Thermographic Evaluation of Concrete Masonry Walls: Have They Been Properly Reinforced?

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ABSTRACT

Infrared thermographers literally walk by more work than they can do. The world is one big radiator, and new, non-traditional applications for infrared thermography are being found every day.

This paper discusses one of these non-traditional applications; specifically, the use of infrared thermography to find whether or not concrete reinforcing (grouting) has been properly placed in Concrete Masonry Unit (CMU) or 'block' walls. These walls are being erected everywhere. They are used to build discount stores and shopping centers, schools and buildings of every size and shape. They are almost never built exactly to specifications, and by using infrared thermography it is possible to see and report the faults in the walls, so that timely repairs can be accomplished.

This paper discusses the development of the technique that we use to image and evaluate these building walls successfully, and to make usable reports of our findings. I also discuss some market factors for infrared on buildings in general.

Keywords: infrared, thermography, concrete, masonry, CMU, walls, grouting, reinforcing, construction

1. INTRODUCTION

The infrared inspection of buildings for heat loss was one of the first commercial uses for infrared thermography. Annually, I get at least thirty inquires, mostly from our website, from people who are interested in going into the infrared business with the idea of checking buildings for heat loss. I tell them the following:

There are four types of buildings by use: residential, commercial, industrial and institutional. Because energy prices in the United States are held low relative to the rest of the world, heat loss surveys are not performed often on buildings. **Residential** owners move frequently and since IR and blower-door testing is not itself remedial, they are not willing to spend very much to find out what is wrong, unless they are uncomfortable. **Commercial** buildings are often leased to a tenant who does not want to make repairs to a building not owned by him. The commercial building owner sees no need in repairing the building because he is not paying the utility bills. **Industrial** building owners will not fix the building unless the operation is being affected. Heating and cooling the building is a small part of his utility bills anyway. They also have more important issues to deal with, like making the widget machines run faster. **Institutional buildings,** like schools and government buildings are usually built under a rigid set of guidelines. These designs are perceived to be sound, as are the buildings.

So until the occupants are miserable, damage is occurring or the operation is affected, and as long as energy prices remain relatively low, heat loss is not perceived to be a problem by building owners. That is why performing heat loss surveys for a living does make the basis of a very good infrared business. Below, I will deal with the <u>structural</u> inspection of the walls of one type of building: CMU or concrete masonry unit. Fig. 1 is a photograph illustrating typical CMU construction.

Figure 1. Typical CMU wall section.

2. THE NEED AND THE MARKET

Structural problems in a CMU building are a problem as can be seen in the thermogram of figure 2. This thermogram of a CMU wall section indicates multiple deficiencies, and as long as the owner is approached before the building is finished, there is a market potential for the structural infrared surveying of buildings.

