A Global Strategy in Evaluating Building Roof Performance and Diagnosing Moisture Intrusion into Roofing Systems Using Infrared Thermography and Other Diagnostic Tools

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ABSTRACT

For the owners and managers of large institutional, commercial and industrial buildings, the potential cost of roof repairs and eventual roof replacement is a major capital expense. In order to allow for the effective management and budgeting of these expenditures, it is imperative that a detailed and accurate maintenance plan for all the roofing systems be developed. The maintenance program should establish a detailed plan of action for the corrective work required to extend the useful life of the existing roofing systems, forecast the eventual replacement of the roofing system, and establish projected budget costs associated with the repairs and replacement of the roofing system.

In association with other diagnostic tools and the understanding of roofing construction and roofing principles, infrared thermography can play a key role in assisting the experienced building professional to effectively establish the existing condition of most conventional roofing systems and to rapidly diagnose problems of moisture intrusion within the roofing system. With this information, a roof maintenance plan and strategy can be developed to forecast all corrective intervention and budget costs related to maintaining multiple roofing systems of large buildings.

The primary objective of this paper will be to provide an increased knowledge to the building thermography community as to the benefits of using infrared thermography as part of a global strategy towards developing an effective roof maintenance plan for building owners and managers.

INTRODUCTION

In Canada, the useful life of a multiply conventional roofing system is considered to be approximately 20 years. In a perfect world, the building managers or owners of large portfolio of buildings would simply require little more than to budget replacement of their roofing systems every 20 years in accordance with this recognized rule of thumb. Unfortunately for those whose professions include the task of having to foresee and project the capital expenses for their properties, there are numerous factors that exist that may contribute to the premature failure of roofing systems well before the expected 20 year mark. With roof replacement costs of conventional roofing systems nearly tripling in the last 15 years in Québec, unexpected capital costs in the millions of dollars that are required 10 or even 5 years earlier than budgeted could create substantial financial tremors for many building owners.

The factors which contribute to the premature failure of the roofing systems may include such latent items as poor original design, deficient workmanship, deficient or inappropriate construction materials and questionable methods of construction. Even in those rare instances when the perfect roof design meets superior workmanship, the premature compromise and failure of the roofing system may still occur due to misuse or abuse of the roofing system in the form of accidental damage caused by building users or building maintenance personnel.

If the building owner is fortunate, the defect or compromise of the roofing system results in an immediate localized leak into the premises below. In this circumstance, if the informed building owner acts quickly enough, addressing the problem of water ingress immediately may only cost a few thousand or even a few

hundred dollars depending on the scope of the problem, and more importantly, helps to preserve the overall integrity and useful life of the roofing system.

In contrast, however, today's modern day roofs, especially those in northern climates are often designed and constructed with moisture tight vapor barriers to prevent condensation from forming within the insulated roofing systems during the heating season. Water absorptive materials such as fibreboard or perlite panels also used as support panels for the membrane above the insulation, and plywood sheets surrounding roof parapets and control joints are also common in the composition and assembly of new roofing systems. The combination of the watertight vapour barrier along the roof deck and the absorptive characteristics of the roofing materials installed beneath the roofing membrane combine to create conditions whereby the water ingress through the roofing membrane does NOT result in an immediate leak into the premises below. Rather the moisture which has penetrated through the roofing membrane is gradually absorbed by the roofing material and retained or imprisoned by the vapour barrier within the roofing system itself. Eventually the imprisoned water spreads through the roofing system by capillary action and absorption by the roofing insulation and sponge-like support panels beneath the roof membrane. The imprisoned moisture causes the roof elements to degrade and also dramatically reduces the thermal properties of the roof insulation which creates conditions favorable to the formation of condensation inside the building. The end result of all these combined conditions is that a significant portion of the roofing system may become irreparably damaged by moisture well before the visible symptoms of any problems or leaks become apparent and well before the expected expiration of the useful life of the roofing system. Consequently, the building owner is forced having to prematurely face the unexpected and sudden high cost of corrective intervention for the replacement of their roofing system.

