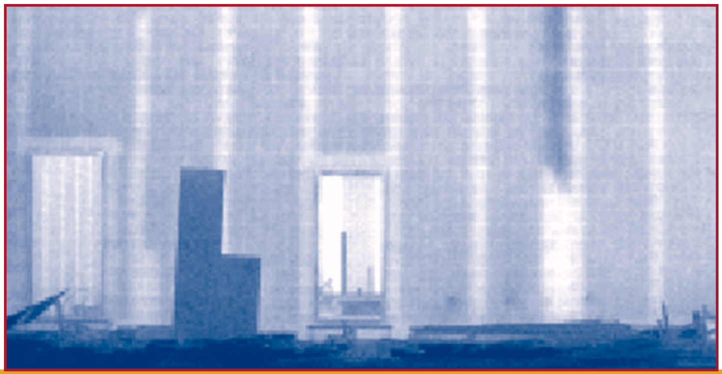
Using Infrared Thermography to Determine the Presence and Correct Placement of Grouted Cells in



SINGLE-WYTHE CONCRETE MASONRY UNIT (CMU) WALLS

By Gregory R. Stockton and Lee R. Allen

Reprinted, with permission, from Volume 3700 Thermosense XXI, The Proceedings of SPIE-The International Society for Optical Engineering, 1999.

ABSTRACT

Determining the placement of reinforcing grout in single-wythe CMU (Concrete Masonry Unit) walls has, in the past, been a painstaking and destructive undertaking. Usually, a test is performed because—by accident—missing cells are discovered when a wall penetration is retrofitted or change order is executed, requiring that the wall be opened. Often, a hammer or hammer drill is used to punch holes where the grouting is supposed to be. The test results are used to extrapolate the extent of the problem. This method falls short, since the sample is so small that only outright fraud can be found, and excess grouting cannot be determined. This paper discusses the results of a joint effort between Stockton Infrared Thermographic Services, Inc. (SITS) and Allen Applied Infrared Technology, Inc. (AAIT) to produce a methodology for using non-destructive infrared thermography to ensure that the design specifications are being met.

INTRODUCTION

It is easy to find buildings that are constructed using CMU (Concrete Masonry Unit) walls. *Figure 1* shows a typical wall. Buildings such as malls, strip shopping centers, retail buildings, schools, and others are built using this method. They are used as inside and outside walls because they are erected quickly, have relative low construction costs, high load-bearing capabilities, fire ratings, and are versatile. With a wide range of densities, colors, decorative outer faces, and treatment options, CMU is a popular method of wall construction.

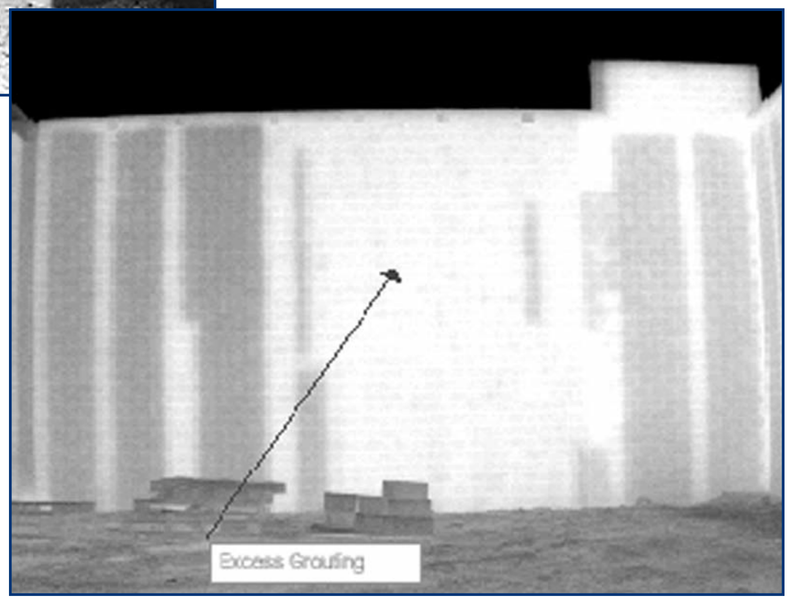
PART I) THE NEED FOR STRUCTURALLY-SOUND CMU WALLS

Value

First, the owner/developer of a building should get what he paid for. The value of the building is dependent not only on its location, location, location—but also on the quality of its construction. The condition of the paint, the flooring, the fixtures, the finishes, and to some extent the roof, are readily assessable. However, the purchaser of a building cannot see inside the walls and therefore cannot make an informed decision with regard to the structure itself.

Liability

After a disaster has occurred, a forensic survey of the walls that are laid on the ground might reveal inadequate grouting. At that moment, the owner would like to have known and acted to correct any faulty construction that occurred during the building process. He may be liable for damage to property and/or loss of life.



Figures 1 and 2) Photograph and thermograph of CMU wall with excess grout.

When construction of a building is planned, an architect is usually hired to oversee design and construction, passing on some of the liability, if disaster happens, to that firm. In turn, the architect hires a structural engineer to design a sound structure which will withstand the structural and wind load requirements of applicable building codes. An insurance company is found to insure the construction. Sometimes a construction management team is hired to ensure that the project runs smoothly, on time, and on budget. A general contractor is engaged (by bidding or negotiating) to oversee construction and provide a warranty, usually for a period of one year, against defects in materials and/or workmanship. The general contractor (GC) hires a masonry contractor to build the masonry walls according to the drawings and specifications.

The owner, at this point, has spread around the liability of acquiring a building that meets the building code requirements and that will be of adequate quality for his purposes. Some of the general contractors pass on some of their liability by hiring a testing company to "sign off" on the building as having met the design specifications. The problem is that the specifications often do not call for all of the walls to be monitored or checked but only a sampling. Everyone involved assumes some amount of liability for the walls. Since he has spread the liability around, the owner sees no need to spend any more money on the project than is required to produce that exact building. This is why only a small percentage of masonry walls is inspected at this time.

