Thermal Imaging for Quality Control of Hot Mix Asphalt

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ABSTRACT: A new method of control during pavement laying operations was developed for use in the field in order to measure homogeneity during pavement laying operations. This procedure involves the acquisition of infrared images of the freshly laid, non-compacted asphalt mat. Acceptance criteria were established for longitudinal thermal segregation associated with paver adjustments and minimum and maximum asphalt temperatures. This quality control procedure, based on performance specifications, includes a mechanism for adjusting the price of asphalt. Initial experiments were conducted in 2007, as part of pilot projects involving several contracts. Application of the method to contracts in 2008 showed improved temperature homogeneity compared to the pilot projects. General results indicate that the quality of HMA placement is improved when performance criteria based on thermal measurements are established in the contract. The use of thermal imaging as an assurance quality control method, combined with the use of material transfer vehicles (MTV) at paving sites, has driven the progress observed in Québec, Canada.

KEY WORDS: Thermal, infrared, quality control, segregation, temperature.

1 BACKGROUND

Placement of hot mix asphalt (HMA) is the most common type of maintenance and construction work performed on Québec's road network. Aside from laboratory testing to verify conformity of component materials and formulation, quality control in the field relies mainly on measuring compaction, and in some cases, evaluating pavement roughness. Monitoring and numerous expert reports have demonstrated that the methods used during placement affect the performance and lifespan of asphalt pavement. In a number of cases, pavement has experienced premature failure due to various aspects of the placement process. A better understanding of the effects of placement methods was required in order to adapt conventional quality control methods.

It is well known that aggregate segregation and higher void content can reduce the life expectancy of asphalt pavement (Linden et al. 1989, Brock et al. 2003). Another type of segregation, thermal segregation was identified in the 1990's in studies conducted by Washington State University (Muench 1998). These studies revealed that the cyclic segregation associated with the end of HMA loading is also caused by variations inside the truck bodies. Colder HMA concentrated in one area can also make the asphalt mat more difficult to compact. Field testing demonstrated that temperature differentials in the asphalt mat in excess of 14°C can cause unacceptable density variations (Willoughby et al. 2003). A field-control procedure was developed by the Washington State Department of Transportation

(Washington DOT) in order to locate these temperature differentials and measure density in cold spots (Muench and Willoughby 2006). Some other roads agencies have planned to develop specifications for preventing temperature segregation.

During the 2005 season, Ministère des transports du Québec (MTQ) conducted a study at various worksites using data obtained with an infrared camera to evaluate various characteristics of the newly laid asphalt. This type of tool makes it possible to visualize the temperature distribution on the surface of freshly placed HMA before compacting and to estimate heterogeneity.

2 EFFECTS OF TEMPERATURE HETEROGENEITIES

Cooling of the truck load results in a non-uniform temperature distribution in the HMA discharged by the paver's conveyor. Distribution of the asphalt in the paver is not sufficient to achieve a uniform temperature, and colder masses of asphalt are concentrated in some areas at the surface of the freshly laid mat. This leads to thermal or temperature differentials (ΔT°) in the freshly placed asphalt due to cold spots. The phenomenon occurs currently when there is a change of trucks, at the point where the cooler masses accumulated at the end of a dump are combined with those at the beginning of the next dump. The aggregate segregation phenomena that result in uneven cooling also occurs in these areas. This leads to heterogeneous temperatures on the mat, causing variations in the surface texture and density (Figure 1).

