further investigation, notably a pattern consistent with moisture accumulation in the front of the building, and a more puzzling pattern at the rear of the building between the 6th and 7th floors.

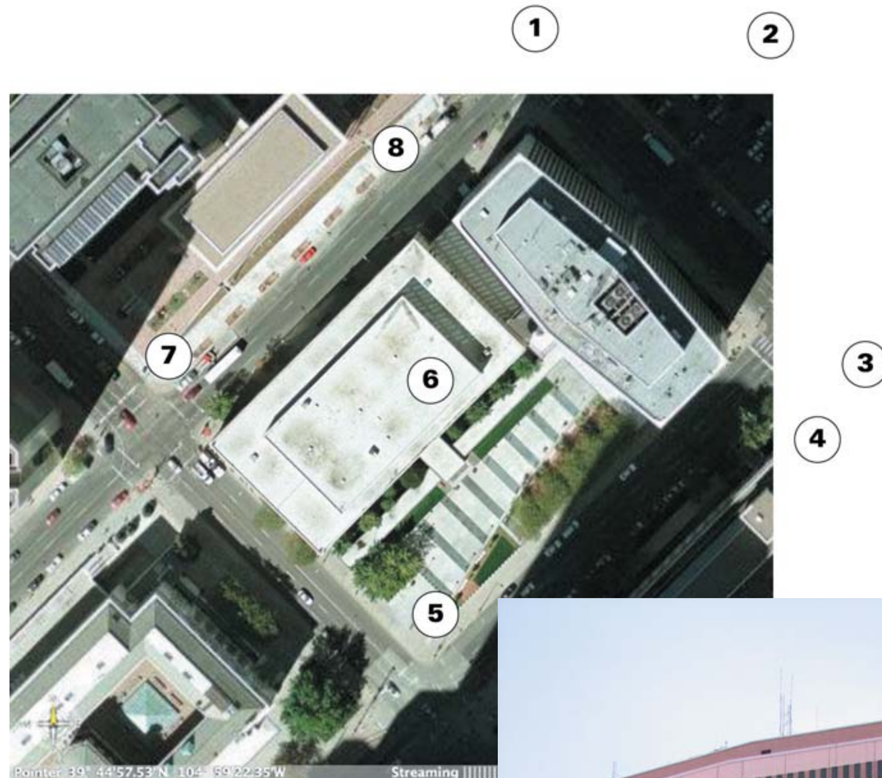


Fig. 16
Federal office building site plan

Fig. 17
Federal office building - location 5

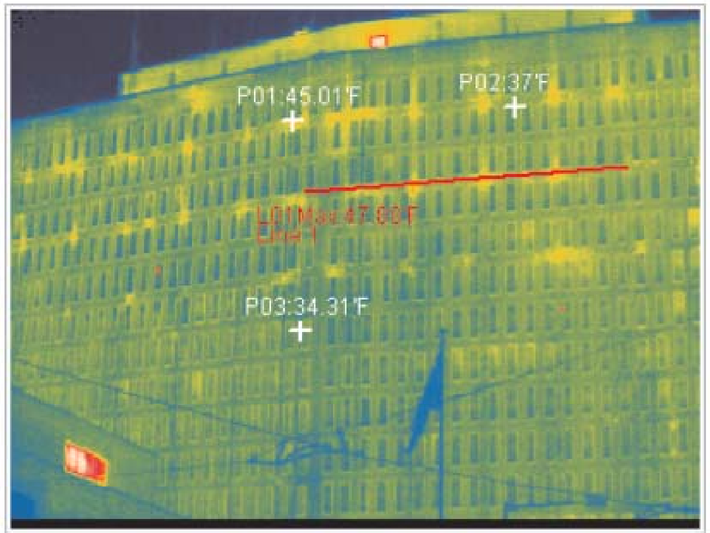
Fig. 18

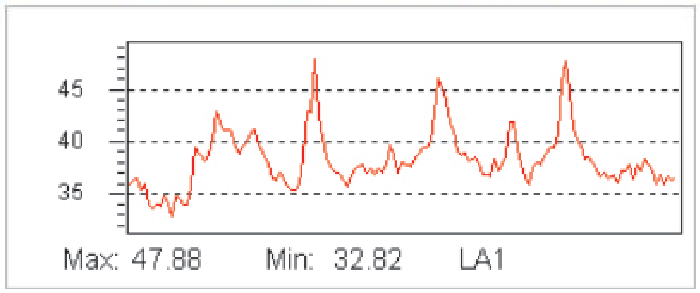
Federal office building - Location 5

The pattern shown here is consistent with air leakage due to the stack effect.

In that phenomenon, warm air rises through the building and leaks out though cracks around windows and at panel joints, showing warm spots on the exterior, just as seen in this image.

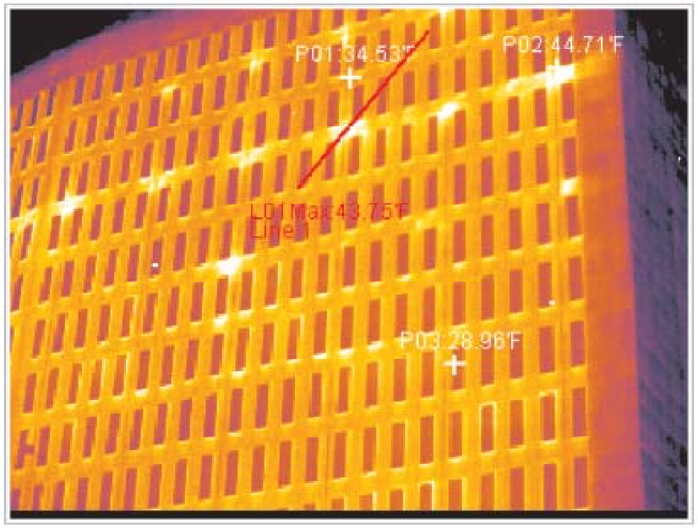
The temperature indicated at point 1, in one of the warm spots is 45°F, at a time when the outdoor temperature and the temperature of much of the rest of the walls is 34°F as shown at point 3.





Project Location:	**Denver Federal District**
Building:	**Federal Office Building (FOB)**
View:	**Location 5**
Weather:	**Clear** **34°F db / 15°F dpt** **Light Wind/ NE**
Comments:	
Thermographer:	**Bret Monroe**

IR Info	Value
Date	2006-3-10
Time	8:26:16
Label	**Value**
P01:Temp	45.01
P01:ems	0.95
P02:Temp	37
P02:ems	0.95
P03:Temp	34.31
P03:ems	0.95
L01:Max	47.88
L01:Min	32.82
L01:Avg	38.29



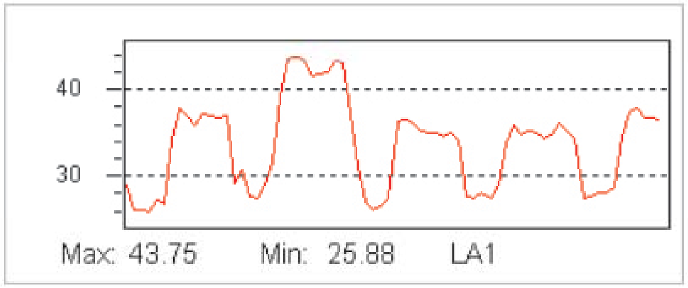


Fig. 19

Federal office building - Location 1

On the back side of the building, the pattern remains consistent with air leakage due to the stack effect.

Project Location:	Denver Federal District
Building:	Federal Office Building (FOB)
View:	Location 2
Weather:	Partly Sunny 50°F db / 16°F dpt Light Wind/ NE
Comments:	
Thermographer:	Bret Monroe

IR Info	Value
Date	2006-3-9
Time	16:32:50
Label	**Value**
P01:Temp	34.53
P01:ems	0.95
P02:Temp	44.71
P02:ems	0.95
P03:Temp	28.96
P03:ems	0.95
L01:Max	43.75
L01:Min	25.88
L01:Avg	33.81

Fig. 20

Federal office building - Location 1

In addition to air leakage due to stack effect, on the back side of the building there is a puzzling pattern of warm surface between the 6th and 7th floors, but only at the northern corner.

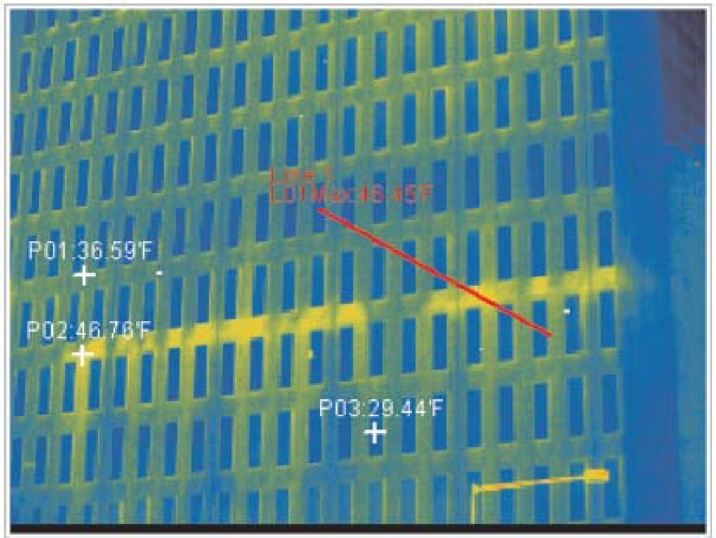
Further investigation will be needed to suggest a cause for this pattern.