As a means to aid the building owner to accurately project and budget the replacement of their roofing systems and to help them avoid having to face the unwanted prospect of having to invests significant funds towards the premature replacement of these roofing systems, it is essential that a detailed Preventative Maintenance Program for the roofs be developed and implemented by the building owner.

The preventative maintenance program for the roofing systems would typically summarize for the building owner the plan of action or scope of roof repairs and associated costs that would be required in the immediate term, short term, and long term as a means to help preserve or prolong the remaining useful life of the roofing systems, as well as project the year and cost when roof replacement will eventually be required. Essentially, the preventative maintenance program provides the owner with a roadmap for budgeting repairs for each and every one of their roofing systems, and greatly reducing the risk of having to deal with the inconvenience and costs of addressing unexpected roofing issues.

Typically the best roof preventative maintenance programs are developed by experienced professional firms and qualified thermographers capable of carrying out the necessary diagnostic analysis and interpretation of data, as well as possessing detailed knowledge of roofing construction and building sciences.

As part of the global strategy in assessing the condition of actual roofing systems and developing accurate preventative maintenance programs for roofing, this paper describes how infrared thermography along with the use of other diagnostic equipment and the understanding of building construction concepts plays a key role in assisting practitioners in detecting non-visible deficiencies in the roofing systems and achieving the desired objectives of the preventative maintenance program for roofing.

PREVENTATIVE MAINTENANCE PROGRAM FOR ROOFING – A GLOBAL STRATEGY

The development of an accurate preventative maintenance program for roofing requires a systematic approach which involves the combination of obtaining historical information of the roofing system, results obtained from a detailed physical assessment of the roofing system, and the knowledge and experience regarding roof construction and building sciences. As such, the best approach towards developing an accurate preventative maintenance program for roofs would involve the following steps:

- **Review of architectural plans of Existing Roofing**
  Whenever available, the existing roof plans and architectural details of the building should be reviewed prior to proceeding with the on site assessment. The information obtained should include

such general items as the age, geometry, and location of the roof basins, layout of all drains and mechanical rooftop units, and most importantly, the **composition** of each of the roof basins to be reviewed. The copies of the roof plans can also be used during the survey on site to directly transfer information or record deficiencies directly onto the drawings for reporting purposes.

Special attention to the roof composition should also be considered well before proceeding with the on site assessment of the roofing system. Some roofing compositions and systems readily allow for standard review practices and diagnosis through non-destructive methods such as infrared thermography. However, most inverted roofing systems and even some conventional roof systems do not allow for the accurate review using infrared thermography and it is good practice to be aware of which roof basins can be analyzed using this technique, and which cannot be prior to initiating the roof assessment on site.

In addition, the original architectural drawings including details involving the air and vapour barrier of the building envelope should also be reviewed by an experienced professional in order to confirm the suitability of the envelope design in terms of heat transfer and moisture vapour travel within the building given its usage. These first steps are necessary in terms of helping to not only define which strategies (destructive and non-destructive measures) and diagnostic equipment that are required to accurately assess the physical condition of the roofing system, but also to foresee some of the potential causes of water ingress prior to assessment on site. For example, in certain instances, this step could lead to the discovery that reports of water ingress or roofing failure may in fact be due to problems of condensation and not necessarily the failure of the roofing membrane.