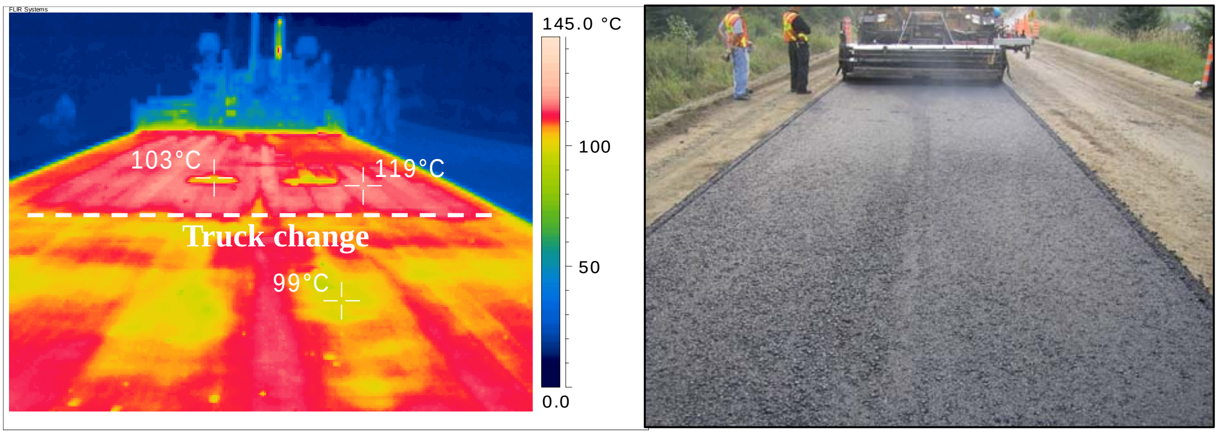

Figure 1: Typical temperature and texture variations resulting from a change of trucks

Other practices also have a negative effect on the uniformity of the texture and temperature of the HMA, including spilling asphalt in front of paver (Figure 2), emptying hopper wings and conveyors, and prolonged paver stops (Figure 3).