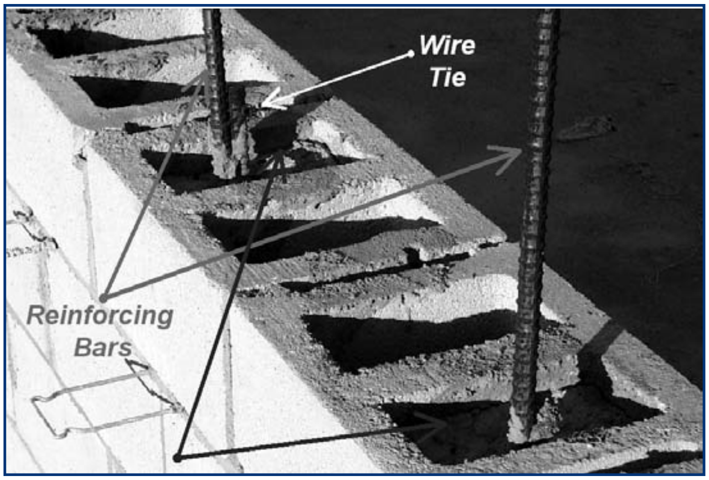
Perception and Reality

Due to their real world experiences at job sites, the perception among engineers and designers is that some "errors" are going to take place during the construction. This leads to a tendency to "over-design" the building somewhat to compensate for inevitable faults, which adds to construction costs and complicates the job. We find many problems, but they are not usually due to fraud. Instead, a lack of skilled supervision on the wall is the reason for most faulty CMU construction. A masonry contractor may seek to take advantage of the fact that since there is virtually no way and/or no will to see inside his work, he can save the expense of putting a highly skilled supervisor on the job. His past experiences tell him to concentrate on what "shows." If the grouting and reinforcement of the walls are of great concern, the GC will lay out the building for his masons. We often find quite a bit of wasted grout in "over-poured" walls. This is due to a long-perceived notion that too much concrete is always better. However, owners concerned about heating and cooling costs do not want excess grouting in the walls, since it displaces the amount of insulation that can be installed. See *Figures 1* and *2*.

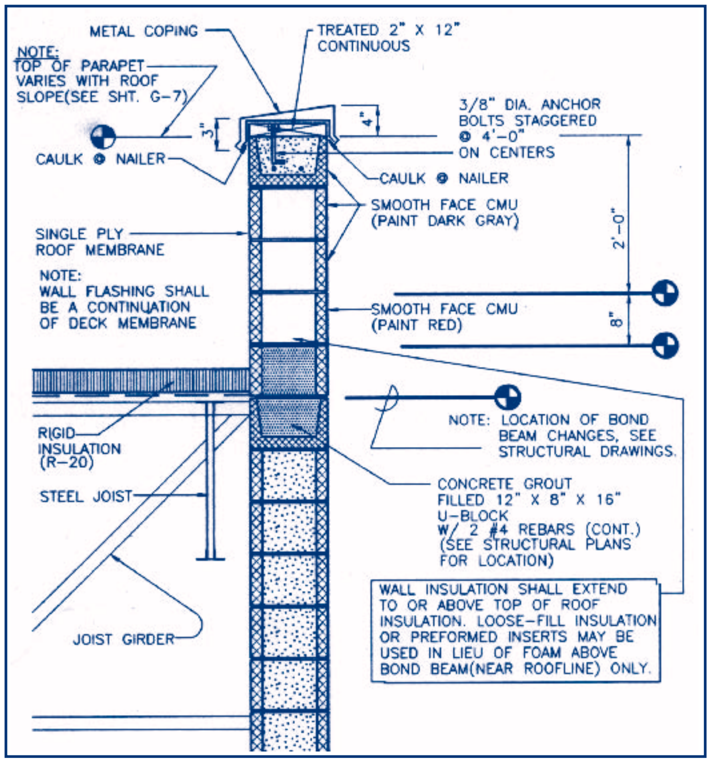
Public Safety

A brick and/or block building "looks" strong, and all buildings are assumed by the general public to be safe. In fact, buildings do not fall down unless some tremendous trauma is visited upon them. Many times CMU walls are reinforced with grout and rebar (reinforcing bars) to serve not only as wind protection (wind load) but also as weight-bearing walls that carry some of the weight (live load) of the roof structure. See *Figures 3* and *4*.

Buildings are assumed to be inherently safe. Some buildings need to be extraordinarily safe, such as schools, hospitals and governmental buildings. They are often used as public shelters against extreme weather conditions such as severe storms, hurricanes, floods, and tornadoes. In these cases, the structural



Above: Figure 3) Typical CMU wall reinforcing.



Right: Figure 4) Typical CMU wall construction drawing.

integrity of the building may be tested under high load conditions where shelter occupants will depend on the strength of the walls for their very safety. The possibility of earthquakes in some areas requires seismic building details.

PART II) CURRENT METHODS OF ENSURING THAT DESIGN CRITERIA ARE MET

There are basically five ways that the owner can ensure a quality product on the job:

On-Site, Real-time Inspection of the Walls

This means having a qualified inspector on site at all times during the construction. Because of the very high costs, this is almost never done. Sometimes a testing company is hired to monitor the wall construction as part of a contract to monitor many trades. The problem here is that time is usually of the essence on these projects, and many trades are working simultaneously to "fast-track" the project. An inspector cannot possibly be at three places on the job site at the same time. Our experience is that (with respect to the placement of grouted cells) there is no correlation between the number of problems found in the walls and whether or not a testing company was hired to watch the construction. City and/or county building inspectors are at the job site only a few hours per week, since they usually have many projects to inspect, and it is not their job to watch constructors.

Installing Inspection Ports in the Walls

Sometimes the contractor will be required to make inspection ports or holes in the wall so that when a pour is made from above, the grout runs out of the wall at these holes. This is a little better method, although the owner has to pay to cut the holes, install removable catches to prevent the grout from running out, patch them after the inspector has approved the installation, and clean the spilled grout off of the wall. This method, too, falls short since:

- It adds much cost to the job.
- A fraudulent contractor can install grout only at the inspection points (although rebar ties can be verified).
- Even when done with the inspector present during the pours (doubling the costs), voids can occur (especially at the top of the wall) above the inspection ports, even though grout runs out.
- Excess grout cannot be determined.

