Original Article

Roof deterioration and impact: A questionnaire survey

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ABSTRACT Roofing is one of the building components which is most subject to deterioration. Maintenance and renewal of roofs are, therefore, crucial and require frequent inspection and good understanding of roof deterioration with time. In an effort towards facilitating roof condition assessment and subsequent repair decisions, this article first discusses the previous studies related to roof inspection and deterioration, followed by a two-stage survey among roofing experts. The first stage elicits the most common defects, their contribution to failure, symptoms of poor and critical roofs, and impact of roof deterioration on other components. Fourteen survey responses were obtained from the Toronto District School Board related to school buildings with low-slope built-up roofs. Based on the first-stage results, a pictorial database of roof pictures with different defects was created and initially ranked. The ranking of pictures was then confirmed through the second phase of the survey. The research provides a better understanding of roof deterioration and the developed pictorial database acts as a visual guidance system to facilitate fast and less subjective inspection of roofs, and ultimately to better asset management of building facilities.

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INTRODUCTION

Roofing is one of the main components of any building and is a relatively large investment (Suarez, 1999). Many studies (for example, NCES, 2003) have identified roofing as one of the most deterioration-prone building components. Therefore, being proactive with the health of a roofing system will ultimately reduce the building financial liability (Suarez, 2005).

The average life of roofs varies by the type and material of the roof (Lewis and Payant, 2000). However, the life expectancy for roofs, like any other building component, is greatly influenced by the presence or absence of a roof maintenance programme (Suarez, 1999). According to the National Roofing Contractors Association, roofs that are not properly maintained will last approximately half of their anticipated normal service life (Suarez, 1999).

Roof systems are generally divided into two categories: low slope and steep slope, as shown in Figure 1. Many studies (Cullen and Graham, 1996; Bailey and Bradford, 2005) have revealed that built-up roof (BUR) systems are the most common roof type in Canada. To facilitate an in-depth investigation of roof defects, this article focuses on BUR systems only. BUR systems have been in use in the United States for more than 100 years. They are generally composed of alternating layers of bitumen and reinforcing fabrics that create a finished membrane. The number of plies in a cross section is the number of plies on a roof. The reinforcing fabrics are also called roofing felts or ply sheets. Roofing felts are reinforced with either glass-fibre mats or organic mats. The bitumen typically used in BUR systems is asphalt, coal tar or cold-applied adhesive. Surfacing for BUR systems include aggregate (such as gravel, slag or mineral granules), glass-fibre or mineral surfaced cap sheets, hot asphalt mopped over the entire surface, aluminium coatings or elastomeric coatings.

PREVIOUS STUDIES ON ROOFING ASSET MANAGEMENT

Previous studies (Cullen, 1993; Cullen and Graham, 1996) have examined the extent of problems encountered from 1993 to 1995 with several roof types, including the BUR. These studies reported the nature, frequency and seriousness of problems experienced with BUR systems. The studies also identified problems and defects for each roof type and their severity levels. For example, Figure 2 shows the frequency of BUR problems.

Figure 1: Roof system classification (based on NRCA, 2007).

Figure 2: Frequency of built-up roof problems.

Asset management systems have been proposed to help large building owners with maintenance and capital renewal decisions to keep the facilities safe and operable with least cost. With respect to roofs, the ROOFER Engineering Management System (Bailey and Bradford, 2005), developed by the Construction Engineering research laboratory, for example, has been used since 1989 by the US army Corps of Engineers. ROOFER includes procedures for collecting inventory and inspection information, evaluating the condition of roofs, prioritizing repair and replacement actions, and developing implementation plans. ROOFER condition assessment procedures are based on standardized visual inspection processes that involve a list of 93 defects that belong to 16 roof distresses. The inspection data provide the information needed to generate condition indexes for the major roof components as well as an overall roof condition index.

Some researchers have successfully used ROOFER for their studies. In Canada, a project called 'Building Envelope Life Cycle Asset Management (BELCAM)' was carried out by the Institute for Research in Construction of the National Research Council of Canada (Kyle and Vanier, 2001a, b). The study collected data from roughly 600 buildings in 15 cities across Canada to calculate the remaining service life of building envelope components, with an initial focus on low-slope roofs. The study revealed that distresses change over time. The majority of the reported distresses occurred on BUR roofs, with roughly one-third related to flashing.

Other research has examined individual roof defects in detail. For example, Martin (1979) studied membrane splitting and its causes. Murray and Booth (1997) explored membrane blisters in BURs. Shahin *et al* (1987) studied membrane and flashing defects of BURs and since roofs do not age uniformly, they suggested dividing the roof into sections and rating each section separately as an effective inspection method. Other studies analysed moisture ingress (Busching, 1979; Desjarlais and Byars, 1997) and air leakages (Fishburn, 1997).