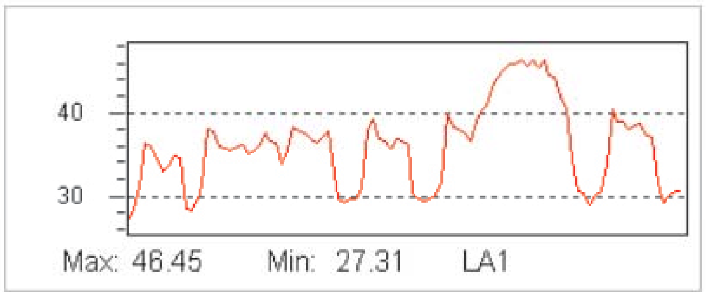
Comments After June 6th, 2006 Inspection

This pattern remains apparent during sumer conditions, in exactly the same loaction, but with a lesser intensity.

This area was investigated thermally from the interior, after considerable effort on the part of local GSA managers. (These floors are occupied by two different Federal law enforcement organizations, each with additional security procedures and escort requirements).

Unfortunately, no explantion for the pattern became evident. The interior finish (gypsum board over stud wall cavity) apparently obscures any interior pattern that might help explain why this area leaks more heat than nearby areas. To further investigate the issue, destructive testing would be needed in the highly-secure offices of two different agencies—a practical impossibility under current circumstances.





IR Info	Value
Date	2006-3-9
Time	16:32:40
Label	**Value**
P01:Temp	36.59
P01:ems	0.95
P02:Temp	46.76
P02:ems	0.95
P03:Temp	29.44
P03:ems	0.95
L01:Max	46.45
L01:Min	27.31
L01:Avg	36.36

Project Location: Denver Federal District

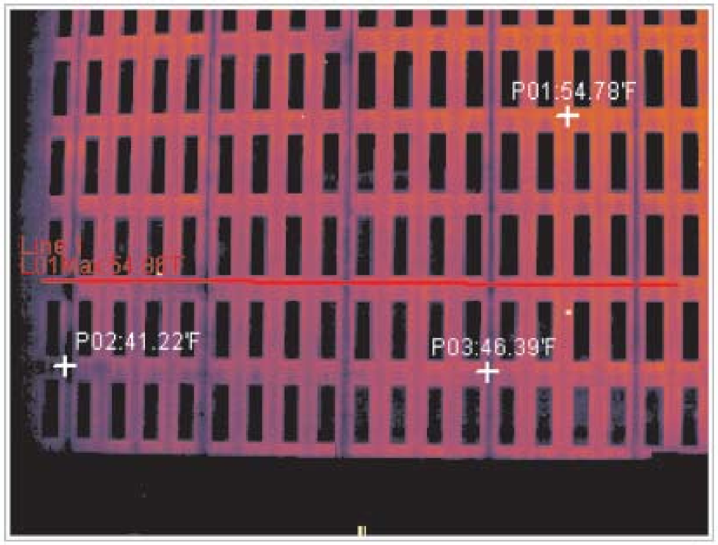
Building: Federal Office Building (FOB)

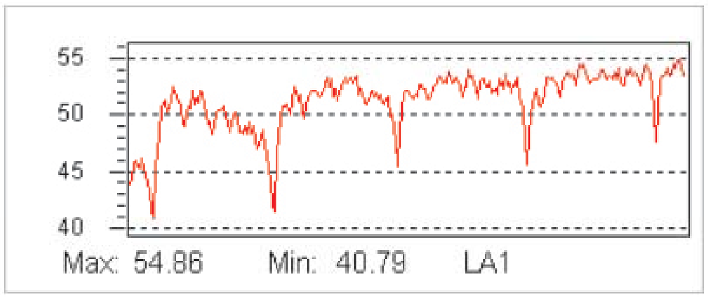
View: Location 1

Weather: Partly Sunny
57°F db / 20°F dpt
Light Wind/ NE

Comments:

Thermographer: Bret Monroe





Project Location:	Denver Federal District
Building:	Federal Office Building (FOB)
View:	Location 6
Weather:	Clear 49°F db / 19°F dpt Still Air
Comments:	
Thermographer:	Bret Monroe

IR Info	Value
Date	2006-3-9
Time	21:16:37
Label	**Value**
P01:Temp	54.78
P01:ems	0.95
P02:Temp	41.22
P02:ems	0.95
P03:Temp	46.39
P03:ems	0.95
L01:Max	54.86
L01:Min	40.79
L01:Avg	51.5

Fig. 21

Federal office building - Location 6

Taken at night, this image is suggestive of excess moisture accumulation near the joints and tracks which might guide a swing stage used for window cleaning.

Further investigation will be needed to confirm or eliminate moisture as the cause of this pattern.

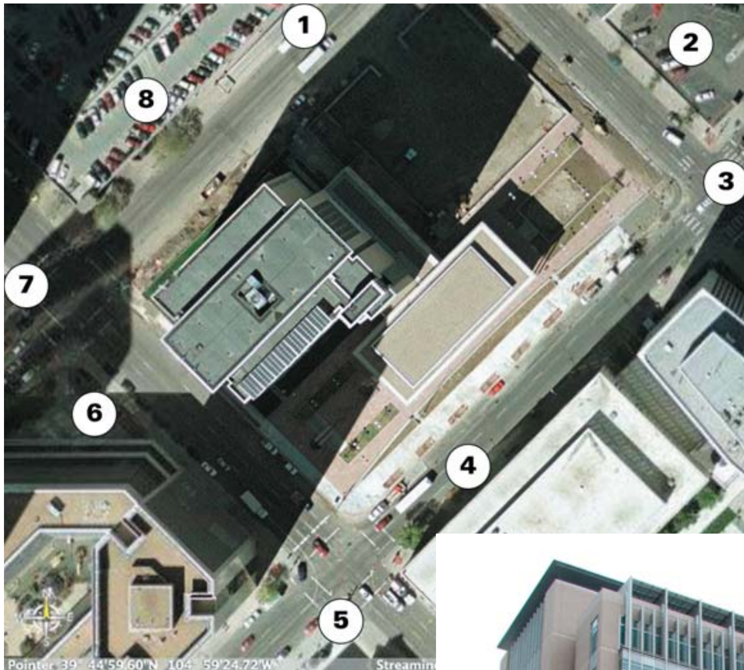


Fig. 22
Arraj Court House site plan

Fig. 23 Arraj Court House - Location 5

Alfred Arraj Federal Court House (Arraj)

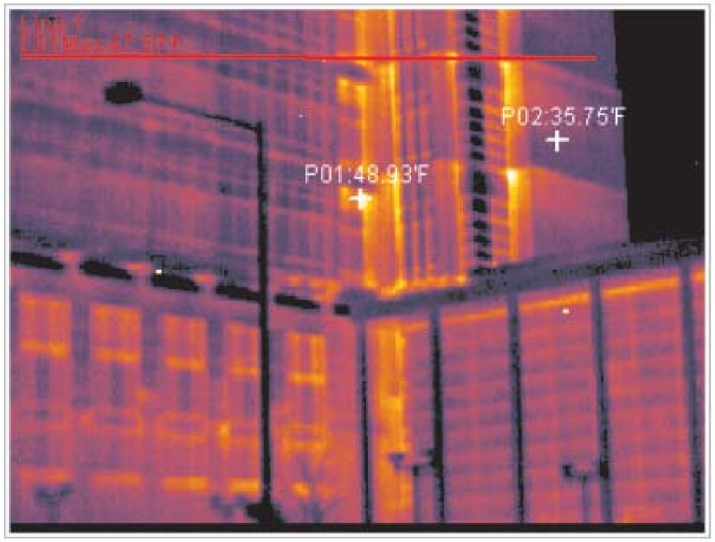
Figure 22 shows the plot plan of the Arraj Court House, and figure 23 shows a visual image of the building taken from location 5. A basic description includes the facts that:

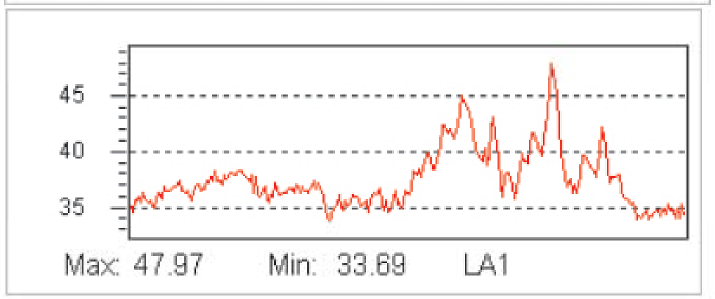
1. The building was completed in 2004 and was designed as a model of energy efficiency. It is 13 stories high, and contains approximately 325,000 gross square feet of space.
2. Its envelope system is complex, consisting of face brick, gravel fill, drainage mat, gypsum sheathing, batt insulation, and vapor barrier. It also makes extensive use of a window curtain wall system.
3. The HVAC System consists of underfloor air distribution for floors 1 through 3 and the courtrooms. Overhead, variable air volume systems serve other areas, and finned-tube radiation under window-wall systems. Steam and chilled water are supplied from district systems. An evaporative cooling system is employed before utilizing chilled water cooling.

The Arraj Court House has had difficulty in achieving the designer's intent of low energy cost. Thermal imaging suggests that one reason may be warm air leakage driven by the intention of maintaining a positive air pressure to avoid cold air infiltration.

Another explanation for the heat leakage may be the fact that considerable air pressure is required from air handlers on the upper floors, in order to push air all the way down to lower floors. Additional air handlers were apparently planned, but were eliminated as a cost-saving measure during construction, leaving the two main air handlers to generate the pressure needed to push air down the building.