Destructive Testing of the Walls

Destructive tests are carried out most often by using a hammer or hammer drill to punch holes in the wall after it has been erected. This method is by far the most unreliable, labor intensive, and ineffective means by which to test the wall. Even though this is the most undesirable method, it is the one most often used after the structural integrity has been called into question—because it is the easiest. Usually, missing cells are discovered because a wall penetration is retrofitted or change order is executed, requiring the wall to be opened. Typically, the sample is so small (3/8 inch - one inch), that it can only be used to find whether the grout is in place at that exact spot. Excess grout cannot be found, and all test areas must be repaired. The results are used to extrapolate what the entire wall would be. Amazingly, we have seen owners approve a job after one in ten holes proves to contain missing grout, thinking they have 90% correct placement!

Non-Destructive X-ray Testing of the Walls

After a problem is discovered, and if the owner wants to know the true extent of the quality of the grout and the reinforcing bars, an X-ray test can be carried out by a testing company. Usually, while the test is effective, it costs more to conduct the test than the wall is worth. In buildings (such as prisons), where costs are not as important a factor, X-ray testing is the preferred method because the placement of the metal reinforcing bars in the wall, as well as the grout, can be documented.

Non-Destructive Infrared Testing of the Walls

Infrared thermography answers the need for an accurate, inexpensive, non-destructive, non-labor intensive method for finding grout in CMU walls. See *Figures 5* and *6*. Wide areas are covered with one shot. Also, small areas can be tested since modern infrared cameras are fairly portable. Scaled AutoCAD drawings of the problem walls can be produced (see *Figures 7* and *8*). Several ways of using active IR to find the grout and the reinforcing metal bars are currently being tested. There are tools that can magnetically find the metal by scanning them across the wall. This is not infrared. We have found that the quality of the grouting is indicative of the accuracy of the placement of reinforcing bars and the quality of the construction in general. If the grout is not properly installed, it does not matter whether the rebar is in the wall or not, since the two work together. If the grout is properly installed, the reinforcing can be spot-checked.

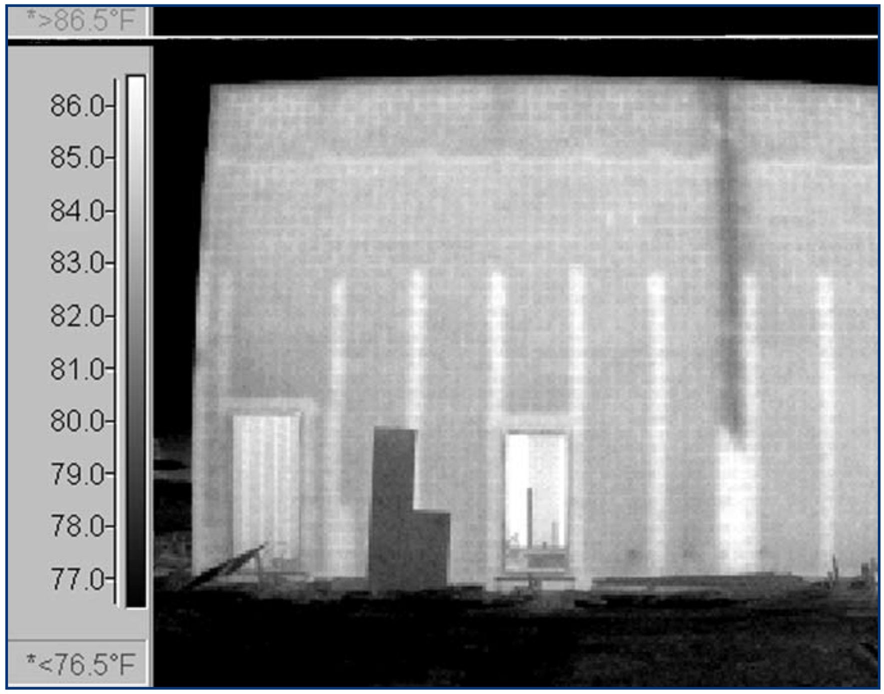
PART III) A HISTORY OF THE DEVELOPMENTS IN METHODOLOGY FOR IR INSPECTIONS

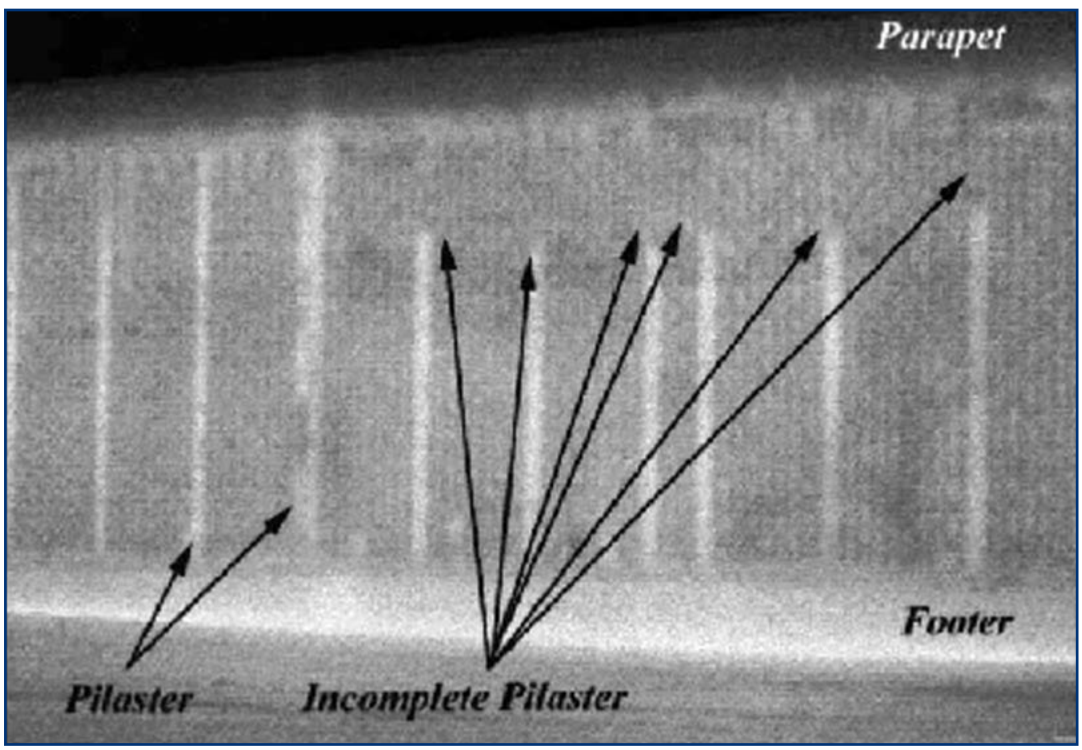
The author's company discovered the need for these surveys and started performing them at the beginning of 1990, after performing some tests to check the quality and measure the effectiveness of different types of insulation products that were being installed in masonry walls. We were using an Inframetrics 600 imager which, at the time, was the state-of-the-art. We found that while a ∅T of as little as 1 to 2° F was sufficient to discern the difference in grouted and non-grouted cells real-time on the screen, a 4° F ∅T was required in order to document the faults. We needed to produce construction-site usable documentation. We were limited by 8-bit analog signals recorded on VHS videotape at 330-lines of resolution. Even using the latest image post-processing hardware/software and the best printing technology available at the time, we needed to be close to the wall (to get the pixels—which limited the amount of wall area that we could document at one time), and we needed to get about a 4° F ∅T.