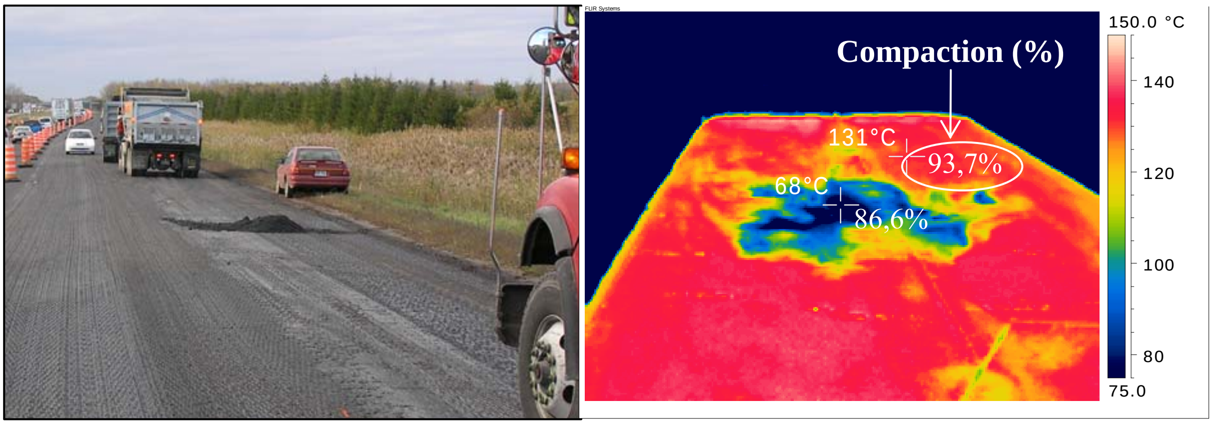

Figure 2: Colder areas due to spillage in front of paver

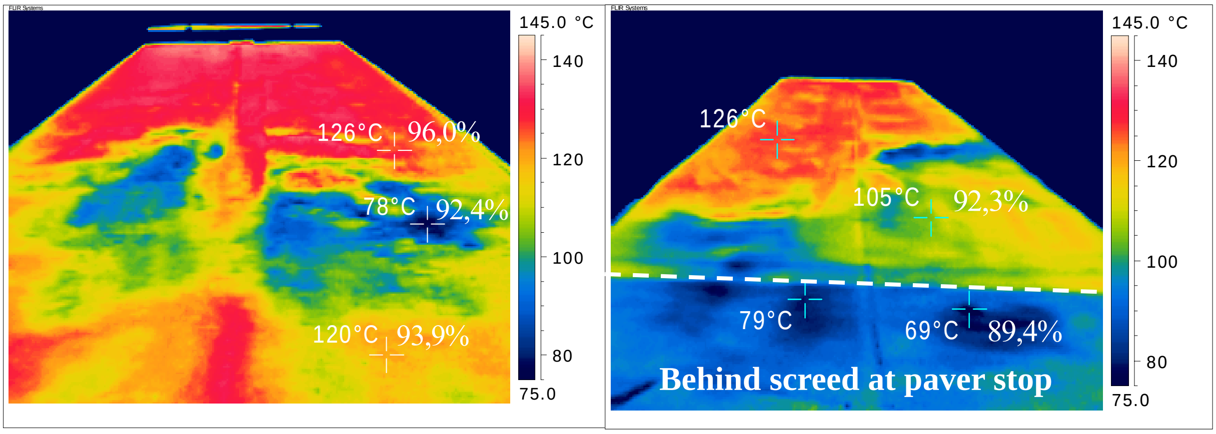

Figure 3: Thermal differentials resulting from complete emptying of hopper and paver stops

These results, which were measured at several work sites, occur cyclically, at intervals of between 15 m and 35 m, depending on strip width and lift thickness.

It can be seen that aggregate segregation and temperature heterogeneity translate into high ΔT° values at the surface that can reach 60°C. Given that the temperature of the colder areas is close to the minimum compacting temperature, the HMA becomes less susceptible to the action of the rollers, to the point where it cannot be compacted adequately and uniformly. These zones that display segregation or variations in surface texture represent potential sites for the creation of premature failures due to moisture absorption, ravelling, bitumen oxidation, and fatigue. These failures may subsequently lead to peeling and potholes, among other problems.

Another type of problem related to the issue of uniformity during lay-down operations is longitudinal (centerline) segregation located near the centre of the paver. Even though this type of failure is not always visible to the naked eye during placement, it can be detected using the infrared camera. These thermal streaks are associated with bad distribution of mix in the mat due to improper settings on the finishers and/or inadequate operating methods. They are the thermal signature of a discontinuity caused either by the presence of aggregate segregation or by a lack of mix (density variation), or a combination of both. Longitudinal thermal segregation shows up as a continuous rectilinear streak can be several on the same image in some cases. This very common deficiency represents an area of weakness with low resistance to thermal contractions. It results in the development of a longitudinal crack near the center of the strip occurring in the first winters following the paving work (Figure 4).

Figure 4: Longitudinal thermal streaks and cracking, usually occurring at centre of the strip

In the study conducted in 2005, cold spots resulting from temperature heterogeneity were detected and located on worksites. A camera was used to take infrared images for temperature analyses. Almost 300 test areas distributed among 28 worksites were used to establish correlations between surface temperature and compaction, measured with a nuclear density gauge. The results show that compaction decreases as the temperature differential (ΔT°) increases, and that the 93.0% compaction required by the MTQ corresponds to a ΔT° of approximately 20°C. The compaction measured on cold spots is generally non-compliant (<93.0%) when the minimum surface temperature is below 100°C (Figure 5). These results are consistent with those obtained by other highway administrations, such as the Washington DOT (Willoughby *et al*. 2002).