Records suggest that 160,000 cfm of outdoor air is sometimes needed to provide sufficient air to all floors—far in excess of ventilation requirements for personnel. This suggests that engineering analysis could find ways to reduce energy consumption in the building.





Project Location: Denver Federal District

Building: Arraj

View: Location 5

Weather: Overcast
32°F db / 16°F dpt
Light Wind/ N

Comments:

Thermographer: Lew Harriman

IR Info	Value
Date	2006-3-10
Time	17:39:49
Label	**Value**
P01:Temp	48.93
P01:ems	0.95
P02:Temp	35.75
P02:ems	0.95
L01:Max	47.97
L01:Min	33.69
L01:Avg	37.48

Fig. 24 Arraj - Location 5

A relatively even pattern suggestive of air leakage is consistent all the way up the front facade of the building, unlike the classic stack-effect pattern of more leakage at the top of the building.

This suggests that perhaps an excess of positive pressure may be responsible for some of the buildings energy consumption.

Also, the heat leakage from the tower at the right of the curtain wall is notable, showing temperatures above 46° when other wall temperatures remain near the outdoor air temperature of 32°F.

Comments After June 6th, 2006 Inspection

One of these patterns repeats during the warm months, in an odd way. Heat appears to be leaking out at the floor-dividing bands. One would expect these to be colder during summer months if they leak heat in the winter.

Some of these patterns could be explained by different materials, with different heat capacity rates, which lag the thermal changes after dawn and after sundown. But air leakage also seems consistent with the winter images, and with building automation records provided during the June visit. These patterns probably have several different causes, which suggests that detailed engineering analysis would be fruitful.

Fig. 25
Arraj - Location 8
Reflections of nearby buildings are evident in the windows of this image.

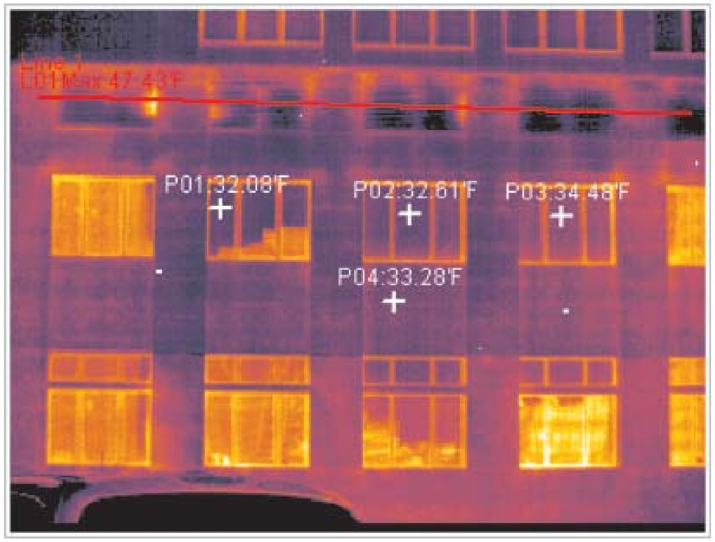
Also notable is the fact that the windows are showing temperatures very near the outdoor air temperature. Even allowing for inaccuracies of low emissivity and reflections, the window performance appears thermally impressive.

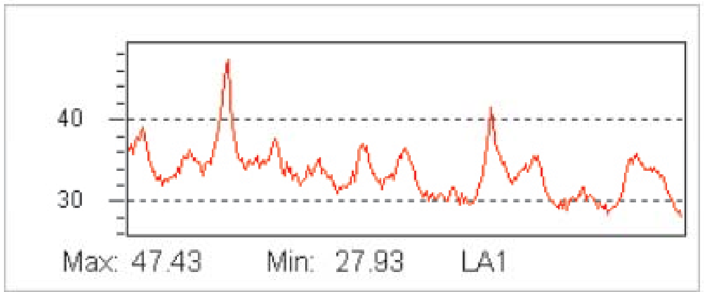
On the other hand, it's not clear why the temperatures of the wall above and around the air intake louvers shown under line 1 are so high. The pattern suggests outward warm air leakage at the very point where one would instead expect a slight inward drift of cold air caused by the suction of the ventilation fans.

Comments After June 6th, 2006 Inspection

Air leakage seems consistent with these winter images, and with building automation records discussed during the June visit.

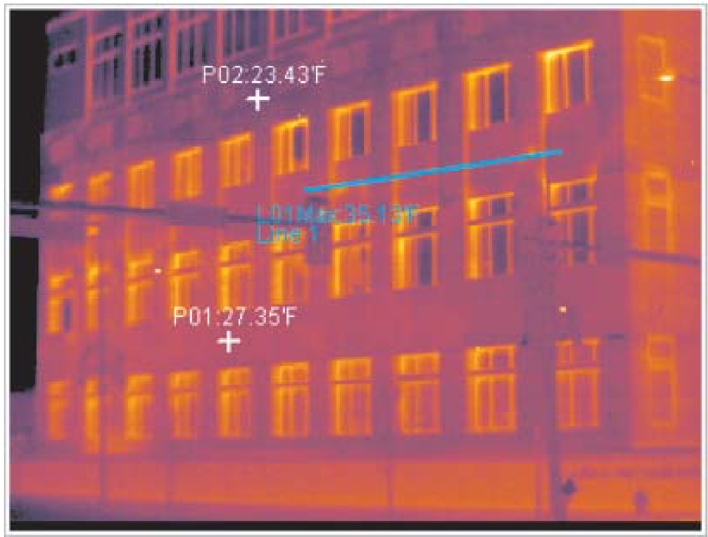
These patterns probably have several different causes, which suggests that detailed engineering analysis would be fruitful, especially in light of the large amount of outdoor air apparently used to generate adequate pressure to reach all parts of the building (160,000 cfm).

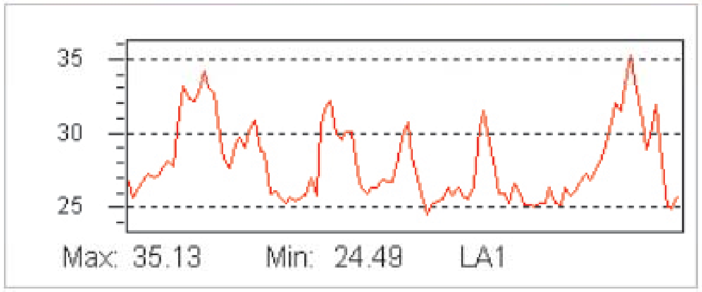




Project Location:	Denver Federal District
Building:	Arraj
View:	Location 8
Weather:	Overcast 35°F db / 13°F dpt Light Wind/ N
Comments:	
Thermographer:	Lew Harriman

IR Info	Value
Date	2006-3-10
Time	13:27:54
Label	**Value**
P01:Temp	32.08
P01:ems	0.95
P02:Temp	32.61
P02:ems	0.95
P03:Temp	34.48
P03:ems	0.95
P04:Temp	33.28
P04:ems	0.95
L01:Max	47.43
L01:Min	27.93
L01:Avg	33.5





Project Location:	**Denver Federal District**
Building:	**Arraj**
View:	**Location 7**
Weather:	**Overcast** **32°F db / 16°F dpt** **Light Wind/ N**
Comments:	
Thermographer:	**Lew Harriman**

IR Info	**Value**
Date	2006-3-10
Time	21:48:38
Label	**Value**
P01:Temp	27.35
P01:ems	0.95
P02:Temp	23.43
P02:ems	0.95
L01:Max	35.13
L01:Min	24.49
L01:Avg	28.05

Fig. 26
Arraj - Location 7
Reflections of nearby buildings are again evident in the windows of this image.

At the lower stories of the building, there seems to be inconsistent thermal behavior of the exterior cladding, with variations in surface temperatures between 25 and 35°F across the level shown under line 1.

Fig. 27

Arraj - Location 6

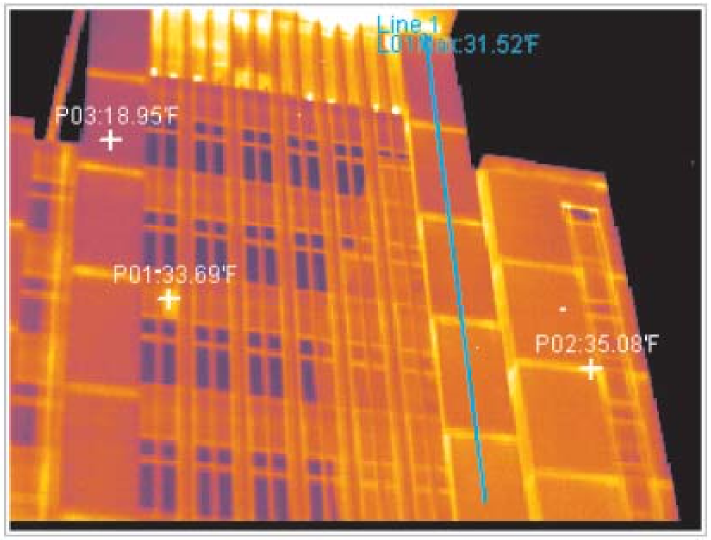
Reflections of nearby buildings are again evident in the windows of this image.

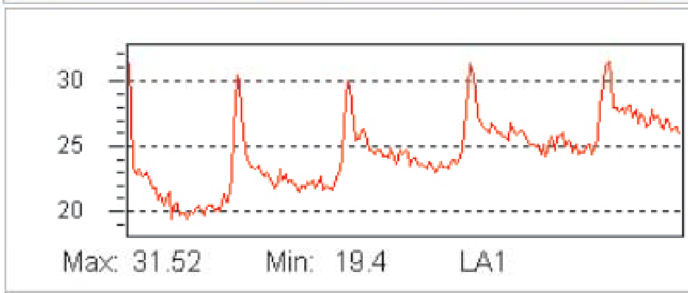
Again, there appears to be inconsistent thermal behavior of the exterior cladding, with variations in surface temperatures between 18 and 33°F between points 1 and 3, and variations between 19 and 31° up the building as shown by line 1 and its companion temperature graph.

