Using Thermography to Find a Class of Latent Construction Defects.

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ABSTRACT

An issue that continues to plague the construction industry, nails and screws coming into contact with copper water pipes, can be diagnosed with infrared thermography. A leak may not immediately occur, but galvanic action between the steel fastener and the copper pipe will eventually lead to a hole in the pipe, although it may take months or years for the leak to develop. Thermal imaging can be used to detect this class of latent defect before it becomes an expensive water leak or mold remediation. This technique relies on the high conductance of the metal screws or nails. By running hot water through the pipes, a metal fastener that is in contact with or near a water line will heat up more quickly, and at a higher temperature, than the nearby wall board, providing an easily observable hot spot for an infrared camera. This paper will describe the techniques developed to detect this class of latent construction defect, and show examples of its use in both renovation and new home construction.

INTRODUCTION

The availability of thermal imaging for use by the construction industry has provided a new tool to help contractors find a class of building defects that are difficult to detect via other methods. Most contractors have had the experience of a nail or screw penetrating a water pipe. Many of these defects are caught during the construction process, but some don't show up until months after the occupants have moved into the structure. Any leak into an occupied area can result in significant damage to flooring, wall coverings and building contents. Slow leaks that aren't detected for months or years can turn into expensive mold remediation problems in the future.

The techniques presented in this paper began as a theoretical discussion during a Building Science training class, and were refined through testing both in the laboratory and on construction sites. The concept is straightforward. Metal is a better thermal conductor than either wood or sheet rock. If a metal fastener is in thermal contact with a pipe carrying hot water, the fastener will appear hotter than the surrounding sheet rock and the temperature difference detectible in an infrared thermogram.

The paper is divided into two sections. In the first, we discuss a jig that was built to test the concept and develop a procedure to test for fasteners in contact with metal water pipes. In the second section we discuss the application of the procedure in a new home under construction, and some of the issues involved in applying the techniques at various stages during the building process.

BUILDING A TEST JIG

In order to test the ability of thermography to detect these construction defects early, we built a small wall with imbedded water pipes. The wall was constructed using standard lumber framed on 16" centers with 1/2" copper pipe imbedded in the studs. The wall was covered with 5/8" sheet rock that was screwed to the studs with 1 5/8" sheet rock screws. Figures 1 and 2 show the wall section before and after the addition of sheet rock.

Normally a 1/2" pipe centered in a 3 1/2" stud should have 1 1/2" of wood plus 5/8" of sheet rock between the room-side of the wall and the pipe. A 1 5/8" sheet rock screw will not reach the pipe even if the screw is over driven by 1/8". To simulate a construction defect we de-centered a section of pipe by 1/2" so that it was close enough to the room-side of the stud that a sheet rock screw could penetrate the pipe if it was driven in close to the pipe's center.

Figure 1 – Test wall before installation of sheet rock

Figure 2 – Test wall after installation of sheet rock

To test for construction defects we ran warm water through the in-wall plumbing. A FLIR B20 high-resolution thermal camera was set up on a tripod and recorded the thermal image at timed intervals. Figure 3 shows the thermal image of the wall in Figure 2 at the beginning of the test. In this test, a domestic water heater supplied water for the in-wall plumbing. The input water temperature was 100°F, and the wall and room were at 60° F. The 40°F temperature difference between the plumbing and the room caused the rock screws that were in contact with the water pipe to become heated and therefore clearly visible in 1.5 to 2 minutes. Image IR_0312 shown in Figure 4 shows a close-up of the center of the wall shown in image IR_0291 at the end of the thermal test. Three distinct hot spots representing sheet rock screws that in contact with the in-wall water pipe.