Over the past nine years, we have developed the following techniques for obtaining the ∅T needed to perform surveys and produce hard copy reports that field personnel can use to make repairs.

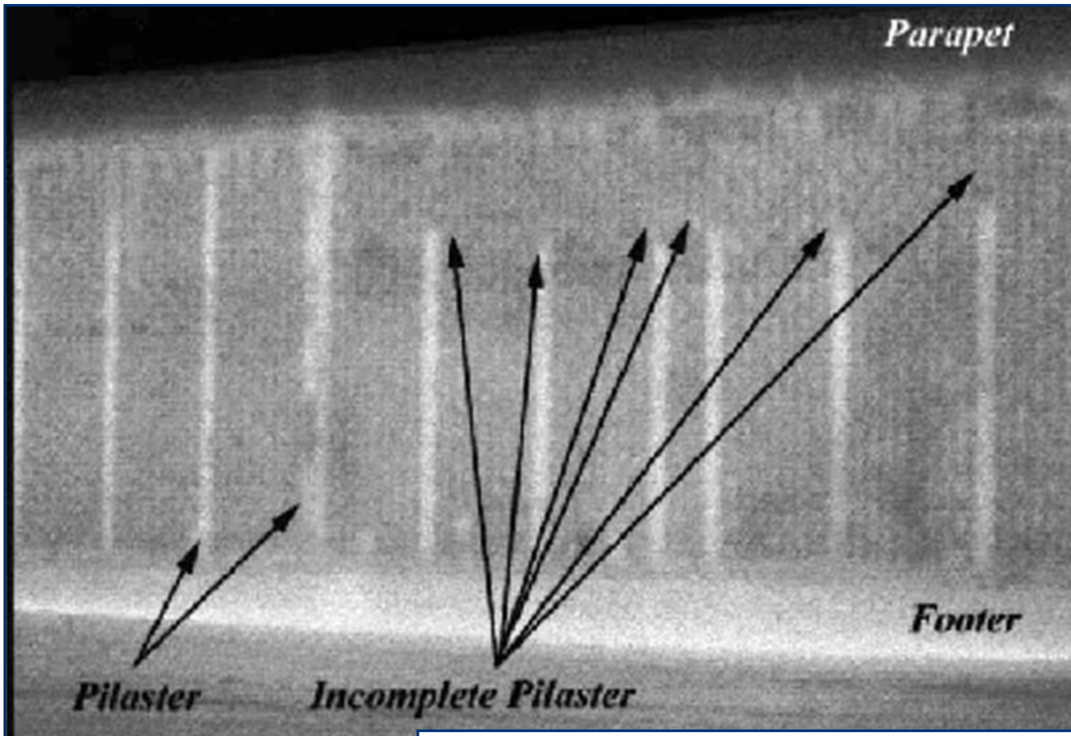
HVAC Control

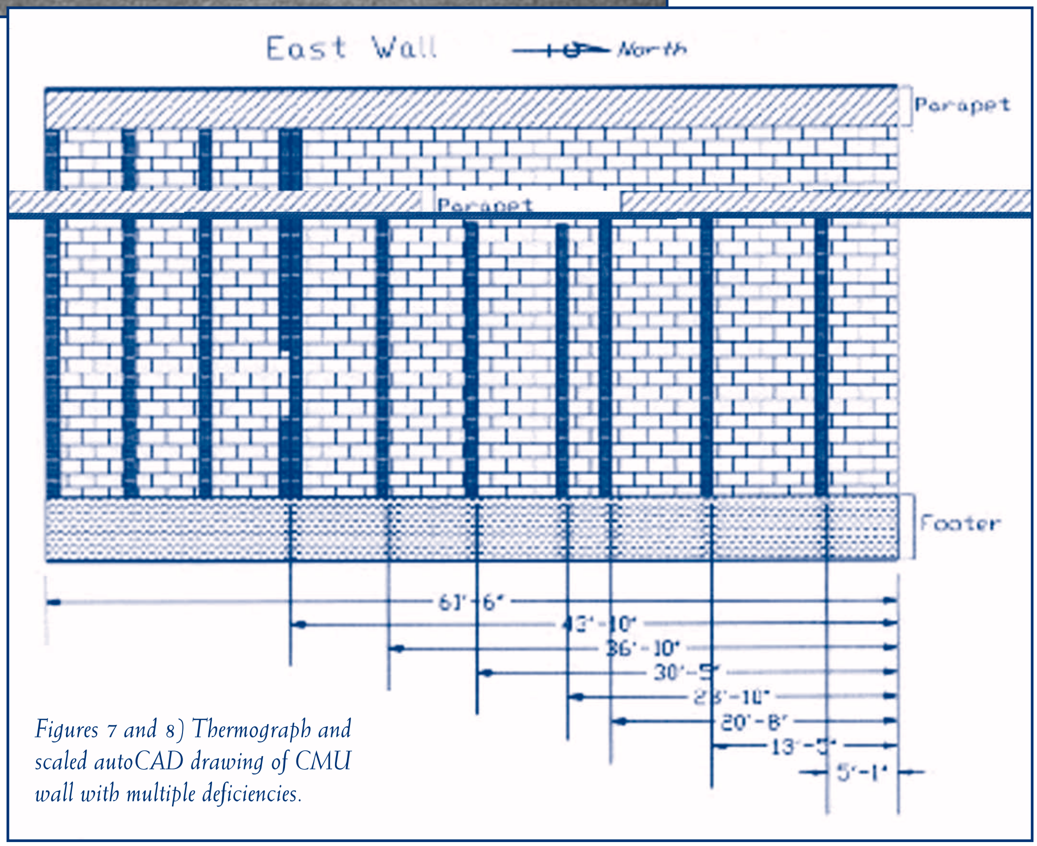
At first, to accomplish an inspection, we went to the building after it was finished and the HVAC system was engaged. For example, with a 70 degree F inside ambient temperature and a 40-50 degree F outside ambient temperature, we were able to get a sufficient delta-T to make a usable, printable report. This worked fine for a few years. With increased business due to higher quality work and increased awareness, with practice surveying the buildings and making the reports, and with steady advancements in computer and printing technology, the reports became better and better.