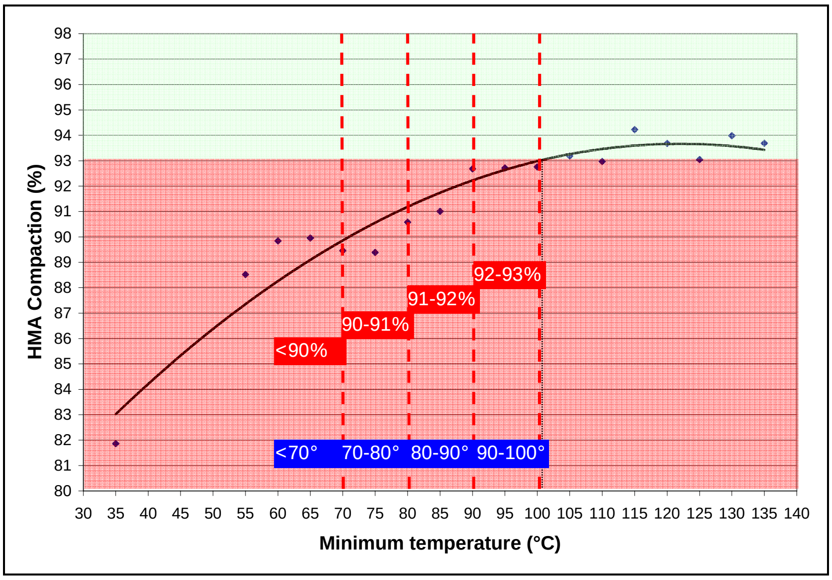

Figure 5: Correlation between compaction and minimum temperature of cold spots

3 THE QUALITY CONTROL METHOD

3.1 Procedure

This new procedure consists of acquiring infrared images of the freshly placed, non-compacted asphalt mat in order to obtain temperature measurements and determine the presence of longitudinal thermal segregation. This procedure also makes it possible to verify whether the asphalt has been overheated during production. The greater the thermal differential is, the greater the likelihood of problems with the density and performance of the bituminous layers. However, it has been observed that thermal differentials are more critical at low temperatures than at high temperatures (Henault and Larsen 2006). For example, a thermal differential of 30°C is more critical between 90°C and 120°C than between 120°C and 150°C. Considering this aspect, and for practical reasons (the possibility of directly determining the readings at the worksite), the control parameter selected for the determination of homogeneity of placement is the minimum temperature (T°min). Overheating of the mixture is verified during placement by determining the maximum temperature (T°max) behind the paver.

The key aspect of the procedure at the worksite is to take temperature measurements behind a paver (Figure 6) when a truck is discharging (or on an equivalent volume, when an MTV is used).

Figure 6: Position for taking temperature measurements behind a paver

When taking measurements, the camera operator takes up a position on one side of the freshly placed asphalt strip. He follows the paver as it moves forward and must remain within 10 meters of it. He must take as many images as necessary to cover the entire mat between him and the back of the paver screed. The rollers must not compact the measurement zone and should remain behind the camera operator while the measurements are taken. This operation is carried out once per 200 or 250-metric-ton lot depending on asphalt plant production rate in metrics ton per hour.

3.2 Infrared cameras

There are several camera models appropriate for field work. The recommended minimal characteristics are a thermal sensitivity of ≤ 0.1°C, an infrared resolution of 160 × 120 (19,200 pixels), and an accuracy of ±2°C or ±2% of the reading. An essential camera option is the ability to display the minimum temperature value in a frame (portion of the image). This function allows the camera operator to quickly determine the minimum value of one or more cold spots while ensuring that it actually represents the temperature of a portion of the mat rather than the temperature of another object. Most models also allow the maximum temperature of the asphalt mat to be displayed and the use of specific functions like spots for thermal streak analysis (Figure 7). Infrared images can generally be analyzed on the camera screen. If some options are not available, it may be necessary to analyze the images by computer using appropriate software.

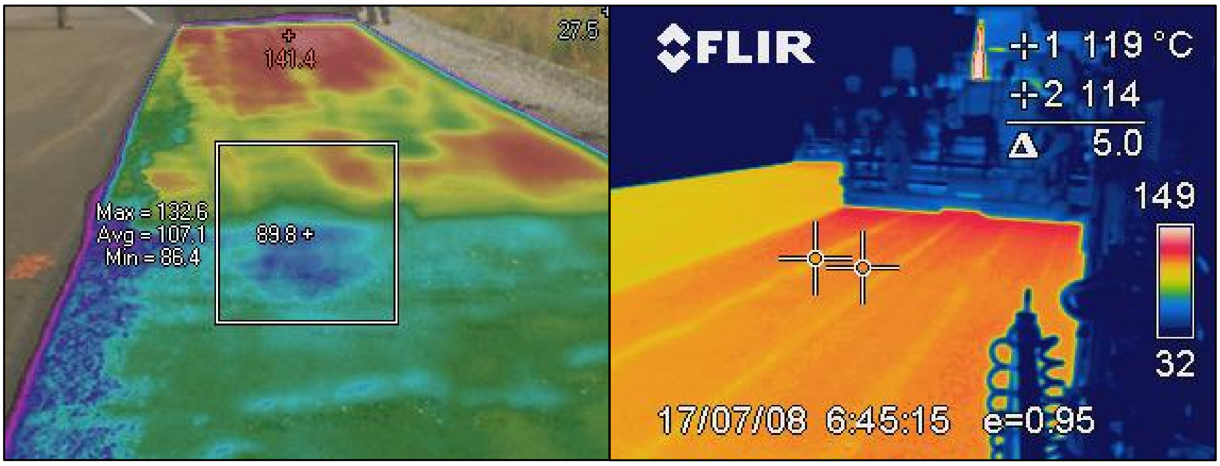

Figure 7: Examples of images produced by analysis tools (box areas and spots)