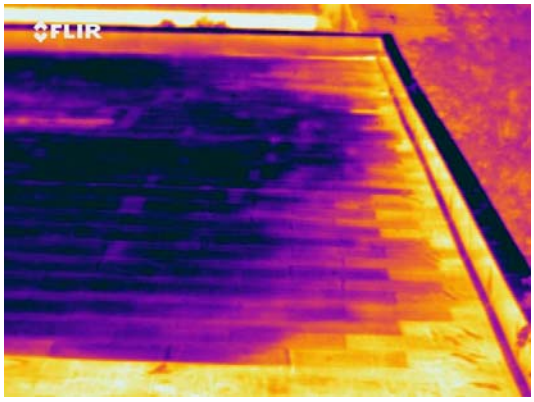


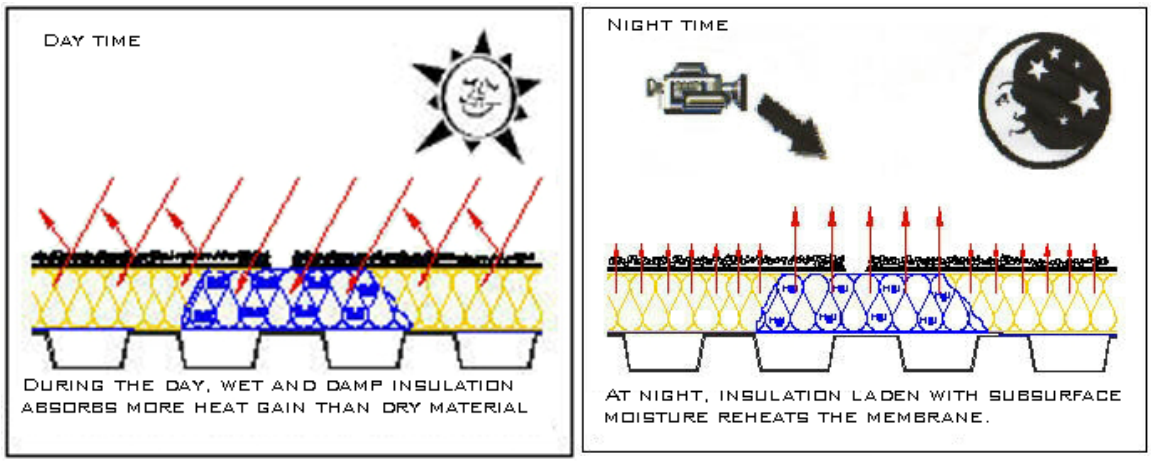
Figure 1. Thermogram showing moisture within the roof caused to by condensation due to high humidity levels and absence of suitable vapour barrier in the building below.

- **Preliminary Visit and Interview with Building Personnel**
  A preliminary visit to the building roofs and interviews with building maintenance personnel often provides invaluable information such as the historical background of the original roof construction, corrective maintenance previously executed on the roofs, identification and the actual composition of roofs basins which had previously been replaced or repaired, and reported locations of both previous and active areas of water ingress below the roofs. This information simplifies calibration of non-destructive moisture detection equipment during the roof assessment and helps to alleviate possible confusion during the interpretation of results during the study when using infrared thermography. For example, a single roof basin that has been replaced with added insulation or non-absorbtive insulation will transmit different readings and images when compared to the adjacent roof basins which have not been modified. Not knowing the maintenance history and the actual composition of all the roof basins to be assessed ahead of time may lead to error in the interpretation of infrared scans. A preliminary visit to the site also gives the infrared practitioner the opportunity to walk the roof during daylight hours to view the roof layouts and help spot membrane and roofing deficiencies, as well as safety issues or tripping hazards that may not be readily visible

during the evening. This also helps in determining whether the roof itself is suitable for infrared thermography to be used as a means to assess the condition of roofing system (see below regarding limitation of infrared thermography for the condition assessment of roofing systems).

Figures 2 and 3. Photos showing signs of water ingress below roof deck (at left) and signs of roof membrane deterioration above

- **Assessment of Roofing Systems Using Infrared Thermography**
  Infrared thermography is likely the most cost effective and efficient tool for non-destructive assessment of conventional roofing systems. In the hands of an experienced professional, the use of infrared thermography can play a key role in helping to quickly determine the location and general scope of moisture imprisonment hidden within the roofing system. The introduction of moisture, whether in the free state or absorbed by the insulation, reduces the insulation's effectiveness and increases its conductivity. During the summer months, under clear sky conditions, the moisture within the roof acts as a large thermal collector and heat sink. At sunset, the roof surface starts to cool rapidly, while the moisture laden insulation continues to emit heat to the membrane from below as it too slowly starts to cool. For many hours following sunset (this duration depends on several variables) the membrane sections above wet sections of insulation of a conventional roofing system will continue to emit heat and remain warmer than the surrounding roof membrane above dry insulation. Through the use of an infrared camera to detect minute variations in the emission of heat of exposed surfaces and to convert this information into an electrical signal and color image, infrared thermography makes it possible to detect/predict the presence of moisture within the insulation of most conventional roofing systems.