Figures 5 and 6) Photograph and thermograph of CMU wall with improper placement of grout.





Figures 7 and 8) Thermograph and scaled autoCAD drawing of CMU wall with multiple deficiencies.

Artificially-applied Heat

During this period, we were asked to survey the inside walls of some of the buildings. Since inside walls have roughly the same temperature on both sides, we had to come up with a way to artificially produce the desired ∅T. Many buildings do not have individual room controls, and those that do usually can only develop a 10-15 degree difference in temperature between rooms at best. So we knew that we could not use the HVAC system.

We tried using space heaters to help heat the room air but found that this process was too slow. Our answer was to get a bigger heater. We chose a "torpedo" type forced-air kerosene heater because it can be directed straight at the target wall, and it can develop a tremendous amount of heat quickly. We found there are three ways of using these heaters. First, one can aim the heater in different directions in the room to heat the air. A second way is to aim the heater at a specific wall, stand on the other side and watch the non-grouted cells heat up, leaving the grouted cells exposed as cooler areas. This takes about 5-10 minutes depending on the density and thickness of the wall and the size of the area being heated. A third (and the quickest) way, is to aim the heater at the wall for about two minutes, remove the heater and since non-grouted cells heat up more quickly, this leaves the grouted cells exposed as cooler areas. It takes only about three minutes, also depending on the density and thickness of the wall and the size of the area being heated.

The Sun's Radiant Heat and Thermal Effects

Early in 1994, our customers started asking if we could perform these surveys during construction. They wanted to make the corrections as early in the process as possible. They (and we) found that even though the masonry contractors knew we were going to inspect the walls upon completion, and even though they knew we could see what was inside the wall, we were still finding many problems. The owners, architects, and structural engineers wanted the repairs made but wanted to avoid the business interruption of having a contractor working on repairs while they were trying to open the doors for business. This was a challenge. We needed a way to heat the walls of a building that had no operative HVAC system and were much too big to heat artificially, at least for what they were willing to pay for the survey.

We had experimented from the beginning with using the air temperature and solar loading of a building to help us perform surveys but it was much easier to use the through-wall effect to achieve our desired ∅T. We knew that late on a clear, cold night, we could definitely perform the survey. Unless it started raining heavily, we were going to get the survey done. Also, there were logistical considerations. Site conditions were much better for our work late in the construction process. Tradesmen are not in the way (and we are not in their way). All of the walls are up. We decided the best way to figure out what worked and what did not work was to go to a job and see what took place thermally, over a 24-hour period. The thermal dynamics of a CMU wall in a building are affected by many factors. Here is what we found:

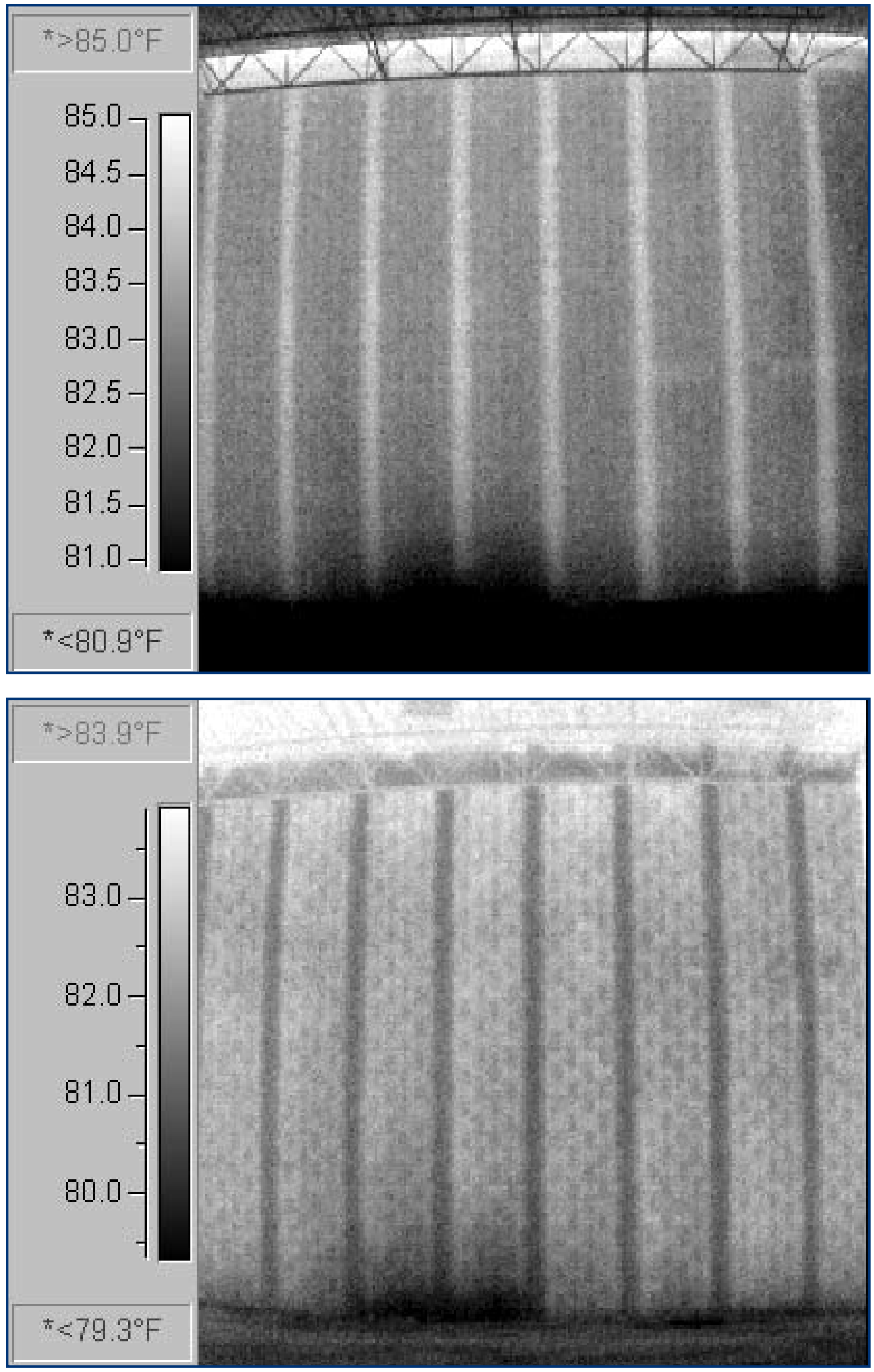
Using the sun's thermal energy to heat the walls of a building without an active HVAC system is the best method, because it is free and powerful. The direct radiation from the sun and indirect result of the rise and fall in ambient temperatures during day and night hours will heat and cool the walls.

After sunset, wall areas that contain grout are warmer than the empty cells because these areas are of higher mass which makes them cool more slowly than those of lower mass (non-grouted cells). Of course, clear nights help the radiation cooling process. At sunrise, the sun radiates into the wall and the ambient temperature rises. Areas of higher mass (grouted cells) warm more slowly than areas of lower mass (non-grouted cells).

This cycle of uneven heating and cooling allows a sufficient ∅T window of opportunity for the inspection to be carried out.

The absorption of thermal energy into a CMU wall may be affected by many factors, including:

- The emissivity of the wall,
- The emissivity of any coatings on the wall (such as paint, filler, or even water),
- The moisture content of any coatings on the wall,
- The moisture content of the CMUs,
- The density of the CMUs,
- The wind,
- The overall weather (48-60 hours prior),
- The orientation of the building to the path of the sun,
- The angle of the sun at different times of the year, and
- Whether or not the building is being artificially heated or cooled from within the building.



Figures 9 and 10) Thermographs of the same CMU wall at two different times during the day.

PART IV) THE NUTS AND BOLTS OF DATA COLLECTION AND REPORTING

Performing the survey during the window of greatest ∅T between grouted and non-grouted cells is of utmost importance. This lag time between the two different masses is the key to success. See *Figures 9* and *10*, of an east-facing wall, taken from inside the building, surveyed during the month of July in North Carolina.

Grouted and non-grouted areas are easily seen. A time vs. temperature graph (*Figure 11*) of a typical wall over a 24-hour period shows how grouted and non-grouted areas heat and cool over the course of a summer day and night. Unfortunately, all walls cannot always be surveyed under ideal conditions. For instance, during the winter months, because of the orientation and low angle of the sun to the building, some outside walls do not receive direct sunlight at any time during the day. This does not mean that these walls cannot be surveyed. The change of temperature over the day is the main factor. Inside walls never receive any direct sunlight. Awnings or canopies may cover other walls. Timing is the key. However, as stated earlier, just