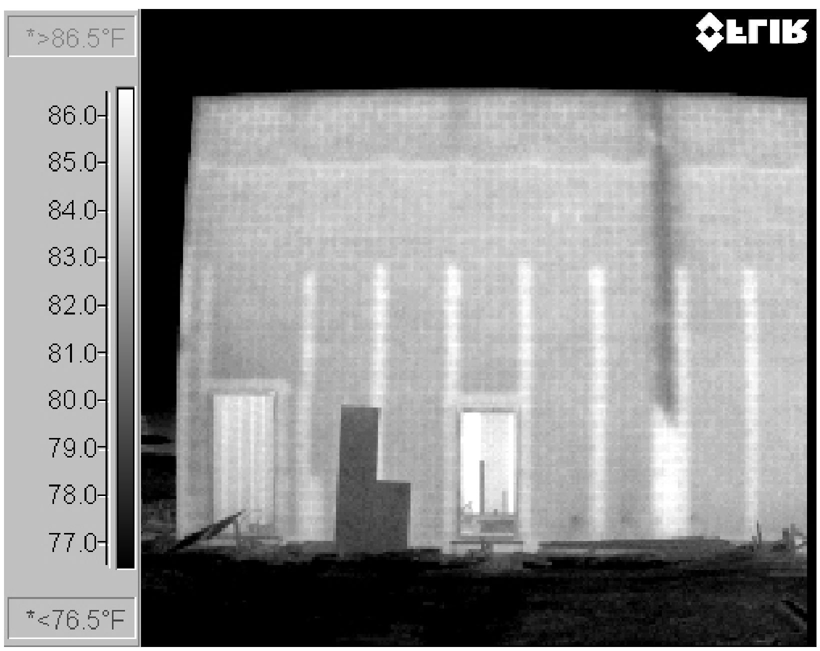

Figure 2. Thermogram of a CMU wall section showing multiple deficiencies. (Pilasters are warmer.)

But, building owners, by and large, are not interested in knowing this information for several reasons. As stated earlier, they may be leasing the building. Also, as long as someone (a testing company) is willing to 'sign off' on the building as meeting the minimum requirements, the owner may consider his liability covered, even though this it is not the case. 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 do not have the time or resources to watch constructors. The insurance companies are only interested in checking a building that will be visited by some terrible trauma, like an earthquake, tornado or hurricane. Since nobody can predict *which* buildings are going to be hit, they do not consider inspecting all buildings to be a cost-effective practice. Generally, the construction management team: the architect, the structural engineer and especially the general contractor, think that no possible good can come from another test. They are given a big incentive [money] to make the project happen on time and within budget. The masonry contractor certainly does not want someone pointing out that he “missed a spot”. Anyway, the perception is that these walls are being built somewhat to spec. Also, engineers tend to ‘over-design’ the building on purpose, so that they are within the minimum requirements even if some of the pilasters are incomplete. This practice costs everyone extra time and money.

We find many problems with the construction of CMU walls, but judge these defects are almost never caused by fraud. Instead, poor supervision on the job is the cause for the poor quality. Some buildings are effectively grouted, but it takes extreme and costly measures. For years, the only way that a building owner had of looking into a masonry wall was to drill (or hammer) a hole in it. This testing method does not work, because only a small sample is tested. X-ray testing is *so* slow and expensive, that it is usually cheaper to knock the wall down and start over if its structural integrity is called into question. If the owner really wants to make sure that the grouting and rebar are in the wall, the most popular means is to require the installation of inspections ports or holes, cut in the block faces. These are installed at every lift height and at all grouted vertical pilaster locations as shown in Fig. 3. This is a very costly, time-consuming and sloppy method. That is why infrared is so valuable. It is fast, inexpensive and accurate.

Figure 3) CMU wall section with inspection ports.

No matter what the perception, there <u>are</u> many problems. Especially with schools, there is a tremendous market potential here. Almost all schools are built using CMU walls. Interior walls can be painted, making a durable, yet inexpensive finish. Exterior walls are painted on the inside and made to receive brick faces or stucco finishes on the outside. Unlike other building owners (who can hire anybody they want to build the building), schools are built with government money and mandated to accept the lowest bidder. The low bidder may not have the money in the job to hire a full-time quality control supervisor. These buildings are public shelters. Get to the owners (the school board and their construction officials) and sell them on the idea! NOW is the time to develop this market. Existing schools are overcrowded and there is money available for new school construction.

3. THE BEGINNING

Early in 1990, I was working with Lee Allen, AAIT Corporation, testing the effects of different types of masonry insulation for a grocery store chain. We were using the building’s heating, ventilation and air conditioning (HVAC) system to create a 20F degree difference in temperature between the inside and outside of the building, in order to see the effectiveness of each insulation. Because surface temperatures are affected by the differences in mass inside the wall, we noticed that many of the grouted cells were out of place, incomplete or missing completely. With an active heat source and a constant 20F degree delta-T, it was easy to see the pilasters (grouted cell columns created by pouring concrete in the cells vertically, as shown in Fig. 4.