For the measurements, emissivity must be set at 0.95 and the ambient and reflected temperature at 20°C. Adjusting these settings to conventional values eliminates any ambiguity in interpreting the measurements.

3.3 Criteria

A system of adjustments to the asphalt price was set up in order to penalize placement heterogeneity problems considered to threaten the achievement of a certain level of quality. Criteria include minimum temperature, maximum temperature, and longitudinal thermal segregation.

The minimum temperature (T°min) acceptable for cold spots is 100°C. When the temperature detected falls below this threshold, the asphalt price is adjusted downward, depending on the value obtained. An adjustment factor of increasing severity is applied for the following predefined temperature ranges as shown in Figure 5: 90° ≤ T°min < 100°C, 80° ≤ T°min < 90°C, 70° ≤ T°min < 80°C, and T°min < 70°C. An adjustment factor may also be applied to each lot having a maximum temperature (T°max) in excess of the maximum mixing temperatures at the plant specified by the binder supplier or greater than 170°C.

Finally, an adjustment factor may also be applied to each lot that exhibits longitudinal thermal segregation. It is a question of analyzing the images to verify if there is continuous transverse discontinuity, regardless of the absolute temperatures values. The longitudinal thermal segregation is measured by locating three transverse profiles of analysis on every thermal streak colder than neighbouring portions of the image. A profile is applied in each third of the longitudinal axis. These profiles are also centered on the same longitudinal thermal streak. The length of an individual profile of analysis has to be at most a third of the width of the strip observed on the image at the location of the profile. When several thermal streaks are present on an image, every thermal streak is checked separately using three transverse profiles of analysis. Longitudinal thermal segregation is confirmed when at least one thermal streak is present on the full length of the strip on at least one infrared image, and when the difference of temperature values between the axis of the streak (minimum value) and the neighbouring portions of the image (maximum value) is at least 5°C on each of the three profiles of analysis. Figure 8 illustrates an example of longitudinal thermal segregation analysis. If longitudinal thermal segregation appears, its presence must be verified by analyzing the images. Given that it is impossible to carry out a full analysis directly from the infrared cameras with all camera models, software may be required to determine if the criteria are met.

