DEFINE THE MOST COST-EFFECTIVE CLADDING SYSTEM IN CANADA RESULTS OF A SURVEY

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Prepared for

Research Division
Policy, Research and Program Sector
Canada Mortgage and Housing Corporation

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part IX of the Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

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DISCLAIMER

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EXECUTIVE SUMMARY

Many different cladding systems have been used on residential buildings and various opinions exist regarding which system is the most cost-effective. The initial construction costs as well as the longterm maintenance and repair costs vary from system to system. Some believe that a cladding which costs less to construct is the most cost-effective even with higher repair costs.

This survey examines initial construction costs, cladding durability and related repair costs, as well as other factors which affect the overall life-cycle costs of the various cladding systems.

Two questionnaires were sent out to developers, property managers, and housing authority officials. The first was intended to determine general repair trends for a large sample of installations. The second was directed at some specific individuals to obtain detailed information. The replies, as well as cost estimates for cladding repairs, were used to determine average repair costs for nine cladding systems.

Of the systems examined, conventional stucco applied to steel stud backup walls was found to be the least expensive system to install while precast concrete panels were the most expensive. The brick veneer/steel stud system was found to have the highest average repair costs while polymer modified stucco and metal cladding systems tend to require the least repairs. Conventional stucco applied to steel stud walls was found to be the most cost-effective over the 25-year life cycle examined while precast concrete was found to be the least cost-effective.

The results of this survey are limited due to the lack of available information. Although total life-cycle costs were calculated, it should be noted that repair costs were largely based on estimates and some inaccuracies may have been introduced into the data. However, the emphasis of the study is on the relative cost-effectiveness of the cladding systems, not the actual life-cycle costs. In conducting this study, it was realized that surveys based on questionnaires are not effective for research projects of this type where detailed information is required.

The rankings of all systems in regards to their installation, repair and life-cycle costs are listed below. The least expensive cladding in each category of costs is given a ranking of "1" with increasing numbers representing more expensive systems.

Cladding System	Installation Costs	Repair Costs	Life-Cycle Costs
Conventional Stucco Applied to Steel Stud Walls	1	8	1
Metal Siding	2	3	2
Conventional Stucco Applied to Concrete Masonry Walls	3	7	3
Metal Panels	5	3	4
Polymer Modified Stucco Applied to Steel Stud Walls	5	1	4
Brick Veneer/Steel Stud	4	9	6
Polymer Modified Stucco Applied to Concrete Masonry Walls	7	1	7
Brick Veneer/Concrete Masonry	7	5	8
Precast Concrete	9	6	9

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1. INTRODUCTION

Many different cladding systems have been used on residential buildings over the years, including brick veneer/concrete masonry (BV/CM), brick veneer/steel stud (BV/SS), precast concrete, metal panels, metal siding, stucco, through-the-wall masonry (TTW), glass curtain walls, stone panels, and other established systems. In addition, new systems utilizing exterior insulation appear to be gaining popularity for both new construction and recladding/ retrofit applications. All of these systems differ in many ways, such as in aesthetics, installation costs, and durability. Therefore, opinions on the various characteristics of the systems differ as well.

Presently, various opinions exist regarding which cladding is the most cost-effective over the long term. Some people may believe that a system which is inexpensive to construct is the most cost-effective while others may feel that a system which costs more initially but normally requires fewer repairs is the most cost-effective. This debate has been unresolved due to a lack of information comparing the costs associated with the various cladding systems.

Since opinions vary and the debate is unresolved, the cost-effectiveness of the claddings should be based on overall life-cycle costs. The life-cycle costs of a building, and hence its cladding system, depends on installation costs, maintenance and repair costs, heating costs for the building, inflation, interest rates and the residual value of the cladding system. These costs can be analyzed using a variety of economic procedures to determine the overall life-cycle costs of the cladding. With the average costs for each cladding system determined, the system with the lowest overall life-cycle costs is the most cost-effective over the period of time examined. This report deals with the average life-cycle costs of various cladding systems, based on a 25-year life cycle, to define the most cost-effective cladding system for mid to high-rise apartment buildings.