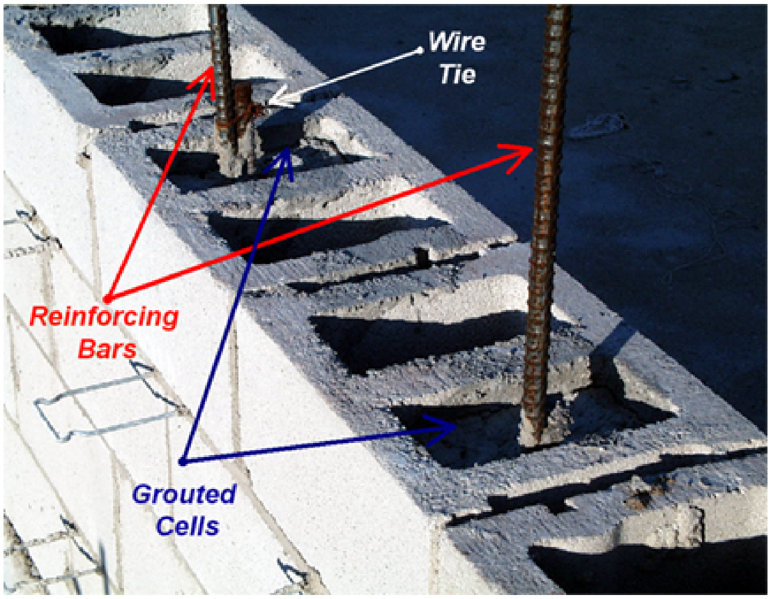

Figure 4) Typical 12" CMU wall construction

We actively sought out interested parties to whom to market our new 'test'. After we found a few clients who wanted to know this information, we set out to improve our methodology. We were working exclusively on new buildings and found that by the time they had the HVAC system active in the building, it was close to being completed. The repairs that resulted from our tests were causing problems for the owners because they were being carried out too late in the building process, resulting in business interruption. So we set out to find a way to do the infrared testing earlier in the building process.

4. EXPERIMENTING WITH THE PHYSICS

We started by heating sections of the building with forced-air kerosene heaters, which worked great on small sections, but took too long on large buildings. So we went back to basics. We knew that the Sun needed to be our heater. If you want to see "inside" something using infrared, you have to either; heat the object and watch the heat come through the other side; or, heat the object and watch the surface heat; or, heat the object and watch the surface cool. Of course, this works with applying *cold* to the surface instead of applying heat to the surface. We tried all three to see which one worked best.

First, we got on the inside of the building on an East wall in morning and watched the Sun's energy come through the wall. Grouted cells, being higher in mass, warm more slowly than the lower mass of insulated or empty cells. This works great, except that you have to follow the Sun around the building. Also, some walls do not receive direct sunlight at any time during a particular day (or season) while others are blocked from sun entirely by the building itself or by an adjacent building or other object(s).

So we went on the outside and watched the surface temperatures change when the Sun hit the wall. Because the Sun's radiation is *so* powerful, often the image becomes 'washed out', especially on reflective surfaces, like painted walls. Also, for the same reasons as stated in the previous paragraph, some of the walls never receive direct sunlight.

Even though we got *some* great imagery, we were discouraged by the imagery on the non-radiated walls. We were not satisfied with 50% or 60 % coverage or mediocre imagery. We were down to one option, which was "heat the object and watch the surface cool ". We waited until 3:00AM and went back to the job site. There they were—blazing hot pilasters, relatively speaking. From both the inside and outside of the building, the pilasters were warmer than the rest of the wall.

5. DEVELOPMENT OF THE SOLUTION

Finding pilasters in the middle of the night had worked. Because the lack of heat is uniform, it is the equalizer. Timing turns out to be everything. Areas of higher mass heat up and cool down at a different rate from those of lower mass as shown by comparing the daytime and nighttime thermograms shown in Fig. 5. The walls absorb the Sun's heat during daylight hours and radiate that energy back into the atmosphere at night. This is why, as with infrared roof moisture surveys, clear nights are preferred so as to see the higher mass [water] in the roof's substrate. Each wall has a thermal 'life' of its own, so we sometimes have to wait for a wall to reach it's peak delta-T between the different masses; grouted and non-grouted cells. Fig. 6 shows a time vs. temperature plot of a South-facing CMU wall, over a 24-hour period.