RESEARCH METHODOLOGY

To better understand the deterioration process of roofs, with respect to defects, symptoms, impact on other building components, and condition

assessment needs, a two-stage survey was designed. Stage I of the survey aimed at obtaining information about four aspects:

1. the effect of a roof's condition on the safety and functioning of a school building;
2. roof defects and their weights;
3. the symptoms of critical deficiencies; and
4. the impact of roofing defects on other components.

Stage II of the survey involved collecting, sorting and rearranging pictures of roofs in different condition states. The results of both stages of the survey were then combined to form the basis for developing a visual guidance system for effective condition assessment of roofs.

To prepare for the surveys, previous condition assessment data from the Toronto District School Board (TDSB) were utilized. In 2003, the TDSB conducted a large condition assessment survey for its almost 600 schools in the Toronto area. Individual reports that described the conditions and expected needs of the schools were first analysed. Since these reports include similar components at various ages (conditions) in different schools, they cover problems that occur to roofs throughout the various stages in roof life cycle. Two types of information were then extracted from these reports: types of defects and their symptoms, and pictures related to those defects and symptoms. Information related to the types and symptoms of defects helped in the designing of Stage I of the survey, and the pictures were used to prepare Stage II of the survey. The details of both stages of the survey are discussed in the following sections.

STAGE I SURVEY

Based on the literature and the large data collected from the TDSB, roofing defects have been categorized under four major sub-groups: membrane-related problems, drainage-related problems, flashing-related problems and hardware-related problems. These were used to design the Stage I questionnaire regarding the effect of the roof condition on the safety and functioning of a school building, roof defects and their weights, the symptoms of poor/critical roofs, and the impact of roof defects on other components. Stage I of the survey targeted 20 TDSB roofing experts, and 14 responses were received. The survey had four sections (Appendix), as follows:

1. *The effect of roof condition on the school*: This section aimed at providing an understanding of the level of safety concern, the level of school interruption and the level of damage to other components when the component is in various conditions (Very Good, Good, Fair, Poor and Critical). This section also included a question related to the remaining service life of the roof in various conditions. The latter question provides an indication of the replacement time required at various conditions. The survey responses are as follows:

- as shown in Figure 3, the average score for the impact of a critical roof on safety is 9 (that is, very high), and the impact of a poor roof is 7;

Figure 3: Effect of roof condition on the school building.

- the average score for the impact of a critical roof on school interruption is 10 (highest), and the impact of a poor roof is 8;
 - the average score for the damage to other components caused by a critical roof is 10 (highest), and the impact of a poor roof is 8; and
 - the average service life for a roof in critical condition is less than a year, with 19 years for one in very good condition.
2. *Relative seriousness of roof defects:* This section focused on understanding the relative importance of a component-specific defect. The respondents were asked to enter values from 1 to 10 (1=same importance and 10=much more important) to provide a measure of relative seriousness of a defect in comparison with other roofs. The user was also given the option of entering an additional unlisted defect for roofing based on their experience. The responses were analysed using the Analytic Hierarchy Process (AHP), which is a mathematical technique for multi-criteria decision-making (Saaty, 1980). AHP uses the results of the pairwise comparisons between each two decision elements, and then calculates their relative importance (or weights). Using the AHP process, the final weights in Table 1 show that Membrane defects are the most critical, while the Hardware defects are the least critical (0.1, least critical).
 3. *Symptoms of roof defects:* In this section, the respondents indicated the condition that corresponds to various roof symptoms. This information was later used in Stage II of the survey to initially classify distress pictures. Based on the received responses, Table 2 shows the symptoms that clearly indicate either a poor or a critical roof. This list can be useful for inspection purposes.

Table 1: Relative seriousness of roof defects

Defect type	Relative seriousness
Membrane defects	0.5
Drainage defects	0.25
Flashing defects	0.15
Hardware defects	0.1

Table 2: Symptoms of roof defects

Symptoms of a roof in critical condition

Lifting up/large openings in flashing
Leakage in hardware
Missing/inadequate flashing
Cracks/broken flashing
Blistering in membrane
Splits/punctures in membrane
Blocked roof drains

Symptoms of a roof in poor condition

Outdated and obsolete hardware
Corroded flashing
Paint/exterior finish problem in flashing
Ridging in membrane
Sealant problem in flashing
Corroded hardware
Debris/vegetation growth in membrane
Noisy/vibrating hardware
Bleed-through in membrane
Eavestrough/downspouts damage
Water ponding

Figure 4: Effect of roof leakage on building components.

4. *The effect of roof deterioration on other building components:* In this section, the respondents provided examples of how roof damage affects other school components. Most of the respondents (11) reported that roof leakage would result in a health hazard because of factors such as mould formation (Figure 4).