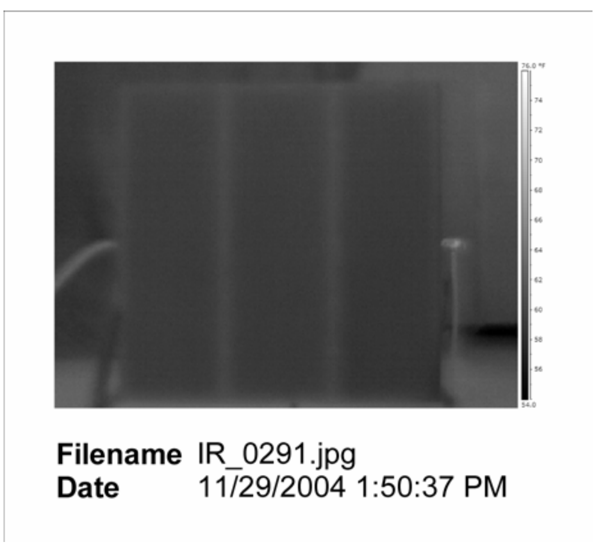

Figure 3 – Thermal image of wall before testing

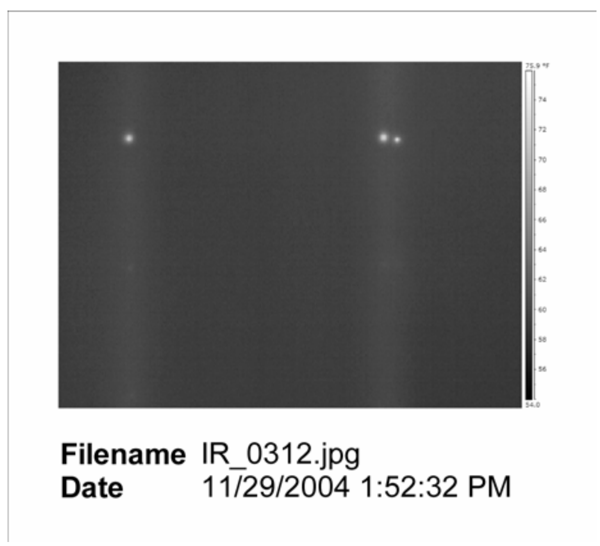

Figure 4 – Thermal image of center of wall after testing

In order to test the robustness of the technique we conducted a number of additional experiments. The results show that the defects are still visible after taping and painting the wall. An additional screw was inserted through the sheet rock that contacted the copper pipe without penetrating it. Figure 5 shows the wall from the back with the screw clearly resting on the copper pipe. Figure 6 shows the resulting thermal image of the wall with the additional screw clearly visible. The “cooler” vertical stripe, as denoted by a dark color, is the result of fresh taping mud, cooling due to evaporation.

Figure 5 – Back of wall with center screw resting on pipe

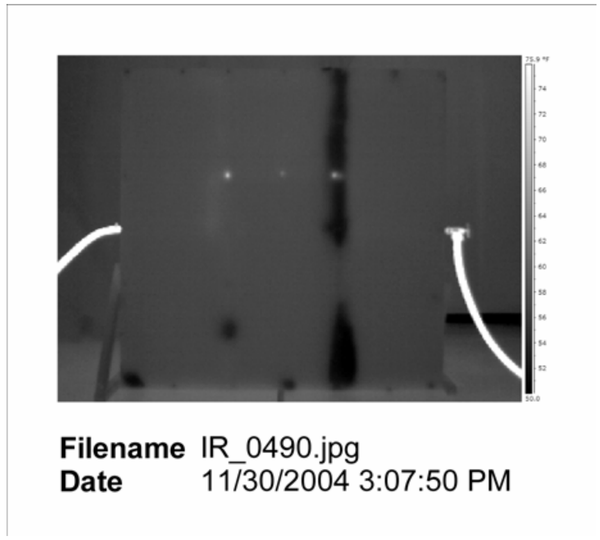

Figure 6 – Thermal image of wall with center screw

The table below shows that under all test conditions the latent construction defects are visible in an infrared thermogram in less than ten minutes of test time.

Test Conditions	Wall Temp	Water Temp	Time required	Final Image
Un-taped sheet rock	60°F	100°F	1.5 min	IR_0311.jpg
Un-taped sheet rock	60°F	80°F	5 min	IR_0346.jpg
Wet mud on joints	60°F	120°F	7 min	IR_0390.jpg
Dry mud on joints	60°F	120°F	8 min	IR_0490.jpg

Figures 7 and 8 show the results of additional tests that are summarized in the above table. Notice the darkened area in Figure 8 that resulted from the cooling due to evaporation of water from the wet taping mud.