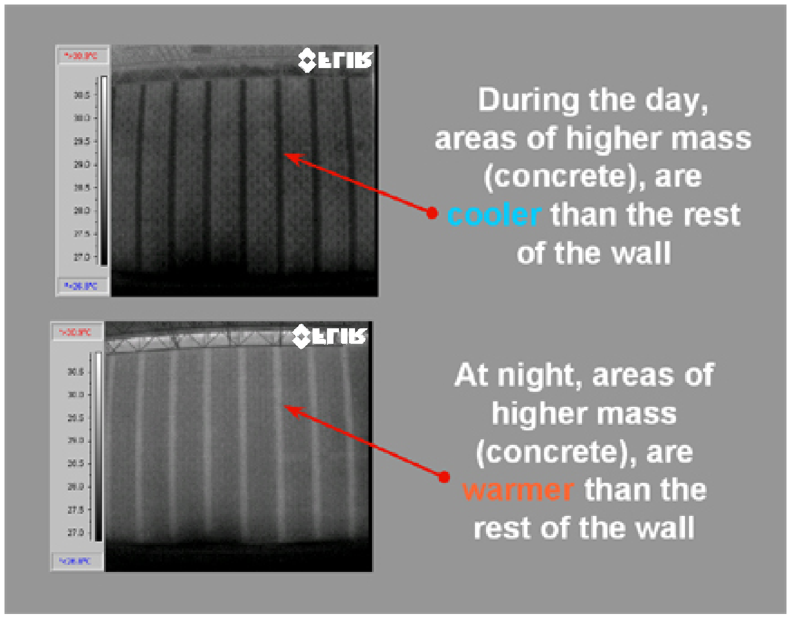

Figure 5. Thermograms showing daytime and nighttime temperature patterns.

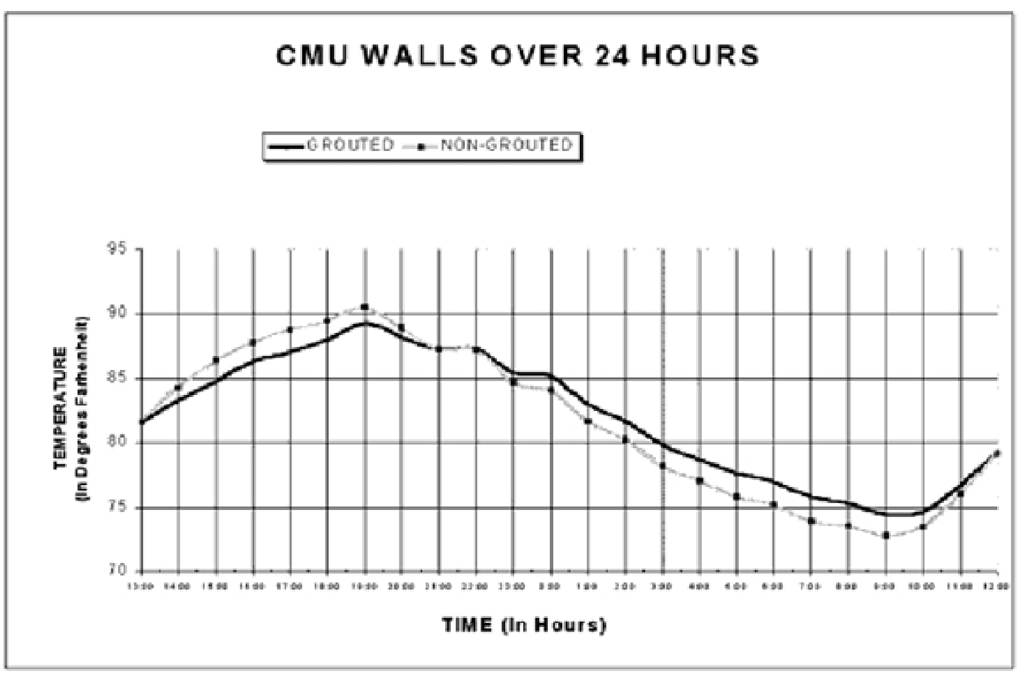

Fig. 6 Time vs. temperature plot of a South-facing CMU wall, over a 24-hour period.