Comments After June 6th, 2006 Inspection

Just as in the images shown in figure 24, this pattern partly repeats during the warm months, in an odd way. Heat appears to be leaking out at the floor-dividing bands. One would expect these to be colder during summer months if they leak heat in the winter.

Some of these patterns could be explained by different materials, with different heat capacity rates, which lag the thermal changes after dawn and after sundown. But air leakage also seems consistent with the winter images, and with building automation records provided during the June visit. These patterns probably have several different causes, which suggests that detailed engineering analysis would be fruitful.





Project Location: Denver Federal District

Building: Arraj

View: Location 6

Weather: Overcast
32°F db / 16°F dpt
Light Wind/ N

Comments:

Thermographer: Lew Harriman

IR Info	Value
Date	2006-3-10
Time	21:35:39
Label	**Value**
P01:Temp	33.69
P01:ems	0.95
P02:Temp	35.08
P02:ems	0.95
P03:Temp	18.95
P03:ems	0.95
L01:Max	31.52
L01:Min	19.4
L01:Avg	24.51

New Customs House (Customs)

Figure 28 shows the plot plan of the Customs House, and figure 29 shows a visual image of the building taken from location 7. A basic description includes the facts that:

1. The building was completed in 1931. It is 8 stories high, and contains approximately 280,000 gross square feet of space.
2. Its steet-exposed envelope system consists of a Colorado Yule marble façade mounted to solid red brick, with plaster on metal mesh as the interior finish. In the courtyard, brick is used as the exterior cladding, without the marble facing used on the faces of the building witch face the street.
3. The HVAC System consists of under-window induction units for perimeter areas using a four-pipe system with 3-way valves. Steam and chilled water is supplied from the Byron White Courthouse via understreet piping, with tertiary pumping in the Custom House. Interior zones are supplied by overhead duct work and diffusers from multizone systems with heating and cooling coils. The principal systems are controlled by a DDC building automation system.

The building performs rather well from a thermal perspective, given its age and lack of insulation. Images from within the courtyard show that the performance of the heating system is not entirely consistent, with considerable heat leakage from basement areas in the northern corner of the building.

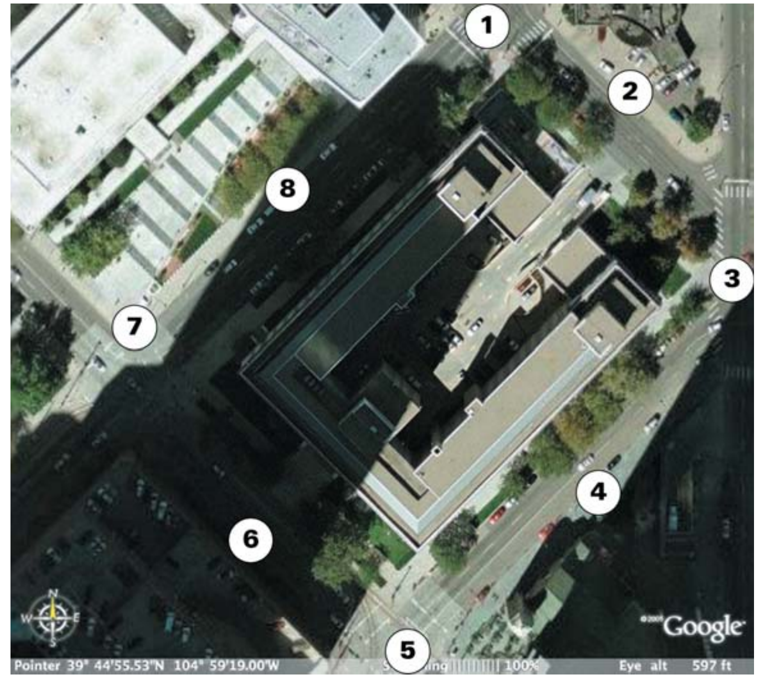


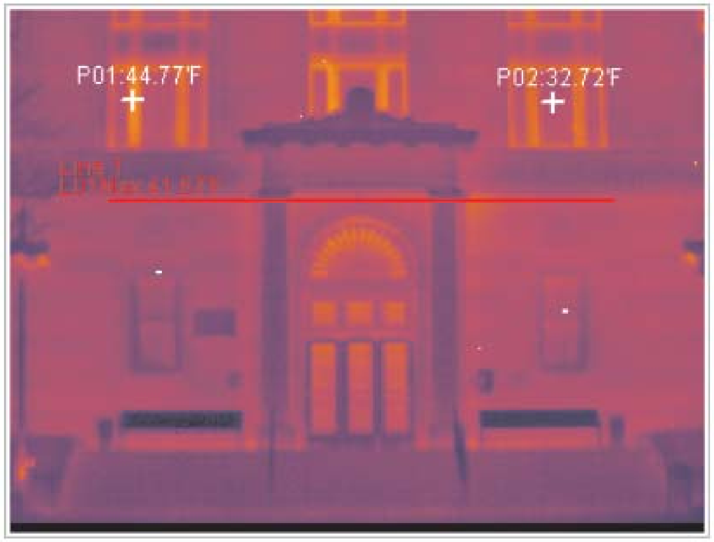
Fig. 28
Customs House Site Plan

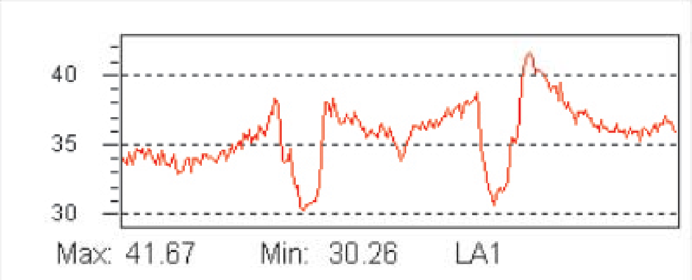
Fig. 29
Customs House - Location 7

Fig. 30
Customs House - Location 6

The window frames are showing heat leakage rates greater than the windows, as one would expect for metal frames without thermal breaks. Point 1, on the frame, shows 44° while the glass surface suggests a temperature of 32°F, very near the current air temperature.

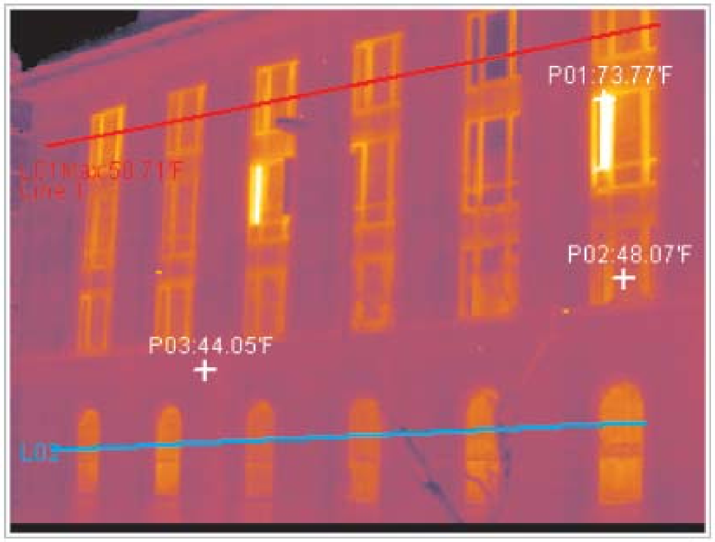
The stone facade performs rather well, given it's age and the lack of insulation, showing a surface temperature only 10° above ambient temperature at the hot spot, and a more typical 5° above ambient in other locations, as shown by line 1.





Project Location:	Denver Federal District
Building:	Customs House
View:	Location 6
Weather:	Clear 32°F db / 20°F dpt No Wind
Comments:	
Thermographer:	Lew Harriman

IR Info	Value
Date	2006-3-11
Time	7:48:30
Label	**Value**
P01:Temp	44.77
P01:ems	0.95
P02:Temp	32.72
P02:ems	0.95
L01:Max	41.67
L01:Min	30.26
L01:Avg	35.7



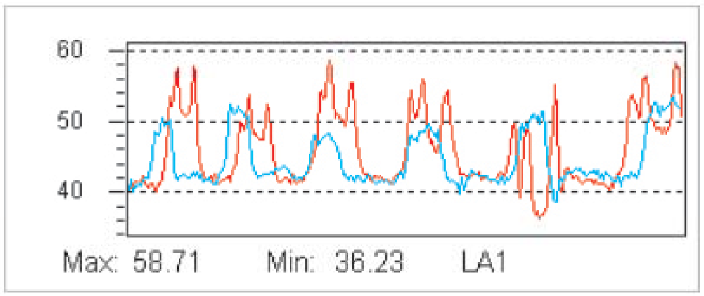


Fig. 31
Customs House - Location 4

The open windows in the third and sixth window bays are quite apparent, based on their much higher temperatures.

Lines one and two compare surface temperatures between upper and lower windows, with better performance from the lower set, which shows colder temperatures and therefore less heat leakage.