Figures 4 and 5. Schematic representation of heat absorption of wet insulation in roof during the day (at left) and heat emitted by roof membrane above wet insulation detected by infrared camera in the evening.

During the infrared scan of the roofing system, the suspect areas are often delineated with spray paint applied directly on the surface of the roof membrane. These areas are measured and then transferred onto plan drawings of the roofing system as part of the recording process. Often depending on the geometry of the building, up to several hundred thousand square feet of roof area can be scanned during one evening until which time the thermal signature from the roof membrane above the wet locations stabilizes with that of the surrounding roof membrane and the signal is no longer detectable.

Figures 6 and 7. Typical infrared scan of wet area within roofing system at left. At right, paint typically used on roof surface to delineate suspect area of roofing system.

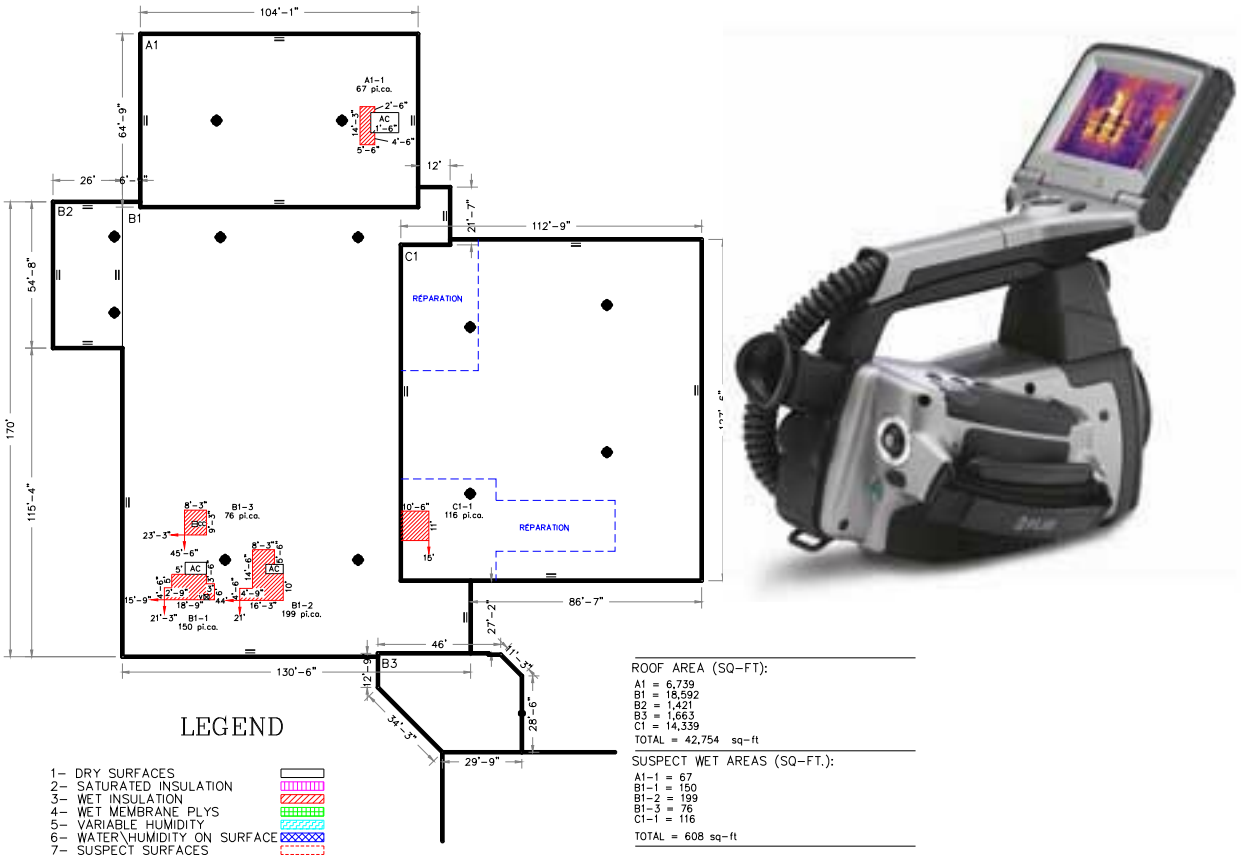


Figure 8. Results of infrared scan transferred onto typical plan drawings of the roofing system with suspect wet areas within roofing system indicated in the drawing.