That problem solved, we set out to make more beautiful imagery and put it on usable, easy-to-understand reports. Remember, at the time, state-of-the-art meant printing 8-bit Inframetrics 600 images captured by a dye-sublimation thermal printer, glued onto the page. The visuals were recorded on the videotape the next day with a camcorder, and printed the same way. We made videotape referencing the time on the camera to a section of the wall. One problem with the reports was the fact that the findings were of a relatively small area of the entire wall section. By the time we backed-up far enough to get a forty-foot wide building section (column line to column line), we lost too much resolution to print a brilliant thermograph.

In 1996, we started using a Mitsubishi 5120-C. Basically, we did everything the same way. Using a 50mm lens however, we could back up far enough to get an entire wall section in the image all at once, because we had 262,000 pixels. 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 a Mitsubishi M-600 in 1997. The M-600 is somewhat lighter, smaller and uses less power. With a newly designed cart, we got around the job sites much easier. Since it has a higher fill-factor, the images were also better. With no color output capabilities, we had to take an image into Adobe Photoshop™ if we wanted to colorize it. In 1998, and still today, we use an Inframetrics 390 ThermaCAM™ with a 32degree wide-angle lens mounted on an Inframetrics 600 cart. The wide-angle lens allows us to get closer to the wall (to get the pixels), while maintaining the column line-to-column line perspective. We are currently using an Olympus D620-L digital visual camera for the photographs. It has a sync flash connection, so we can set off a large flash when needed.

Schools are more complicated than the typical retail building, so we record audio (voice) information onto the videotape, calling out the column lines or other information. 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 sequence) and adjust them before digitally pasting them on the report page.

6. THE FINISHED PRODUCT-THE REPORT

Making a quality report takes some effort. You have to know how to read the building plans. We usually print a draft copy of the report the next morning, before going back to the jobsite, so the photographs can be properly lined-up with the thermographs. The report should include the following:

- A hard-back thermographic report notebook, printed on photo-quality paper, containing:
    - Report letter explaining the survey, and giving an account of the conditions and any notations.
    - An individual thermographic report of each problem area, with thermographs and perfectly matched photographs. Also, the exact location of the problem, referenced by wall section and description of the anomalies found. The thermograph and/or photograph should have arrows pointing to problems.
- A videotape of all infrared imagery of every wall, taken from the inside and the outside of the building.
- An original building drawing (supplied by the owner) marked with stick-on arrows, indicating the position of the camera, the direction of the shot and the corresponding thermographic report number.
- A CD with the PowerPoint presentation of the entire report, the digital image files of all infrared images, and the digital image files of all photographic images.

The report should be hand-delivered and presented to the client by PowerPoint slide presentation. A complete original (not color copy) should be made of all components of the report, including the marked plans, CD and videotape, for field use.

7. CONCLUSIONS

Today, infrared thermography is the best tool for the surveying of a masonry wall to find deficiencies in the structural components and/or the thermal envelope. It is fast, inexpensive, accurate and it will save money on the job in many ways. Using the methods described above, CMU walls can be effectively and efficiently surveyed. Once the owner is confident that the specifications will be followed, his designers can stop specifying more grouting than is necessary. This will save the owner on materials and the contractor time on the job. The high costs of other, less effective inspection and verification techniques such as ‘ports’ can be avoided, since the walls can be accurately checked once, after they are erected, but before the resulting repairs can cause delays. Lastly, contractors who are not willing to put qualified supervision on the job and build the building right the first time, will either absorb the expense of making the repairs or hire companies that will build it right to start with.

This and other non-traditional uses for IR are being developed daily. Some of these can be quite profitable for the infrared thermographer. Their challenge is to find, develop and successfully market their techniques.