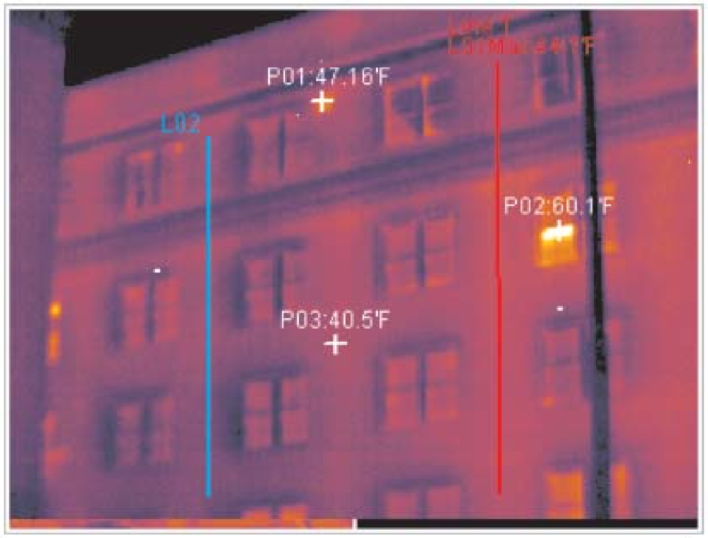
Project Location:	**Denver Federal District**
Building:	**Customs House**
View:	**Location 4**
Weather:	**Clear** **51°F db / 15°F dpt** **Light Wind/ NE**
Comments:	
Thermographer:	**Bret Monroe**

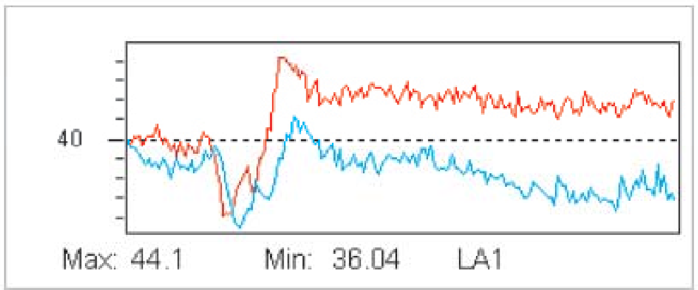
IR Info	Value
Date	2006-3-9
Time	17:51:13
Label	**Value**
P01:Temp	73.77
P01:ems	0.95
P02:Temp	48.07
P02:ems	0.95
P03:Temp	44.05
P03:ems	0.95
L01:Max	58.71
L01:Min	36.23
L01:Avg	46.46
L02:Max	54.06
L02:Min	38.97
L02:Avg	45.15

Fig. 32
Customs House - Location C4

The brick facade in the courtyard shows more heat leakage at the lower stories than at the top–the reverse of what one would expect with stack effect air leaks.

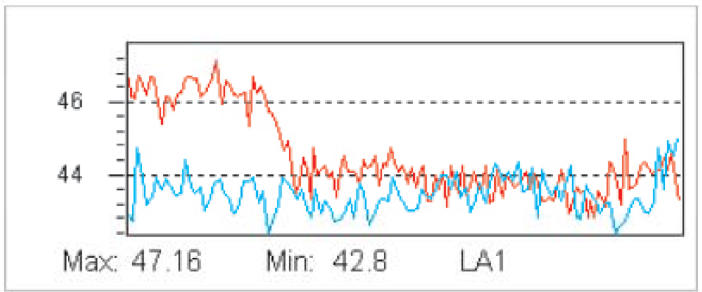
The pattern suggests that the heating system is overheating the lower floors in this location.





Project Location:	Denver Federal District
Building:	Customs House
View:	Location- Courtyard 4
Weather:	Overcast 36°F db / 16°F dpt No Wind
Comments:	
Thermographer:	Lew Harriman

IR Info	Value
Date	2006-3-10
Time	17:4:44
Label	**Value**
P01:Temp	47.16
P01:ems	0.95
P02:Temp	60.1
P02:ems	0.95
P03:Temp	40.5
P03:ems	0.95
L01:Max	44.1
L01:Min	36.04
L01:Avg	41.3
L02:Max	41.08
L02:Min	35.51
L02:Avg	38.24



Project Location:	**Denver Federal District**
Building:	**Customs House**
View:	**Location- Courtyard 4b**
Weather:	**Overcast** **36°F db / 16°F dpt** **No Wind**
Comments:	
Thermographer:	**Lew Harriman**

IR Info	Value
Date	2006-3-10
Time	17:2:2
Label	**Value**
P01:Temp	41.85
P01:ems	0.95
P02:Temp	47.49
P02:ems	0.95
L01:Max	47.16
L01:Min	42.8
L01:Avg	44.51
L02:Max	45.01
L02:Min	42.18
L02:Avg	43.44

Fig. 32

Customs House - Location C4

Hot spots are also found when moving horizontally across the brick surface. Note the cooler temperatures across line one compared to line two, and the 48° temperature shown at point 2 compared to the 42° temperature at point 1.

The basement level in this section of the building apears to be leaking more heat than other locations, suggesting that the heating system is overheating the basement.

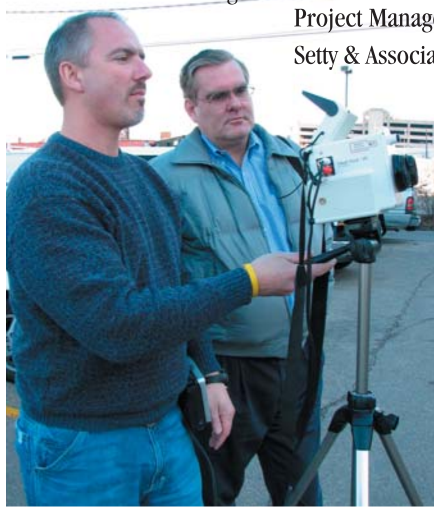
This is consistent with the personal observations of Jodi Thompson, who occupied an office in this basement during the two years she served as Project Manager for the Byron Rogers Courthouse renovation.

- End of Section 3 -

PROJECT TEAM

Bret Monroe
Senior Thermographer
Mason-Grant Consulting

Tim Woerner, P.E.
Project Manager
Setty & Associates



Lew Harriman
Lead Thermographer & Report Writer
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Jodi Thompson
Denver Liaison & Support
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GSA - Denver
Federal Center Liaison & Support

Building Exterior IR Inspection Protocol

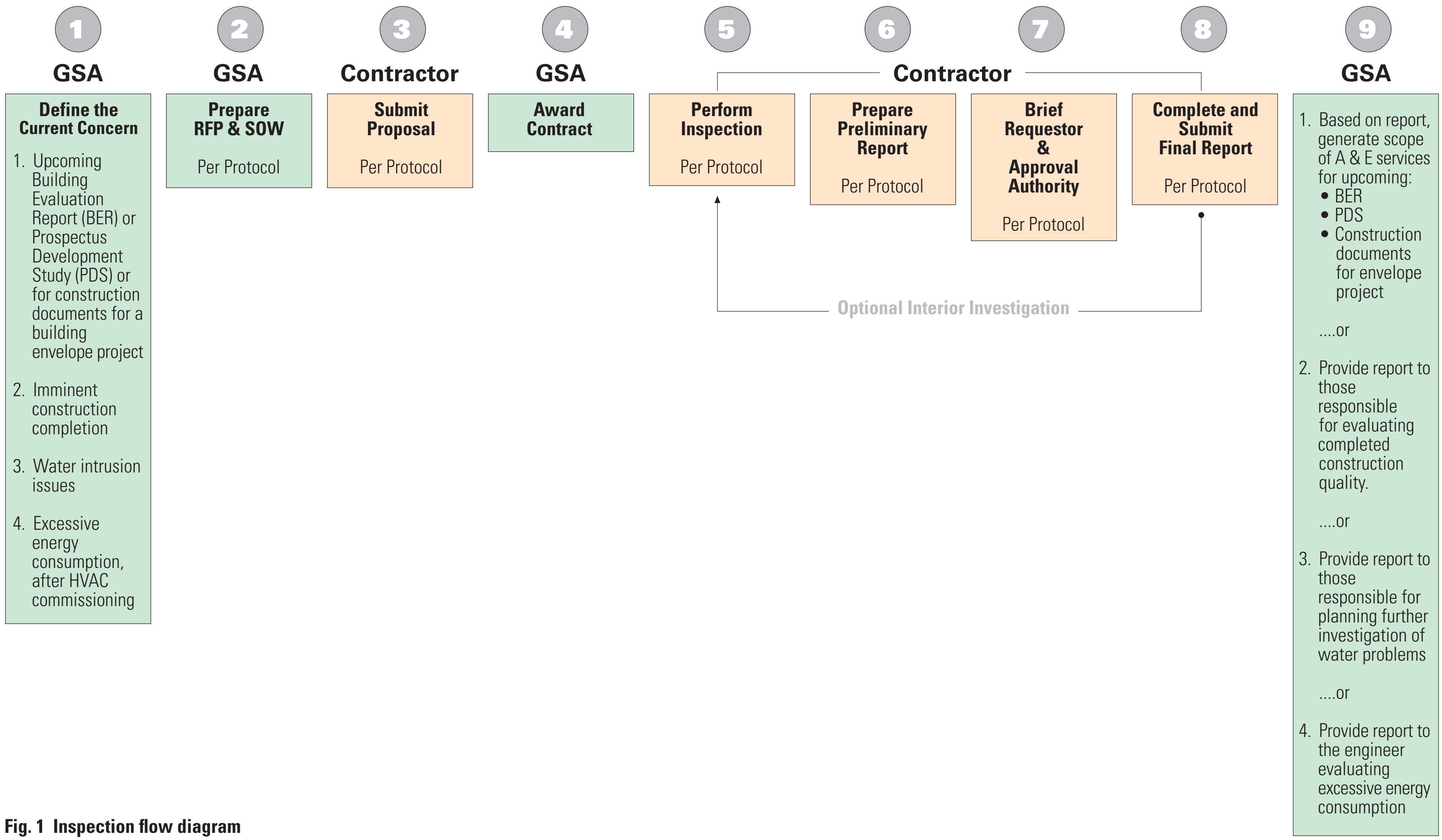

Fig. 1 Inspection flow diagram

EXTERIOR-ONLY IR INSPECTION

Inspecting from the exterior alone limits the number of questions about the building that can be answered with certainty. Indeed, an exterior-only inspection sometimes raises as many new questions as it provides answers. But it is also clear that exterior-only IR inspections can provide significant amounts of useful information to GSA construction managers and building managers.