In this way, infrared thermography of roofing systems provides the information necessary in helping to determine the expected scope of immediate repairs and helps to predict the expected remaining useful life of the roofing system which is the core objective of developing an accurate preventative maintenance program for roofing.

Despite its obvious advantages, infrared thermography alone however, cannot provide all the information required for the development of a complete preventative maintenance program for roofing. It is critical to understand that several limitations do exist regarding when and how infrared surveys of roofing systems can be used successfully. Conditions which restrict or prevent the use of infrared themography as a means to effectively assess roofing systems include, but are not limited to, the following:

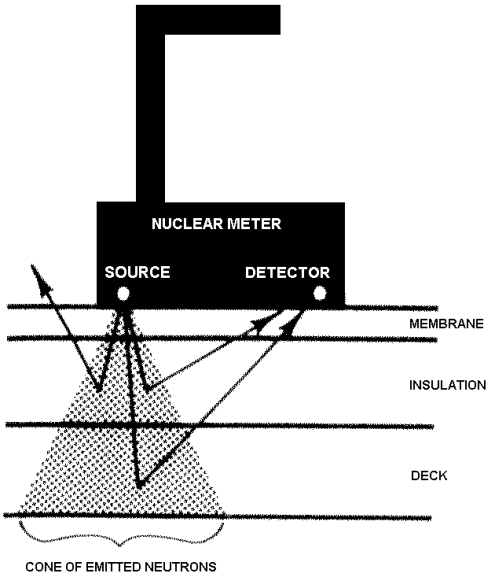
I) Inability to review most inverted roofing systems (where ballast and insulation is installed over the roofing membrane);
II) Inability to effectively review conventional roofing systems when non-absorptive support panels (ex. cement board) and/or insulation form part of the roof composition;
III) Inability to review systems where ponding water or moisture on the roof surface is present;
IV) Infrared thermography of roofs is limited to mostly nighttime review during the cooling seasons with light winds no greater than 10mph – limited window for review;
V) Cannot achieve reliable results of roof areas which surround clusters of installed rooftop mechanical equipment due to reflective surface of units;
VI) Cannot effectively review most upturn detail (membrane flashing);

Given these limitations, it is clear that other diagnostic approaches and tools may be required in order to provide the global assessment required for the preparation of an accurate preventative maintenance program for given roof system under certain conditions.

- **Non-Destructive Assessment of Roofing Systems to Assist Infrared Thermography**
In localized areas or instances where infrared thermography cannot be utilized to assist with the assessment of a given roofing system, other non-destructive diagnostic tools and equipment may be used to address these given areas, and to validate the results of the infrared survey in localized areas.

The diagnosis of such locations on the roof generally require the use of **capacitance meters** and **nuclear meters** in order to try and detect moisture imprisoned within the roofing system.

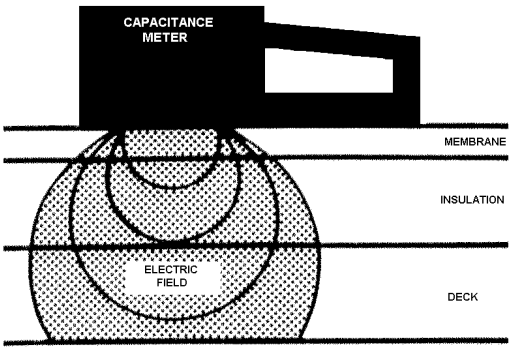
The **nuclear meter** used for roofing assessments is specifically designed for performing roof moisture surveys. Its calibration differs from the nuclear density meters used to measure in situ soil moisture. A roof moisture gauge sends a cone of fast neutrons into the roof. The neutrons bounce off materials in the roof and some return to the sensor located inside the nuclear device (see figure below). The speed of the neutrons is slowed if they come into contact with hydrogen atoms. Typically the presence of hydrogen atoms in roofing systems is due to the presence of water (**H_2O**) within the roof composition. The sensor within the nuclear moisture meter detects and displays an appropriate reading when the neutrons are slowed by hydrogen atoms within the roof system and consequently is able to confirm water presence within the roofing system. Other roofing materials may also contain hydrogen atoms and therefore must be differentiated from the hydrogen atoms contributed by the presence of water. Usually readings are taken on a 5’ by 5‘ foot grid marked directly on the roof surface.