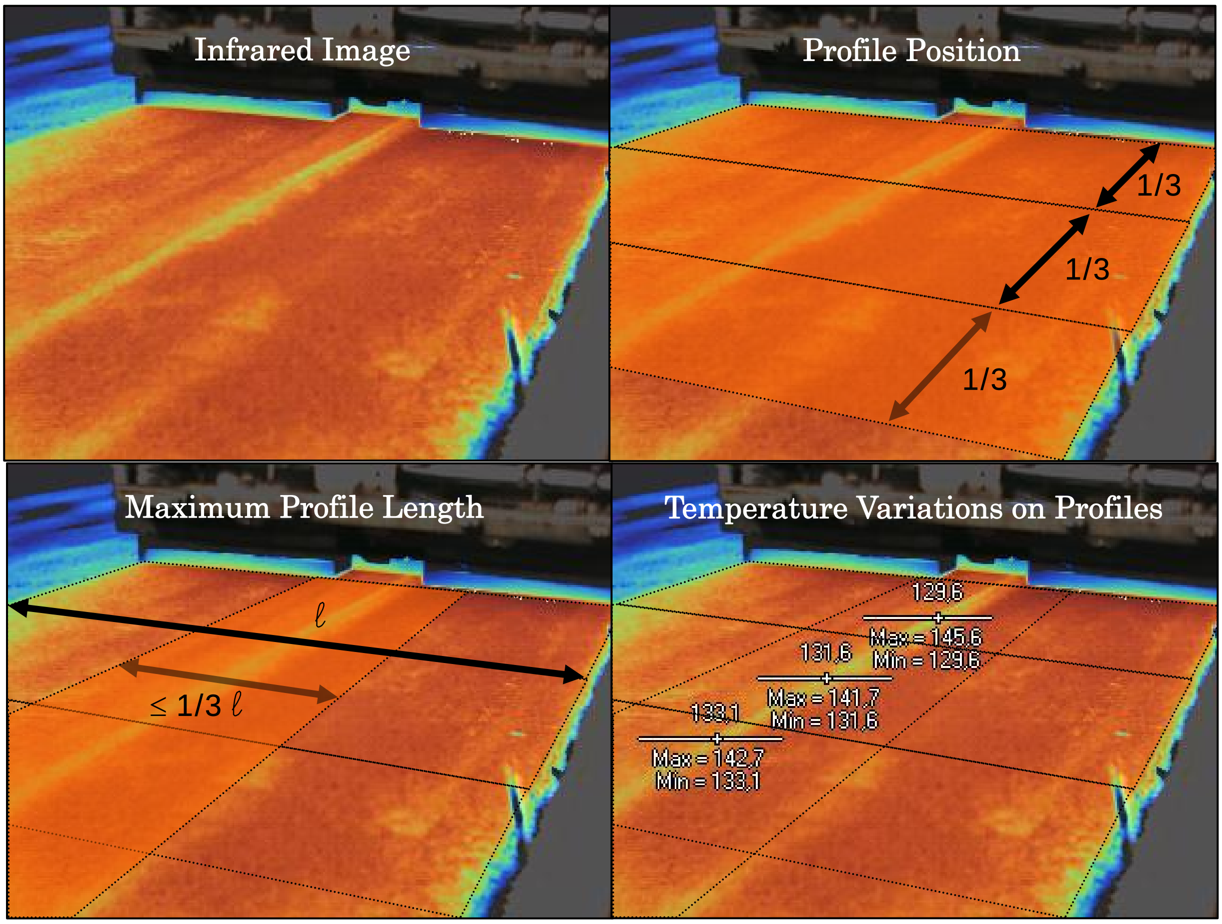

Figure 8: Analysis of a longitudinal thermal segregation

3.4 Calibration

The infrared camera used must have a valid calibration certificate. However, the infrared camera must also undergo a validation procedure. The objective is to make sure that the measuring instrument has not experienced drift. This validation procedure is performed every seventh calendar day during the term of asphalt placement contract, or whenever doubt arises as to the reliability of the results. Ideally, the validation procedure should be carried out at the beginning of the contract, or at least once per contract. These intervals may be adjusted by the operator, depending on the stability of the measurements or if there has been breakage or misuse of the tool.

The validation procedure requires the use of an infrared laser thermometer with an accuracy of ±1ºC, and a guide plate with a rod that is approximately 400 mm long and a circular perforation approximately 75 mm in diameter in order to allow for temperature readings to be taken at the same location in the centre of the hole.

4 APPLICATION RESULTS

4.1 Projects in 2008

Following pilot projects carried out in 2007, specifications for about ten 2008 Ministry of Transport asphalt paving contracts called for the use of thermal imaging as a means of quality control. The criteria set out in the specifications are related to temperature homogeneity verify by minimal temperature of the cold zones (100°C) and maximum temperature (maximum 170°C) and longitudinal thermal segregation. The tonnages of HMA put down by contract vary from 8,600 to 31,400 metric tons, for a total of about 200,000 metric tons. Seven of these projects took place on highways, while three others took place on main provincial roads.

4.2 Homogeneity

Proportions of non-compliant lots with regard to the minimal temperature criterion for all the 2008 contracts are summarized in Figure 9. MTVs helped contractors comply with this criterion more easily, as the results of 10 contracts carried out in 2008 show. Percentages varied from 0 to 3.1%, for an average of 1.5%. However, cold spots can be created if there are waiting time due to a lack of trucks or if hot mix is spilled on the surface in front of the finishers. In the 2007 pilot projects, the average percentage of non-compliant lots recorded was 3.5% with MTVs and 36% without MTVs. The maximum temperature criterion was respected for all lots of measurements, which is reassuring with regard to the risk of overheating of the HMA for the controlled contracts.