What exterior-only inspections can accomplish

Without any need to enter the building, IR inspections can:

1. Identify the location of large amounts of outward air leakage from high-rise buildings during the winter.

For major renovation projects, this allows construction planners to identify just where the building must be tightened-up. Such projects will save significant amounts of wasted energy, and will reduce the amount of rain water and snow melt which will enter the building to cause structural damage and mold growth. For buildings completed just before or during cold weather, exterior IR inspection will identify leakage areas that need attention from the design and construction team before the building is accepted by GSA. Also, fixing these leaks will save considerable amounts of energy over the life of a new building, and make it less prone to the water leaks which lead to premature structural failure and mold growth.

2. Identify the probable extent and location of missing or poorly-installed insulation.

Conditions are ideal for locating insulation problems when the outdoor air temperature is more than 20°F below the indoor air temperature, and when the solar influence does not obscure the pattern when viewed from outdoors.

In fact, the pattern of missing or poorly-performing insulation can sometimes be seen at less than a 20°F difference between indoor and outdoor air temperatures. But the 20°F minimum ΔT allows a more reliable conclusion concerning the presence or absence of such a problem. This means that inspections are possible during the daytime in summer months, as long as the solar influence can be excluded, e.g.: inspecting the north side of the building, without reflections from surrounding buildings. Still, the most reliable results are achieved at night, during cold months.

One limitation is the uncertainty concerning the nature of the insulation defect. The thermal patterns of wet insulation and missing insulation or unevenly-compressed batt insulation will look quite similar. But in all cases the pattern indicates a problem. So although the responsibility for having created that problem cannot be determined by exterior thermal imaging alone, thermal imaging is an economical first step in determining whether a significant problem exists, and if so, where it is probably located.

3. Immediately identify the location and probable extent of moisture intrusion into EIFS cladding (Exterior Insulation & Finish Systems–also known as "synthetic stucco").

EIFS exterior cladding dominates low-rise commercial buildings in the US. GSA leases space in many such buildings. Trapped water in EIFS cladding has led to significant mold growth in the sheathing of the exterior walls, which adversely affects the health and productivity of asthmatic and mold-sensitized employees, resulting in lost productivity and the distraction of personal injury litigation. The first step in eliminating these costs is a thermographic inspection from the exterior, during either summer or winter. Based on the results, further moisture measurements can be made to quantify the problem (again, working from the exterior alone), which allows construction planners to plan repair or replacement of the EIFS, or for GSA to negotiate with the leased building owner to accomplish these repairs comprehensively, at no cost to the government. The best results are obtained immediately after dawn, when the sun hits the portion of the building in question. The thermal lag of the wet material provides a clear and distinct dark pattern in any suspect areas.

4. Immediately identify the location of missing grout and reinforcing steel in single-thickness masonry block walls, during construction.

This capability allows construction project managers to be certain that the wall has the structural integrity intended by the designer–before the wall is covered by cladding or interior finish and the moment is gone for low-cost correction of this life-safety-related building defect.

5. Identify possible locations of excessive moisture accumulation in mortar droppings behind brick veneer walls.

This defect can be sometimes be seen through IR imaging, given a favorable sequence of weather during spring, summer and fall. Inspection for this problem is best performed after a significant rain which is followed by bright sun, just after dawn on a dry day.

Mortar-clogged drainage behind brick veneer has become more common in recent years. Moisture accumulation in the mortar leads to mold growth in sheathing, as well as corrosion and failure of brick ties, occasionally with catastrophic consequences during high winds, with the potential for injury of bystanders. The ability to inspect a new wall for this problem is limited to some extent by weather. But if spray testing is allowed from the exterior during dry, sunny weather, the defect can be identified and corrected before GSA accepts the building. This will save repair costs and reduce the potential for mold-related IAQ problems.

6. Identify and locate excessive heat leakage through and around window and door frames.

Excessive heat leakage can be seen during any season of the year, provided that the outdoor air is at least 20°F above or below the indoor air temperature, and provided that the inspection can be accomplished before dawn or at least 3 hours after sundown.

Such an inspection allows the construction manager to be more certain that the thermal performance of the integrated installation is as specified, avoiding the cost of lost energy for the life of the building. For the manager of existing buildings or for the construction planner, such inspections allow rapid initial assessment (in a qualitative way) of whether a project to seal up cracks or to replace the window units might be economically advantageous. The IR inspection by itself does not answer the essential question of economic payback of such a project. But it does allow the project planner to better determine whether a detailed engineering assessment of window replacement or air sealing might show positive economics.

7. Identify poorly-performing gas-filled double glazing.

Faults in double glazing can be seen at night, when the outdoor temperature is more than 20°F below the indoor temperature.

When an insulating, double-pane window loses some of its gas through seal leakage or through small cracks, its insulating properties are greatly diminished, leading to energy losses during both winter and summer months. The thermal pattern created by lost gas is apparent when viewed through an infrared camera, provided that there is a significant temperature difference between indoor and outdoor air temperatures (greater than 20°F), and provided that there is no solar influence to generate reflections that would obscure the pattern. As a practical matter, these limitations mean that inspecting for lost gas is best done at night, and during winter months. During hot weather the energy loss may be equally important, but the outdoor air temperature at night is seldom at least 20°F above the indoor temperature, so the pattern is usually quite difficult to see during warm months.

8. Identify areas of possible excess moisture accumulation in roofing.

Such inspections are performed at least three hours after sunset, on a clear night, when the roof is dry and there is at least a 20°F difference between indoor and outdoor air temperatures.

This capability is significantly limited by weather. In addition to the conditions above, the roof must be dry, and without patches of ice or snow. Also, the roof must have no greater than a 1.5 inch layer of gravel ballast. Roof access is also required for "walk-on" inspections, so an IR inspection is not entirely free from the need to enter the building.

An infrared image of the roof taken from a camera-equipped airplane is sometimes more cost-effective and less disruptive of building operations, and demands less security coordination than inspection from the rooftop itself. But after both walk-on and aerial inspections, the moisture content of the roofing must be measured with meters before firm conclusions can be drawn from the thermal images.

In spite of these limitations, external IR roof inspection is widely-used. It saves a great deal of money. IR inspection can identify suspect areas clearly and target them for replacement, avoiding the high cost of water damage, and reducing the cost of disposing of toxic waste generated by replacing an entire roof.

Inspections for new construction

These observations suggest there are practical uses for exterior-only IR inspections in both new and existing construction. Construction managers would be well-advised to consider exterior-only thermal imaging analysis at two stages of the project:

1. After exterior masonry block walls have been erected, but before any roofing is added over them, and before any exterior cladding is added to their exterior surfaces.

The purpose of this inspection is to determine if there is any missing grout in cells which should be filled.

2. After HVAC commissioning, but before the exterior enclosure is accepted.

After the HVAC system has been comissioned, the purposes of an exterior-only inspection can include locating:

- Unintended outward air leakage
- Moisture accumulation under EIFS cladding
- Missing or poorly-performing insulation in walls
- Damaged gas-filled windows
- Mortar-filled cavities behind brick veneer

Inspections of existing buildings

For existing buildings, IR inspections can be useful before major renovation is planned in detail, and after more conventional investigation methods have come up against their limitations. Specifically, building managers should consider exterior-only thermal imaging inspections in four situations:

1. Before contracting for any building evaluation report, and before any design begins for a modernization project.

In existing buildings, developing the scope for a renovation project is the most cost-effective use for exterior-only thermal imaging.

At this stage–before any project scope is developed, the thermal inspection can be very useful. It can direct the engineers' and architects' attention to any unforeseen major problems in a matter of hours, at low cost, with very little intrusion into building routines. The cost-savings from directing renovations at big problems rather than at small problems can be very significant. For example, the images gathered from the pilot project provided ample evidence of this fact. The volume of outward air leakage from one building was not at all expected before thermal images showed the problem.

Exterior-only IR inspections should be performed in all buildings scheduled for BER's, PDS's or other envelope upgrade, but *before* the scope has been defined. The IR inspection should be directed towards locating:

- Excessive outward air leakage during both occupied and unoccupied HVAC modes of operation
- Moisture accumulation under EIFS cladding
- Missing or poorly-performing insulation
- Moisture accumulation in brick veneer or masonry block exterior walls
- Damaged gas-filled glazing

2. After HVAC recommissioning, if a building still uses an apparently excessive amount of energy.

In most cases, recommissioning the HVAC system is the quickest and most cost-effective way to reduce excessive energy consumption. But if recommissioning is complete and the building *still* uses an excessive amount of energy, the next logical step in identifying and locating energy losses would be an exterior thermal inspection. In this situation, the inspection should be looking for:

- Outward air leakage
- Missing or poorly-performing insulation
- Damaged gas-filled glazing

3. After mold growth and indoor air quality complaints have been investigated by industrial hygienists, and after these professionals suspect that there my be water leakage through exterior walls or roof which is contributing to the problems.