Figure 5: Sample of the Excel sheet for Stage II survey.

Initial Condition: **Critical**
Re-Ranked Condition: **Poor**

Comment: The drain needs to be cleared and the roof condition re-assessed.

Figure 6: Survey response for a sample picture.

STAGE II SURVEY

This stage of the survey aimed at creating a database of pictures of roofs ranked according to condition and degree of defect. A preliminary database was first created by extracting pictures from the extensive database of past assessment reports and other historical data of the TDSB. Under each category of defect from Stage I, symptoms were identified and pictures were found for each symptom. The pictures were then sorted according to four levels of severity: Good, Fair, Poor and Critical. Using these pictures, a survey form was implemented in a simple interactive

Figure 7: Sample of the pictorial database to support roof inspection.

Excel spreadsheet and sent to group of TDSB roofing experts to confirm the preliminary ranking and categorization of the picture. Drop-down menus and zoom functions were added to allow the experts to confirm/modify/annotate the information associated with each picture (Figure 5).

Stage II of the survey was sent electronically to the TDSB roofing experts. The experts viewed and commented on the pictures by zooming in and then re-assessing the pictures based on their experience. The TDSB experts made interesting observations for many of the pictures. For example, the comment about the picture in Figure 6 shows the blockage of roof drain was re-ranked as 'Poor' rather than 'Critical' because, in the expert's judgment, the roof drain needs to be cleaned and the roof re-assessed. Once the pictures were properly categorized, a pictorial database was then created to support the inspection of roofs. A portion of the pictorial database is shown in Figures 7 and 8.

CONCLUSIONS

Buildings are complex in nature and involve a large number of diverse interrelated components. Using a two-stage survey approach among experts in the field of roofing, this research provided an understanding of important concerns related to roofs, which is a key building component. Stage I of the survey analysed roof defects, their associated symptoms

Figure 8: Sample defects in the pictorial database.

and the impact of roof defects on other components. Stage II of the survey, on the other hand, involved collecting, sorting and verifying pictures of roofs with different levels of defects. The results of the surveys paved the way for the development of a pictorial guidance system to support roof inspection. The system makes the inspection process less time-consuming, more economical and less-subjective.

This research is potentially beneficial to large organizations, such as the TDSB, that have a large network of buildings and a stringent budget for facility renewal. Several potential improvements are also being explored to maximize the benefits. The visual guidance system is being expanded to include additional pictures for a number of key building components such as boilers, electrical switchgear, fire alarm system and windows. Analysis of optional repair strategies and their costs is another direction of ongoing research, in addition to asset prioritization and optimum fund allocation. The combination of these efforts could be the starting point related to the development of an efficient asset management system for buildings.

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APPENDIX

Survey

Expert opinion on roofing systems

We ask your help in participating in a survey on roof deterioration.

This survey has two simple sheets that will take about 10 minutes of your time.

I. How various roof conditions affect the school?

If Roof Condition is:	Level of Safety Concern (1=Low to 10=High)	Level of School Interruption (1=Low to 10=High)	Level of Damage to Other Components (1=Low to 10=High)	In this condition, the roof will likely need to be replaced within (years)?
Very Good	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>
Good	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>
Fair	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>
Poor	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>
Critical	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>	<div><div></div></div>

II. How do you compare the seriousness of roof defects?

Seriousness Comparison Among Roof Defects	Drainage Problems 2	Flashing Problems 3	Hardware Problems 4	(Other, Specify) 5
Membrane Problems 1				
Drainage Problems 2				
Flashing Problems 3				
Hardware Problems 4				

Please enter a value (1 to 10) in the empty boxes.
(1 = same importance;
10 = Much more important).

Example: a value of 5 in the yellow box indicates that Defect 2 is 5 times as serious as Defect 3.

III. Please define the various problems associated with roof defects.

Membrane Problems	Indicated Roof Condition ^a	Drainage Problems	Indicated Roof Condition ^a	Flashing Problems	Indicated Roof Condition ^a	Hardware Problems	Indicated Roof Condition ^a
Blistering		Roof Drains Blocked		Corrosion		Corrosion	
Bleedthrough		Inadequate Drains		Paint/exterior finish		Noise / Vibration	
Ridging		Inadequate Slope		Cracks/broken		Leakage in hardware	
Torn membrane		Gutter damage		Missing/inadequate		Outdated / obsolete	
Vegetation growth				Lifting up/Large hole			
				Sealant problem			

^a**Roof condition:** Very Good; Good; Fair; Poor; or Critical.

IV. Please give examples on how roof leaks affect other components?

Example: Roof leakage affects the Interiors Finishes of the school. This is because the water penetrates into the ceiling and stains and damages the ceiling tiles/interior paint.

Example 1:

Example 2:

Example 3:

Example 4:

Thank you for your cooperation.