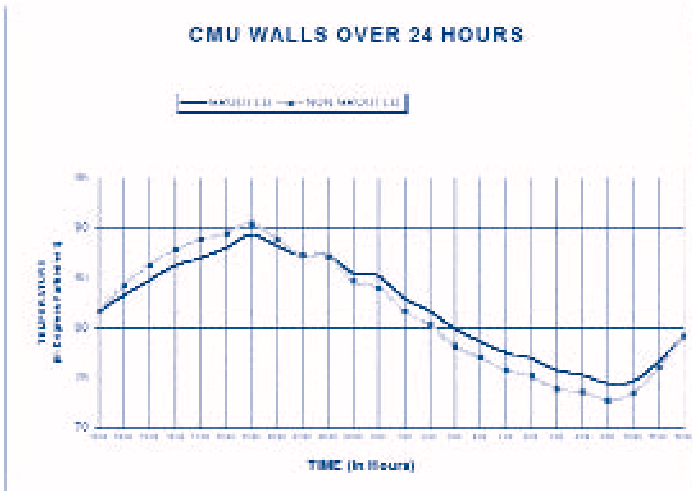
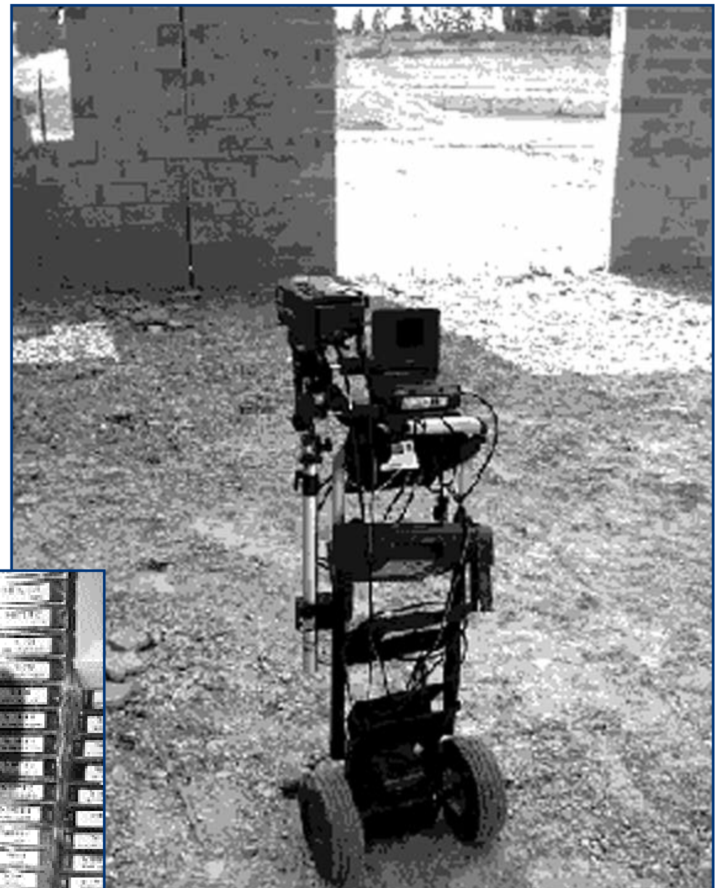
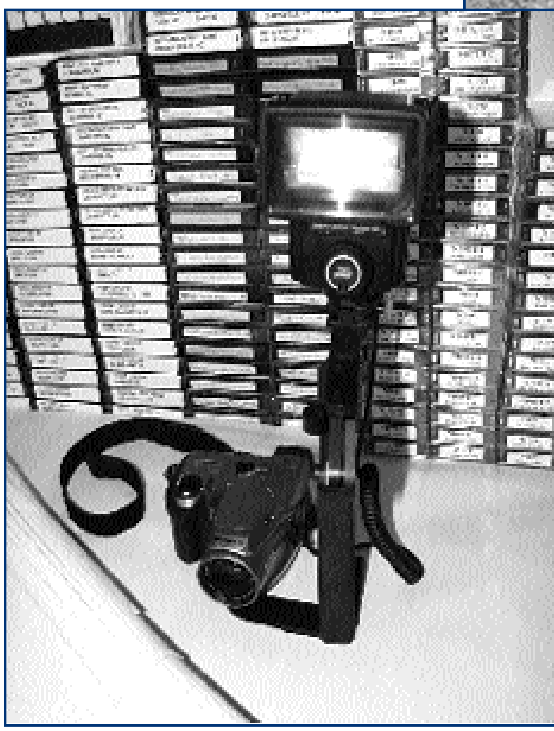


Figure 11) Time vs. temperature.



Above: Figure 12) Photograph of a cart-mounted 390 ThermaCAM™ with continuous recording system.



Left: Figure 13) Photograph of a 1.4 megapixel digital camera and flash assembly.

being able to discern where the grout is, standing in front of the wall, is not going to produce a usable report. The imagery has to be of sufficient quality to print so that the repairmen can use the printed report to fix the problems. High-quality visuals are very important here. Also, the visual and infrared images need to match. We have found that color imagery, in some cases, helps field personnel understand the images easier. We also use computer tools such as arrows and boxes on the images.

When we began surveying these types of buildings, we were using an Inframetrics 600, always mounted on its cart. During the night, we recorded all infrared imagery of each wall on videotape, panning back and forth, up and down, until the wall was completely covered. We surveyed the inside and outside of each wall, creating a detailed data log and collected infrared images of all wall locations. When a thermal anomaly was discovered, we "froze" the image and recorded it (in black and white and multiple colors). Then we left a space of about thirty seconds blank on the videotape immediately behind the "frozen" image.

The next day, we went back to the walls in order, playing the tape forward and reviewing the walls that we were standing in front of the night before. When we found the anomalies on the videotape and on the wall, we recorded a matching visual image with a camcorder, in the blank space. To make the thermographic reports, we captured a frame and printed the images with a thermal printer to prepare the report, gluing the thermographs and photographs directly to the page. Later, we started using a video frame capture board in the computer to "cut" the infrared and visual images from the videotape and "paste" them onto the report page.

In 1996, we began using a Mitsubishi 5120-C to perform the surveys. Basically, we did everything the same way, although having a focal plane array with 512 x 512 pixels was a definite improvement. Using a 50mm lens, we could back up far enough to get an entire wall section (these buildings use a grid line system based usually on structural column lines) in the image all at once. This made report preparation a little easier, and the image quality was much better. The 5120-C is a large and power-hungry instrument. Hauling the camera, power supplies, monitor, huge cable, recording equipment and two deep-cycle batteries (200 pounds) around muddy, hole-ridden job sites became a real problem.

We were using an M-600 within one year. The Mitsubishi M-600 is somewhat lighter, smaller, and uses less power. With a newly designed cart, we could pull it around the job sites much easier. Since it has a higher fill-factor, the images were also better. With no color output capabilities, however, we had to take the images into Adobe Photoshop® in order to colorize them.

We began using an Inframetrics 390 ThermaCAM® cart-mounted system (see *Figure 12*), recording continuous Hi8mm videotape in 1998. Currently we use a digital visual camera (see *Figure 13*) for the visuals. When we survey large and/or complicated buildings, we record audio (voice) information onto the video, calling out the column lines or other information. Since it does not have the pixels that the Mitsubishis have, we are using a 32-degree wide-angle lens, which allows us to get closer to the wall (to get the pixels) while maintaining the column line-to-column line technique. The big advantage to the ThermaCAM® is that it is small, lightweight, and we can save 12-bit images with the on-board PCMCIA flash card. This allows us to use TherMonitor® Pro software to recall the images in order and adjust them to our liking. We then cut and paste them into our custom PowerPoint® templates. Photo-quality prints of individual report pages are then produced to make the report. Since they are .ppt files, we can project them on screen during the report presentations.