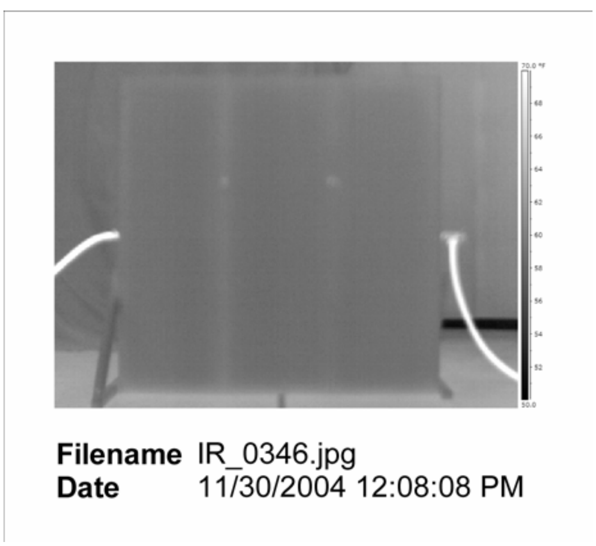

Figure 7 – Un-taped sheet rock, 20 °F temp. difference

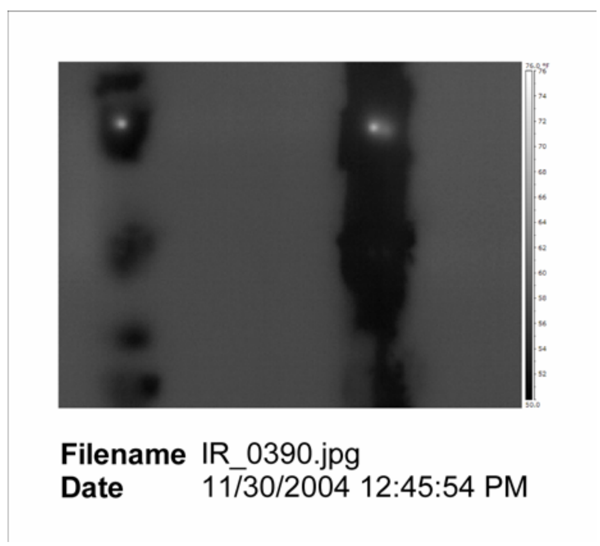

Figure 8 – Thermal image with wet taping mud on joints

The testing suggests a technique for locating latent water pipe integrity defects in construction projects using an infrared detecting camera. Loop the hot and cold water supply systems together and circulate hot water through the pipes. After ten minutes of running hot water through the pipes it should be possible to detect any fasteners that are in contact with the pipes by using an infrared detecting camera.

TESTING FOR DEFECTS ON CONSTRUCTION SITES

The test wall convinced us that it was feasible to test for screw-in-pipe defects in ongoing construction projects. The next step was to try the techniques on a construction site. Imaging Perspective, LLC has developed techniques for visually locating sheet-rock screws that are close enough to water pipes to cause concern. Figure 9 shows one such situation where a sheet-rock screw has been installed into a double stud through which a copper water-supply pipe is routed. From the visual image it appears that the screw could penetrate the pipe if the pipe is off center in the stud.

The screw in question was identified early in the construction process before a hot water heater was installed at the site. A small portable hot water heater was brought onto the site and used to circulate hot water through the pipes in the looped hot and cold water delivery systems. Because the storage capacity of the portable heater was less than the water storage capacity of the pipes under test it was necessary to run the re-circulating water heater for several hours in order to bring the entire system up to testing temperature.

Figure 9 – "X-Ray" view of nail (at arrow) near insulated copper water pipe passing through double stud.

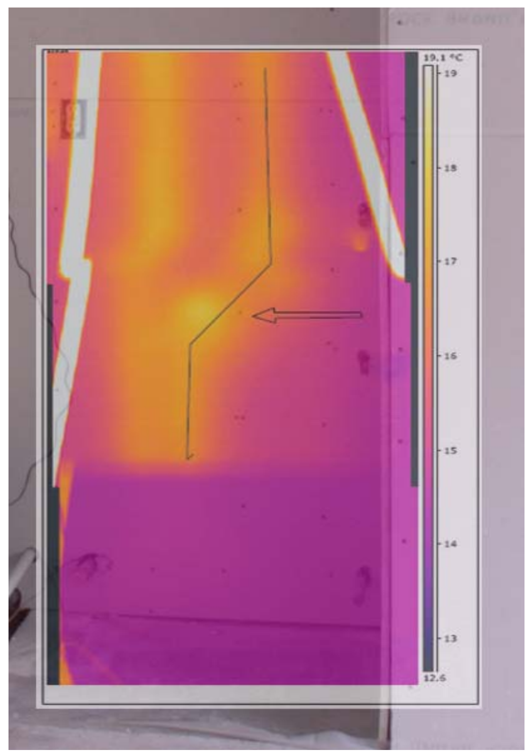

Figure 10 – Thermal overlay of nail (at arrow) near water pipe. Centerline of pipe marked by black jagged line.