Figures 9 and 10. Use of nuclear meter used to detect moisture in the roofing system.

A **capacitance meter** creates an alternating current electrical field in the materials below it (see figure below). The ability of those materials to store and dissipate electrical energy is related to their dielectric properties. The dielectric properties of water are significantly different from those of roofing materials. The dielectric constants of most materials used in roofing range from 1-4, whereas the dielectric constant of water is 80.

Numerical readings are obtained at grid points about 5 feet apart. Capacitance meters are quite sensitive to moisture just below their base. It is essential that the surface of the membrane and any gravel on it be dry when readings are taken. The presence of a small amount of water within the plies of a bituminous built-up membrane will be noted easier with a capacitance meter than a nuclear meter or infrared camera.



Figures 11 and 12. Use of a capacitance meter used to detect moisture in the roofing system.

With the exception of inverted roof systems, both the nuclear meters and the capacitance meters offer an alternative to assess roofing systems and detect imprisoned moisture in roof areas, or in conditions or locations where infrared thermography cannot be used effectively. They can also provide a second validation to infrared results wherever moisture is detected within localized areas

of the roofing system. The only drawbacks to these two systems are that they require multiple readings to be taken and significantly greater time to assess the condition of an entire roof basin than compared with infrared thermography.

It is because if the different limitations and varying advantages in relation to roof assessments that a thorough roof assessment and preparation of an accurate preventative maintenance plan for conventional roofing systems requires the use of a combination of non-destructive equipment including an infrared camera, a capacitance meter, and a nuclear meter.

- **Exploratory Openings - Validating Results of Non-Destructive Assessment of the Roofing System**
  Despite the advancements and benefits provided in moisture detection equipment such as infrared thermography, nuclear meters, and capacitance meters, over large areas, exploratory openings in select locations in the existing roofing system is nonetheless required to provide final confirmation and validate the results obtained from the non-destructive assessment of the roofs. In addition the exploratory openings provide confirmation of the actual roof composition. The exploratory openings, which vary in size, are executed in a few select areas where moisture detection equipment has registered possible moisture within the roofing system, as well as in areas where moisture was not detected. These openings also help to confirm the depth at which moisture is imprisoned in the roofing system or within the plies of the roofing membrane. An experienced roofer should be mandated to execute the required openings and subsequent repairs under the supervision of the roofing professional. In cases where the roofing system is still within the warranty period, the exploratory openings and repairs should be executed by the same roofer who is providing the warranty in order not to risk nullifying the roof warranty.

Figures 13, 14, and 15. Exploratory openings executed in roofing system to confirm roof composition, to validate results of infrared thermography study, and to determine actual location of moisture within the roof components.

PRESENTATION OF PREVENTATIVE MAINTENANCE PROGRAM FOR ROOFING

Once the roof assessments have been completed, an experienced professional is called upon to develop a preventative maintenance program for the roofing. Often presented in the form of two tables; One table which provides the synopsis of the results of the roofing assessment and severity of the deficiencies detected or observed, and a second table which provides a summary of the recommendations for corrective work over the next 5 or 10 years, and associated budget cost estimates for all the corrective work recommended.

The information provided in the tables for each of the roof basins reviewed generally consists of the following:

- Identification/Label of each roof basin on the building(s);
- Area/Size of each roof basin;
- Roof Membrane Type;
- Roof System identification (Conventional, Inverted, Ventilated)
- Current years of service;
- Remaining expected years of service;
- Area of Saturated Insulation;
- Various membrane deficiencies;
- Caulking Deficiencies;
- Recommendations (replacement, localized repairs,…etc.)
- Projected year for repairs and/or replacement and associated budget costs

This information is also presented with recommendations for typical maintenance items involving roofing including maintenance to roof drains, repairs to all area of visible deterioration of the roofing membrane including such typical items as membrane blisters, ridging, fishmouths, tears or splits in the membrane, replacement of damaged metal flashing and stack jack sleeves, and the removal of existing debris or vegetation present on the roof surface, as a means to preserve or prolong the remaining useful life of the roofing system.