Under some such circumstances, exterior thermal inspection can help locate moisture accumulation in the exterior walls, which can help locate the source or water leaks.

But it's useful to keep in mind that locating the origins and paths of exterior water leaks will be very cursory and incomplete without *interior* IR inspection as well, and without extensive moisture content readings, as well as destructive testing from the inside

Exterior IR inspections will be one of many tools necessary to locate water leaks. But the total process is often time-consuming, labor-intensive, expensive and disruptive to building occupants, no matter how high-tech the tools may be.

4. When water leakage through the roof is suspected, and after internal condensation has been ruled out as the source of the indoor moisture.

In many cases, high indoor dew points are responsible for the indoor moisture and drips mistakenly attributed to "roof leaks." But if the indoor dew point is low, and if water appears to be entering the building after rain, then exterior-only thermal inspections of the roof can help locate the source and extent of the roof leak. The exterior IR roof inspection serves as a precursor and a guide for the necessary but more disruptive indoor portion of such investigations.

Limitations of exterior-only inspections

The previous section discussed what is possible with exterior-only inspection, along with the limitations specific to particular types of inspections.

But there are also general, inherent limitations that come from not being able to access the interior of the target buildings. It is important for managers to keep these in mind to avoid misunderstandings about what IR inspection can accomplish by itself. Inherent limitations include:

Cannot locate *inward* air leakage, under most circumstances

Inspection from the interior would allow the inspector to locate areas where outdoor air is leaking into the building, instead of just out of the building. For the outside alone, there are very few situations where inward air leakage is apparent through IR imaging.

Cannot trace the path of water leaks, nor estimate their severity.

Without the ability to inspect from the interior, and to use moisture meters on indoor surfaces, it will not be possible to trace the path of water leaks from the exterior wall, which greatly restricts the ability of the inspector to locate the exterior wall leakage points. It may be possible to make an educated guess as to the location of leaks from the exterior alone, but in most cases it will not be a reliable indicator. And without indoor access, estimating the magnitude of any water leakage problem will not be possible.

Cannot quantify energy loss due to air leaks

Without the ability to use blower doors or the HVAC system to adjust ventilation air quantities and measure them, it's not possible to estimate the magnitude of energy losses from air leaks–typically the largest energy loss that is discoverable with thermography. This restricts the ability of the engineer to compare the costs vs. benefits of any project to fix air leakage problems.

Cannot easily quantify energy losses due to insulation deficiencies

This is a limitation of thermography itself, rather than a result of only inspecting from the exterior. One can know the outdoor surface temperatures through thermography, and one assume the indoor surface temperatures will be close to the indoor air temperature. But that does not mean an engineer can calculate annual energy loss with any satisfying degree of confidence. The temperatures indicated in the images apply to a single moment in time, not to the entire year. Also, the temperatures shown are subject to variations in the emissivities of different materials in the walls, which leads to considerable measurement error. Further errors are introduced by reflections from nearby buildings and roads.

So although thermography from the exterior can improve the engineer's estimates of heat loss for his building models, the annual heat loss estimates will always remain estimates rather than precision calculations.

Suggestions for IR inspection protocols

Based on these observations, GSA managers should consider five key points with respect to exterior-only IR inspections:

1. Recognize that exterior IR inspections are the 1st step in a three-stage process

Exterior IR inspection will have to be followed by interior IR inspections to further isolate and define the extent and the nature of any problems. Then an architectural engineer or other expert in forensic investigation of building enclosures will use the exterior and interior IR results as the basis of further investigations, developing formal recommendations and cost estimates for the repair of the problems. The IR inspection results cannot provide cost-benefit estimates–the results can only point the building enclosure expert towards the relevant issues, and suggest the probable locations and extent of problems.

2. Describe the building in thermographically-relevant terms

An infrared inspector needs to know quite a bit about the building before he or she can determine the cost of an inspection and the resulting report. The attached form shows what information is necessary for a potential contractor to provide a reliable not-to-exceed cost proposal.

In addition, the inspectors results will be more certain, and will be achieved at lower cost, if he is provided with construction drawings for the exterior enclosure before he is asked to provide the cost of inspection services. All uncertainty about the enclosure leads to higher costs when preparing a cost estimate for IR inspection.

3. Limit and describe the purposes of the requested inspection

Knowing the reasons for the inspection, and what the report is intended to accomplish, and for whom, are also essential elements of cost for the potential contractor. Much time and money can be saved for the government if the inspector does not have to look broadly, when the issues in question are really rather narrow. A clear statement about the ultimate purposes of the report will reduce uncertainty, and therefore eliminate needless costs.

4. Define the range of calendar dates when the building can be expected to achieve these purposes.

The season of the year, together with the exact geographic location of the target building and the purposes of the inspection are the three basic elements of cost from the contractors perspective. Some purposes cannot be achieved in hot weather, or can only be achieved in dry weather. Knowing the allowable season for the inspection, within a range of a few weeks, is essential if the contractor is to be confident of being able to achieve the stated purposes of the inspection. Also, the season must be known in order for the contractor to assure the government that personnel resources will be available in the required time slot.

5. Define the required components of the inspectors report

IR inspection reports vary widely between vendors, and there are no published industry standards. The protocol describes the elements of a report which will be sufficient for most GSA purposes.

IR INSPECTION PROTOCOL

Section 1 - Basic Inspection Requirements

Provide a not-to-exceed cost proposal to inspect the subject building:

- From the exterior alone. No interior access will be available during the inspection.
- Using high-resolution thermal infrared cameras (at least 320 x 240 sensor resolution in IR wavelengths between 8 and 14 microns) and visual cameras.
- On a mutually-agreed date during the period from ____(day/month/year) to ____(Day/month/year).
- Before dawn on the agreed date, or at a time sufficiently free from solar influence that the thermographer and the approving authority agree will achieve the purpose of the inspection described in section 3.
- At a time when the air temperature difference between indoors and outdoors is at least 20°F, or a lesser number agreed between the thermographer and the approving authority as being acceptable to achieve the purpose of the inspection as described in section 3.

Section 2 - Subject Building

The subject building is (completed construction/ under construction), and has the following characteristics:

Name: ____________________

Location: ____________________(Street)

____________________(City)

____________________(State)

____________________(ZIP code)

Principal functions: ________________

____

____

____

Gross sq. ft: ______________________

Number of stories: __________

Basic shape of the floor plates: ___________

Exterior claddings: (1)________________

(2) ________________

Window frame materials: (1)________________

(2) ________________

Roof types: (1)________________

(2) ________________

HVAC system types: (1)________________

(2) ________________

Approximate year of construction: _______

Section 3 - Purpose of the inspection

The purpose of this inspection is to provide a report containing thermal images paired with visual reference images in both video and still image formats, and accompanied by written commentary along with a verbal presentation which will show GSA personnel the probable locations and extent of one or more of these possible building defects.

Check all that apply for the desired inspection, and briefly describe any parts of the building of greater interest than others with respect to these issues:

- ❑ **Excessive outward air leakage**
- ❑ **Moisture intrusion under EIFS cladding**
- ❑ **Missing or poorly-performing insulation in the exterior walls.**
- ❑ **Missing grout in concrete masonry block**
- ❑ **Excessive heat leakage through or around windows, doors and other wall penetrations.**
- ❑ **Excessive moisture accumulation in exterior brick veneer and/or exposed masonry block**
- ❑ **Excessive heat leakage through roof insulation**

SECTION 4 - CONTACT PERSONNEL

Requesting individual

________________________ (Name)
________________________ (Job Title)
________________________ (Employer)
________________________ (Organization/office symbol)
________________________ (Street Location)
________________________ (City)
________________________ (State)
________________________ (Zip)
________________________ (Cell phone)
________________________ (Office phone)
________________________ (eMail)

Individual who will approve the report

________________________ (Name)
________________________ (Job Title)
________________________ (Employer)
________________________ (Organization/office symbol)
________________________ (Street Location)
________________________ (City)
________________________ (State)
________________________ (Zip)
________________________ (Cell phone)
________________________ (Office phone)
________________________ (eMail)

Security clearance authority for the building exterior

________________________ (Name)
________________________ (Job Title)
________________________ (Employer)
________________________ (Organization/office symbol)
________________________ (Street Location)
________________________ (City)
________________________ (State)
________________________ (Zip)
________________________ (Cell phone)
________________________ (Office phone)
________________________ (eMail)

Property management authority for the target building

______________________ (Name)

______________________ (Job Title)

______________________ (Employer)

______________________ (Organization/office symbol)

______________________ (Street Location)

______________________ (City)

______________________ (State)

______________________ (Zip)

______________________ (Cell phone)

______________________ (Office phone)

______________________ (eMail)

Section 5 - Work sequence

1. Kickoff meeting

Upon award of a contract and prior to submitting the work plan the inspection contractor shall meet with the requesting individual, the report approval authority, the target building security clearance authority and the target building property management authority. The purpose of the meeting is to review and confirm the purposes of the inspection, and to inform the inspector of current needs and concerns regarding security, building access restrictions, preferred inspection timing, work rules, or other factors which could affect the inspector's ability to achieve the results required by the requestor. This meeting will form the basis of the contractors work plan.

2. Submit work plan for approval

Following the kickoff meeting, the contractor shall provide a brief written work plan describing the proposed:

- Date and time for the inspection.
- Expected date and time for any meeting to discuss preliminary observations, and the proposed date for the meeting to present and review the draft report.
- Confirmation of any instructions regarding security, site access, inspection timing or other relevant factors conveyed to the contractor by the requestor, or conveyed to the requestor by the contractor.