Figure 10 shows an infrared thermogram superimposed over the area shown in Figure 9. The arrow in Figure 10 points to the same nail indicated by the arrow in Figure 9. The thermographer highlighted the centerline of the pipe that can be seen passing through the double stud in Figure 9. From the infrared thermogram it is clear that the nail is offset from the centerline of the water pipe far enough that there is little probability that it has contacted the pipe. In addition the temperature of the nail was determined to be half way between the temperature of the pipe conducting through the plaster and the ambient temperature of the wall. This is consistent with the screw reaching a thermal equilibrium while imbedded in a thermal insulator (wood) between a heat source (the pipe) and a heat sink (air). Our conclusion in this case was that the screw in question had not come in contact with the water pipe and was not a potential latent construction defect.

In order to further test the thermal properties of screws near but not touching water pipes we built a jig that allowed us to test the heating effect on screws imbedded in wood at various distances from a heat source, the hot pipe. The jig is shown schematically in Figure 11. A metal pipe was inserted at an angle through a 2x4 and sheet rock screws inserted throughout the length of the pipe. The first four screws, left to right, penetrated the pipe while the other three stopped short of touching the pipe. The jig is shown visibly in Figure 12. Impedance of the screws touching or penetrating the pipe was tested, confirming contact with the metal pipe. Tap water from a hot water line was run through the metal pipe. After one minute into the test, the temperature of the screws started to increase from 23°C to an eventual 33.7°C, 40 minutes into the test. Infrared thermograms of the jig are shown in Figures 13 and 14.

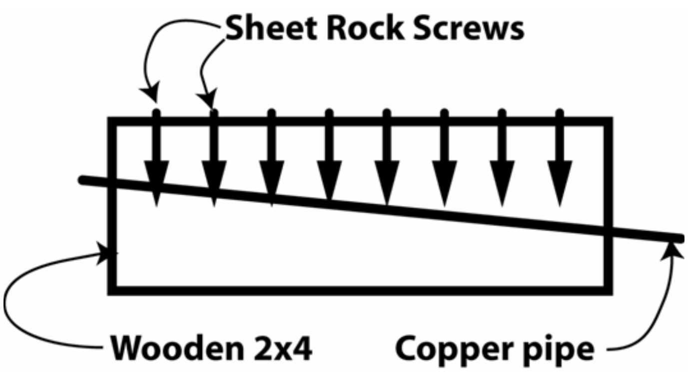

Figure 11 –Schematic cross section of jig to test thermal signature of screws imbedded in wood at various distances from a heat source.

Figure 12 –Visible image of the jig in Figure 11 under test.

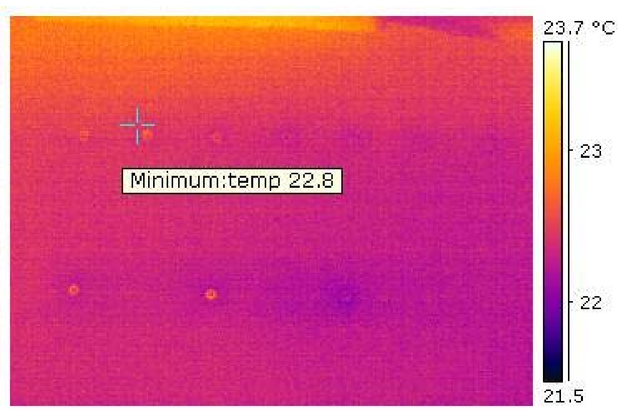

Figure 13 – Infrared Thermogram showing the screw temperature at the start of the test.

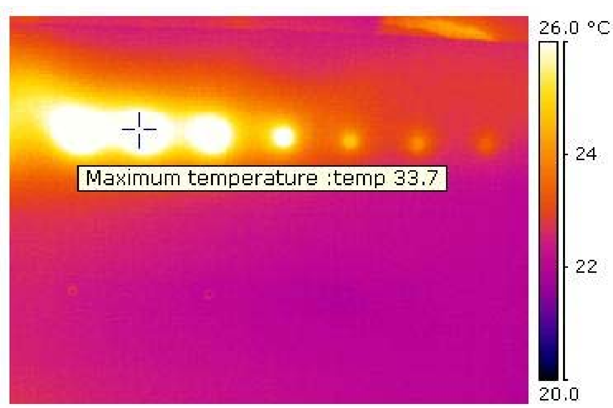

Figure 14 – Infrared Thermogram showing the maximum temperature, 40 minutes into the test

SUMMARY
Thermal detection using infrared thermography has been shown to be an effective technique to test for fasteners in contact with metal water pipes during the construction process. The test can quickly detect potential latent construction defects that won't show up until months or years after the project has been occupied. Although a variety of defensive techniques such as metal protection plates have been used to prevent these screw-into-water-pipe defects, this technique can confirm that no such defects are present at the time the construction is completed.

ACKNOWLEDGEMENTS
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