The tables and recommendations of the preventative maintenance program for the roofing are often presented along with a schematic plan view drawing of the roofing system of the buildings whereby all the roof basins and all the deficiencies recorded during the roof assessment and areas of recommended roof repairs are also identified.

Table 1 – Typical Sample of Results Summary of Roofing Assessment

DOSSIER: T-0202A

GROUP	BASING	AREA	MEMBRANE	ROOF SYSTEM	YEARS OF SERVICE	WET INSULATION (2)		MEMBRANE FLASHING - OPEN JOINTS (31)		EXPOSED MEMBRANE FLASHING (34)		EXTERIOR WALL CAULKING (51)						TOTAL			
		(M^2)				QTY	M^2	QTY	M^1	QTY	M^0	QTY	M^1	QTY	M^2	QTY	M^2	M^2	M. L.	M^2	M. L.
T1 - Office																					
	C5-C7	406	MULTIPLY	CONVENTIONAL	19							2	9						9		
	C6	265	MULTIPLY	CONVENTIONAL	19																
	C8	231	MULTIPLY	CONVENTIONAL	19	1	20.8											20.8			
	C9 @ C11	633	MULTIPLY	CONVENTIONAL	19																
	F26	444	MULTIPLY	CONVENTIONAL	19					1	19.3								19.3		
	F27	27	MULTIPLY	CONVENTIONAL	19					1	3								3		
T1 - Workshop																					
	A1	528	MULTIPLY	CONVENTIONAL	19	2	74.7											74.7			
	A2	541	MULTIPLY	CONVENTIONAL	19	1	74.1											74.1			
	E13	590	MULTIPLY	CONVENTIONAL	19	1	106.9					2	30					106.9	30		
	E25	392	MULTIPLY	CONVENTIONAL	19	1	45.9					2	22.5					45.9	22.5		
	B4	84	MULTIPLY	CONVENTIONAL	19							4	32						32		
	E15	502	MULTIPLY	CONVENTIONAL	19							2	9						9		
	D12	140	MULTIPLY	CONVENTIONAL	12			2	3										3		
	E14, E23, E24	1499	MULTIPLY	CONVENTIONAL	19																
T4 - Workshop																					
	E26	52.4	MULTIPLY	CONVENTIONAL	19							2	15						15		
T2 - Office																					
	C12	689	MULTIPLY	TERRACE	19	NON INSPECTÉ															
T3 - Canopy																					
	A3	213	MULTIPLY	VENTILATED	19																
T4 - Canopy																					
	E16 @ E22	3223	MULTIPLY	CONVENTIONAL	19																
TOTAL:	29	10459.4			**TOTAL:**	6	322.4	2	3	2	22.3	12	117.5	0	0	0	0	322.4	142.8	0	0