3. Obtain written security authorization

Upon approval of the contractors work plan, the requestor shall coordinate with the approval authority for exterior security of the target building, who shall provide the contractor with a written and signed authorization to perform the inspection. Copies of that document shall be carried by all inspection personnel at all times during the inspection, and shown to security staff on demand, along with government-issued photo identification.

4. Inspect the building

The subject building shall be inspected in accordance with the approved work plan and security authorization. The requestor (will/will not) require a verbal report of preliminary observations after the inspection and before preparation of the draft report.

5. Submit draft report

The draft report, containing information described in section 6 (Report requirements), shall be provided to the requestor no later than ___ days after the date of the inspection.

6. Meet with and brief the approval authority

After the requestor has had an opportunity to review the draft report, the contractor shall meet with the requestor and others as defined by either the requestor or the approval authority to answer questions and to receive instructions regarding any necessary modifications to the draft.

[Optional] 7. Followup IR inspection from the interior

After the approval authority has been briefed regarding the preliminary results, the contractor will be provided with limited access to the interior of the subject building for the purpose of further defining the probable nature and extent of thermal anomalies identified from the exterior. In the proposal, the contractor shall include a minimum of ___ person-hours of effort to perform such followup investigations, and to report on them to the approving authority.

The contractor shall also provide the hourly rate schedule for any employees he recommends for such followup investigations, in case further investigation is required.

8. Submit final report

The contractor shall provide __ printed copies of the final report, as well as __ copies in the electronic formats specified by section 6, no later than ___ days after the final meeting with the approval authority.

Section 6 - Report requirements

The report shall be sufficient to achieve the purposes of the inspection as defined in section 3 of this request for proposal or as modified by mutual agreement during the course of the project. But as a minimum, the report shall contain:

1. Summary

Provide a summary of principal observations, conclusions and recommendations relevant to the purposes of the inspection, with the signature, name and contact information of the person who prepared the report.

2. Purposes of the inspection

Document the purposes of the inspection as described in this request for proposal or as modified by mutual agreement during the course of the project.

3. Site plan

Orient the site plan diagram with North towards the top of the page, and with the actual photo shooting locations clearly noted on the plan using eight (8) compass location numbers. The number 1 shall represent the thermographers approximate location when shooting the corner or face of the building which faces most nearly north. The location numbers shall ascend in clockwise sequence around the building, so that the number 8 represents the position for shooting the corner or face of the building which faces most nearly northwest.

4. Building description

Provide the building description in at least as much detail as described in the request for proposal or in the latest scope of work. In addition, provide visual photographs of the building in this section, taken from all eight compass points.

5. Video clips

Provide brief grayscale video clips, containing both high-resolution IR (minimum 320 x 240 sensor resolution) and visual views of the subject building.

As a minimum, provide clips which pan slowly from left to right, showing the entire width and height of the building, from the eight (8) compass points identified on the site plan. Provide additional video clips as necessary to show, as clearly as thermal circumstances allow, the anomalies identified by the inspector as well as their IR and visual contexts. Each clip shall begin with the name of the subject building, the date and time the video was taken, the outdoor air temperature and the compass point from which the video was shot. The end of each video clip shall describe the make and model of the cameras used, and the full name and organization of the videographer and the video editor.

The target length of these clips is 10 to 30 seconds each. After the full-building traverse, the clips shall switch back and forth between visual and infrared views, stopped over areas identified has having significant thermal anomalies.

6. Still images, comments and image documentation

Provide high-resolution (minimum 320 x 240 sensor resolution) radiometric infrared images, paired with visual images with a nearly identical field of view and accompanied by written comments. These comments connected to the images are the essence of the report. They shall address how the images suggest the presence and extent of defects that were the target of the investigation, or the fact that the images suggest that such defects are not present.

The comments should also include any recommendations concerning further forms of investigation which may help confirm or eliminate the probability of a defect, or which may help assess the extent of a potential problem.

Further, surface temperatures shall be indicated in the middle of any relevant thermal anomalies, as well as on a similar but unaffected portion of the building surface to allow quantitative comparison.

Also, each image pair and its written comments shall be annotated with reference text which describes the location, authorship and thermal parameters for the thermal image. Using small and unobtrusive type, include on the same page as each image pair:

- Compass location number from which the image pair was taken
- Date and time the image pair was taken
- Outdoor air dry bulb temperature and dew point
- Approximate wind speed and direction
- Approximate cloud cover, if any (Overcast, partly cloudy or clear)
- Any precipitation, and its approximate duration prior to the shot (Heavy rain, light rain, intermittent rain, fog or no rain during approximately __ hours before the image was taken)
- Camera emissivity setting when the thermal image was taken
- Full name of the thermographer who took the thermal image
- Manufacturer, model number and serial number of the thermal camera used to capture the image
- Full name of the person who generated the comments (if different from the camera operator)

The number of images shown in the report shall be sufficient to confirm the probable presence or absence of the defects targeted by the inspection and described in section 3 of this request for proposal (Purpose of the inspection). But as a minimum, the images shall include at least one pair of visual and thermal images taken from each of the eight compass locations, with a field of view sufficient to cover the full height and width of the building from that vantage point.

7. References

Include any brief, specific reference material or suggestions to guide the requestor in further investigation of the issues raised by the report.

8. Contact information

Provide the name and contact information of the requestor, approval authority, security authority and contract manager, as well as any relevant personnel who participated in the project from either the contractors organization or from the government. In short, any person who may be able to inform future readers of the report with respect to its purposes, observations and conclusions.

9. Report formats

The report shall be provided in ____ copies, in both printed and electronic formats, including:

a. Printed document on glossy paper, in color

b. Electronic copy of document, in PDF format

c. Native electronic file of the printed document

d. JPEG versions of all IR images in the printed report

e. Native thermographic image files and native visual image files for images contained in the printed report

f. Edited video clips showing traverses of the building from eight (8) compass points, using both IR and visual video cameras, in either Windows® media, Quicktime® or Flash® formats

The printed reports shall be printed on both sides of the sheet, and shall be bound with helical coils, to lay flat. The electronic files shall be provided on a single CD or DVD, as required by the size of the report files.

Section 7 - Qualifications & Tools

Contractor shall submit documentation of the qualifications for each member of the proposed thermography team, and a list of tools to be used for the inspection and for generating the report.

Note that the experience of the proposed thermographers, personally, is the issue. The experience of the contracting organization, while useful, shall not be a substitute for the required minimum qualifications for thermographers, which shall include:

1. Successful completion of a course and an examination which complies with the guidelines established by the American Society for Nondestructive Testing (ASNT) for the training of Level I thermographers.
2. Two (2) years of experience in diagnosing problems of the exterior enclosures of buildings, using infrared cameras. (Note: Experience investigating problems of electrical systems, mechanical equipment or catastrophic interior water damage is useful. But such experience shall not substitute for the requirement to have at least two (2) years of experience in diagnosing problems of the exterior enclosures of buildings.)
3. Three (3) project references for investigations of building enclosures which are similar in relevant aspects to that of the target building. Provide the name, telephone number and email address of the person who was the approving authority for each of these projects, along with a one-line description of the issues investigated.

Submit the manufacturer and model number of all proposed visual and IR cameras, and the name, manufacturer and version number for any software to be used for thermal analysis and report-writing. Minimum standards for IR cameras shall include:

1. Minimum sensor resolution of 320 x 240 pixels with a maximum NEDT of 80 milliKelvin degrees
2. Radiometric imaging capability, with a pixel-to-pixel thermal sensitivity of no greater than 0.1°C
3. Matching visual image capability in the IR camera body, to ensure a visual reference for all IR images, taken at the same moment and with the same field of view as the IR image.
4. Video-out capability, for live recording of both visual reference and IR video clips as defined in section 6.

REFERENCES

1. *ISO Std 6781. Qualitative Detection of Thermal Irregularities in Building Envelopes – Infrared method* (Also known as European Standard EN 13187:1998 and Deutsche Norm DIN 13187. International Organization for Standards. Geneva, Switzerland. (www.iso.org/)

2. *ASTM C 1060–90. Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings.* (Reapproved 1997) ASTM International, Philadelphia, PA. www.astm.org

ADDITIONAL RESOURCES

Building Enclosure Thermography

Nondestructive Testing Handbook, 3rd Edition, Volume 3, Infrared and Thermal Testing. 2001. Maldague & Moore, Editors. American Society for Nondestructive Testing. Columbus, OH (www.ASNT.org)

A Visual Moisture Detection Method: Using Infrared Imaging to Locate Moisture in Buildings. 2004. Lew Harriman, HPAC Engineering Magazine, December 2004. Penton Publishing, Cleveland, OH. (www.moisturedm.com/html/accessories_training/free_downloads.html)

Design & Hygrothermal Behavior of Institutional Building Enclosures

Building Envelope Design Guide, 2005. (Website) Federal Envelope Advisory Committee of the National Institute of Building Sciences. Washington, DC (http://www.wbdg.org/design/envelope.php)

Building Science for Building Enclosures, 2005. John Straube, Ph.D. & Eric Burnett, Ph.D. Building Science Press, Westford, MA. www.buildingsciencepress.com

Designing the Exterior Wall, An Architectural Guide to the Vertical Envelope. 2005, Linda Brock, AIA. John Wiley & Sons, Hoboken, NJ www.wiley.com

Moisture Analysis and Condensation Control in Building Envelopes, 2001. Heinz Treschel, Ed. ASTM International, Philadelphia, PA. www.astm.org

Water in Buildings: An Architect's Guide to Moisture & Mold, 2005. William Rose, Ph.D, AIA, PE John Wiley & Sons, Hoboken, NJ www.wiley.com