4.3 Longitudinal thermal segregation

Proportions of non-compliant lots with regard to the longitudinal thermal segregation criterion for all the 2008 contracts are summarized in Figure 8. The results vary from 0 to 24.2 %, for an average of 9.4 %, which represents an improvement compared with 45% average obtained in 2007. As has been observed for several years, the use of MTVs has not eliminated this phenomenon. Steps contractors have taken to solve this problem have had positive results. The solutions they have implemented include maintenance of the finishers, addition of certain parts and modifications to operating methods (screed adjustments, augers height, speed, etc.).

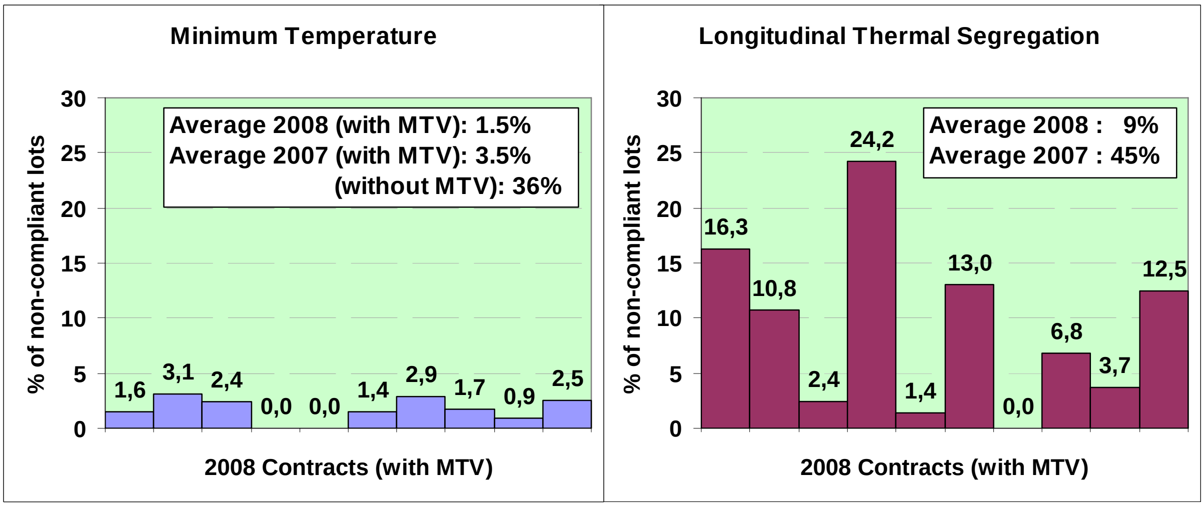

Figure 9: Results of non-compliant lots by contract for minimal temperature and longitudinal thermal segregation criteria

5 CONCLUSIONS

A dissuasive quality control procedure adapted to asphalt paving was developed to address problems affecting placement quality causing premature deterioration. The established criteria (minimal temperature of the cold zones, maximum temperature indicative of overheating and longitudinal thermal segregation) were set at realistic thresholds that ensure good pavement behaviour. It is easy to check compliance with these quality criteria on construction sites using infrared cameras currently available on the market.

The procedure, consisting in measuring the temperatures on the surface of the HMA mat behind the pavers during the unloading of the trucks, is carried out at pre-established intervals. These verifications are made after the spreading operation, just before compaction, which is the final operation. As a result, the criteria applied under this method represent results-based requirements that depend on a number of factors, including meteorological conditions, mixing temperature, haul distance, number of trucks, wait times, system used to cover truck loads, asphalt spills, use of remixing equipment, method of operation, paver speed and settings, etc. The method takes these various factors into account and therefore directly focuses on the final result, which in turn determines pavement performance.

Results from the first year of application show an improvement compared to the pilot projects in 2007 with regard to the homogeneity of hot mix lay-down operations. They indicate the quality of operations improves when contracts are subjected to performance criteria based on thermal measurements. The use of thermal imaging as a controlling tool, combined with the use of MTVs on construction sites, has led to remarkable progress. MTQ will continue to use infrared imaging to pursue its quality objectives.

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