LEVEL OF SEVERITY (MEDIUM OR HIGH): RED
LEVEL OF SEVERITY (LOW): GREEN

Table 2 – Typical Sample of Summary of Recommendations

DOSSIER: T-0202A

GROUP	BASINS	AREA	MEMBRANE	ROOF SYSTEM	YEARS OF SERVICE	REMAINING YEARS OF SERVICE	WET INSULATION (2)	MEMBRANE FLASHING - OPEN JOINTS (51)	EXPOSED MEMBRANE FLASHING (34)	EXTERIOR WALL CAULKING FAILURE (51)	2007		2008		2009		2010		2011		TOTAL	
		(m²)					QTY (m²)	QTY (m)	QTY (m)	QTY (m)	ACTION	$	ACTION	$	ACTION	$	ACTION	$	ACTION	$		
1er	A1	528	MULTIPLY	CONVENTIONAL	19	1	74.7				REF	79,200										
1er	A2	541	MULTIPLY	CONVENTIONAL	19	1	74.1				REF	81,150										
1er	C8	231	MULTIPLY	CONVENTIONAL	19	1	20.8				REF + CORR	25,761										
1er	E13	590	MULTIPLY	CONVENTIONAL	19	1	106.9			30	REF	88,500										
1er	E25	392	MULTIPLY	CONVENTIONAL	19	1	45.9			23	REF + CORR	44,154										
Total	**5 basins**	**2282**					**322.4**			**53**		**318,765**										
2e	B4	84	MULTIPLY	CONVENTIONAL	19	3 @ 5				32	CORR	2,500	REF	9,044								
2e	C5	120	MULTIPLY	CONVENTIONAL	19	3 @ 5				9	CORR	1500	REF	19,920								
2e	C6	265	MULTIPLY	CONVENTIONAL	19	3 @ 5							REF	28,532								
2e	C7	286	MULTIPLY	CONVENTIONAL	19	3 @ 5							REF	30,794								
2e	C9 @ C11	633	MULTIPLY	CONVENTIONAL	19	3 @ 5							REF	68,155								
2e	E26	52.4	MULTIPLY	CONVENTIONAL	19	5							REF	5,642								
2e	F26	444	MULTIPLY	CONVENTIONAL	19	3 @ 5			19				REF	47,805								
2e	F27	27	MULTIPLY	CONVENTIONAL	19	3 @ 5			3				REF	2,908								
Total	**10 basins**	**1911**							**22**	**41**		**4,000**		**212,800**								
3e	E14	660	MULTIPLY	CONVENTIONAL	19	5									REF	71,062						
3e	E15	502	MULTIPLY	CONVENTIONAL	19	5				9	CORR	1,000			REF	54,050						
3e	E23	474	MULTIPLY	CONVENTIONAL	19	5									REF	51,036						
3e	E24	365	MULTIPLY	CONVENTIONAL	19	5									REF	39,300						
Total	**4 basins**	**2001**								**9**		**1,000**				**215,448**						
4e	E20	285	MULTIPLY	CONVENTIONAL	19	7											REF	30,686				
4e	E21	769	MULTIPLY	CONVENTIONAL	19	7											REF	82,798				
4e	E22	376	MULTIPLY	CONVENTIONAL	19	7											REF	40,484				
4e	C12	689	MULTIPLY	CONVENTIONAL	19	3 @ 5											REF	103,350				
Total	**4 basins**	**2119**																**257,318**				
5e	A3	213	MULTIPLY	VENTILATED	19	7													REF	22,934		
5e	E16 @ E19	1793	MULTIPLY	CONVENTIONAL	19	7													REF	193,052		
Total	**5 basins**	**2006**																		**215,986**		
TOTAL:	29	10319				**TOTAL:**	322.4		44	103		323,765		212,800		215,448		257,318		215,986	**1,225,317.00 $**	

LEVEL OF SEVERITY (MEDIUM OR HIGH): RED
LEVEL OF SEVERITY (LOW): GREEN

ACTIONS : REPLACEMENT (REF) REPAIRS (CORR) GARANTY (GAR) VISUAL (VIS) EXPERTISE (EXPERT)

SUMMARY

The key to providing building owners with an accurate and efficient preventative maintenance program for multiple buildings and roof basins, requires the combined expertise of an experienced building or roofing professional and a qualified thermographer. The review of architectural plans and historical information regarding the roofing system by a qualified professional is essential to obtaining the necessary information on what strategy and diagnostic tools shall be required in order to proceed with the roof assessment. The roof assessment should make use of infrared thermography as a means to most effectively and efficiently assess large number and areas of roof basins. Other non-destructive diagnostic tools such as nuclear and capacitance meters should also be used in order to validate the results of the infrared scans, and to review specific roof areas that are unable to be scanned by infrared thermography. Exploratory openings at localized areas in the roofing system are also critical as part of any roof assessments in order to validate the interpreted results of the non-destructive surveys. The results and recommendations which form the basis of the preventative maintenance program is best presented in the form of tables and schematic drawings which illustrate the areas of roof repairs or replacement, and the associated budget cost estimates.

ABOUT THE AUTHOR

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