The completed report package from a qualitative infrared thermographic survey of masonry walls should include:

- VHS copy of the original Hi8mm or Super-VHS infrared videotape of the entire survey from both inside and outside of the building.
- Printed hard copy report cover letter explaining the procedures, conditions, areas that contain anomalies, etc.
- Individual thermographic report pages of the findings, explaining exact location (referencing column lines) and condition of the walls in question, using photo-quality prints of the visual and infrared imagery.
- A copy of the pages of structural drawings that have a plan view of building (with the column lines indicated) where the anomaly is found. The plan should be marked with arrows as to the position of the IR camera and the direction that the image was taken.
- A complete copy of the original report (of the same highest quality), for field personnel use.

Also, the report should be hand delivered and presented formally to the owner, architect, or structural engineer. Questions can be answered immediately and repairs can begin before the walls are covered.

PART V) USES FOR IR SURVEYING OF EXISTING CMU WALLS

Before a building is purchased, a potential owner can check the masonry walls. If problems are found, the price can be negotiated accordingly. When an architect is designing a building retrofit or addition, he could have an infrared survey performed in order to discover where the reinforcing is in the building. The walls can be marked so that the contractor can "tie-in" the addition to the existing building and know where to attach new structural members. Similarly, if the owner wants to add a floor to the building, this type of information could be invaluable.

PART VI) CONCLUSIONS

Using one or more of the techniques described in this paper, an infrared thermographer can successfully survey just about any CMU wall in any building. This brings benefits to building owners in particular and to the building industry in general.

Here are the advantages:

CMU Wall Construction

Usually, the construction of these types of buildings is more or less in this order:

- Site work
  - Foundation & footings
  - Steel for walls
  - Masonry walls
- Steel for roof
- Roof
- Floors
- Coatings
- Fixtures
- Finishes
- Furnishing

(Electrical and mechanical systems are installed at various times throughout the process)

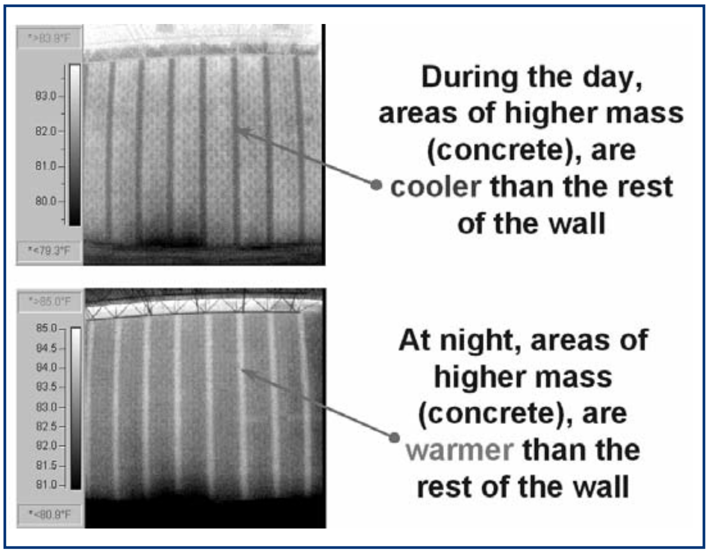
A 12" CMU (block) is 12" wide x 8" high x 16" long. Usually, there are two voids inside, making the total solid volume 60%. Blocks are commonly produced either in a 12", 8", or 6" thickness. The size, density, and amount of the CMU that is solid are specified depending on the use of the wall—i.e., load-bearing wall, outside wall, inside wall, firewall, partition wall, sound wall. The size and number of reinforcing bars in the grouted cells, the amount and type of grouting, and the spacing of grout–ed vertical and horizontal reinforcing are dependent upon structural requirements and other factors.

Typically, a metal reinforcing bar comes up from the footing and is tied (usually with wire) to the next reinforcing bar. The wall is laid up in "lifts" to the maximum specified height. At that time, the cells (voids) are filled from above with grout (concrete mix), either by pumping or by pouring it out of buckets. *Figure 3* shows an example where the designer specified vertical reinforcing in grouted cells to be placed every 24" on center. The mason must place a reinforcing bar and grout every third cell.

Grouted areas in masonry walls can be detected by using infrared thermography. These include:

- Vertical reinforcing (commonly called pilasters).
- Horizontal reinforcing, usually in the form of continuous bond beams.
- Filled cells at steel plate attachment points .
- Reinforcing around openings such as doors and windows.

- Confident that what they put in the specifications will actually be built, designers can stop "over-designing" buildings to compensate for inevitable faults in CMU walls. This will save owners from paying for more materials in the building than they really need. It will also simplify construction and save valuable time on the job.
- Because walls can be verified as safe, owners and their insurance companies will enjoy the confidence that the building will hold the weight of the roof and withstand high winds.
- General contractors can reduce the cost of inspections, since the walls can be checked once, at the end of the job.
- Masonry contractors who are not willing or capable of producing wall structures that are free of defects will not bid on projects requiring infrared inspection.
- If faults are discovered, high quality reports can be generated and presented to the owner, so that repairs can be carried out in a timely manner.



Infrared thermography can be used on the job site as an effective way to improve the quality of construction. The challenge for infrared thermographers is to continually make improvements to equipment and techniques, so that they can efficiently and effectively collect data and produce understandable, usable, competent reports for building owners. ■

About the Authors

GREGORY R. STOCKTON

Gregory R. Stockton is President of Stockton Infrared Thermographic Services, Inc. Based in Randleman, NC, the corporation operates six complete infrared systems in five divisions. Greg has twenty years experience in the con struction industry, specializing in energy-related technologies. He is an Infraspection Institute Certified Infrared Thermographer (#3583) and publishes technical papers for the infrared industry.

LEE R. ALLEN

Lee R. Allen, 75, served in the US Merchant Marine from 1943-1948. He was a heating and insula tion contractor between 1948 and 1989. In 1980, he started AAIT (Allen Applied Infrared Technology). Allen chaired Thermosense XV (the conference of the International Society for Optical Engineering) in 1993. Lee claims to be the oldest active infrared thermographer in America.