For established claddings, life-cycle costs were based on data received through the completion of questionnaires as well as estimates for hypothetical repairs. The questionnaires were used to assemble the following information:

- popularity of each cladding system
- incidence of repairs
- extent of repairs
- repair costs for each type of repair
- original construction costs

Replies to the questionnaires were analyzed to determine the average installation costs as well as the average repair costs of various cladding systems. The life-cycle costs of these systems were calculated based on the replies to the questionnaires and on assumptions regarding investment rates, inflation and the residual value of the claddings.

Heating costs are an important factor in wall systems' operating costs since systems with less insulation within the walls result in higher heating costs than systems with ample insulation. However, most residential buildings today are constructed with R_{si}-3.5 (R20) insulation in the walls and, although the wall elements of the various cladding systems have different R-values, the overall thermal resistance of all systems examined do not differ significantly. Therefore, heating costs did not play a role in the analysis of life-cycle costs since there are only minor differences in the various systems' effect on heating costs.

For new cladding systems, manufacturers' published data and test reports were to be used to estimate the life span of the system, maintenance and repair costs, and installation costs. This part of the study did not develop as originally intended since the only new system analyzed involves claddings which utilize a polymer modified stucco over rigid insulation. Other "new systems" were generally found to be new products which fall in the conventional categories of precast concrete panels and metal claddings. The life-cycle costs of the new system examined were calculated based on installation costs, expected maintenance and repair costs, and the expected residual value of the cladding.

2. METHODOLOGY

At the beginning of this project, it was realized that a large amount of information would be required to determine the life-cycle costs of the various cladding systems. Therefore, it was decided that questionnaires would be distributed in four cities across the country to obtain information. The cities selected were Halifax, Montreal, Toronto, and Calgary. The population for sampling included developers, property managers and housing authority officials.

2.1 Development of Questionnaires

It was decided that two different questionnaires should be prepared for collecting data relating to maintenance and repair costs. The first questionnaire was of a general nature and was directed at many individuals to obtain a large sample of cladding installations. The second questionnaire was quite detailed and was intended to provide responses for specific installations.

The purpose of the first questionnaire was to determine general trends regarding cladding system usage and repairs. Questionnaire #1 was set up such that the respondents could list the number of installations his/her organization owned or managed and how many of them were repaired. For each cladding that was repaired, the respondent was asked to list:

- building height
- building age
- type of cladding repaired
- age of installation when repaired
- replacement cladding, if applicable

The advantage of using the first questionnaire to determine general trends is that it was possible for several installations to be sampled with only one reply. Therefore, many installations could be sampled even with a low response rate.

The purpose of the second questionnaire was to determine maintenance and repair costs for buildings which have undergone cladding repairs. For each sample building, questionnaire #2 was intended to determine:

- size, shape, orientation and age of building
- quantities of each cladding used
- building age
- structural make-up of building
- original construction details
- maintenance costs
- repair costs
- possible causes of distress

The second questionnaire was intended to provide the bulk of the information required involving the type and costs of repairs which are required for each cladding system as well as how old the installations normally are when the repairs are required.

To determine the installation costs of the more common cladding systems, a third questionnaire was developed. Questionnaire #3 described two hypothetical buildings, a mid-rise and a high-rise, and five cladding alternatives for each building. Since there are many variables within each cladding system, the average type of construction was outlined for each cladding. This questionnaire was used to provide the average unit costs of construction for each system on each of the buildings described. In order to ensure that all cladding systems were equal in terms of thermal resistance, and therefore heating costs, each system was selected such that the overall R-value of each cladding systemwas approximately equal.

2.2 Gathering of Required Information

2.2.1 General Trends

Sampling for the first questionnaire was obtained in two ways. Firstly, an extensive list of property management and development companies was compiled using lists of names and addresses available to the general public. No attempt was made to identify specific firms which are involved with residential buildings. The response rate was expected to be low from this group however, due to the nature of questionnaire #1, many installations could still be sampled with a low response rate. Secondly, maintenance directors at the municipal offices for the provincial housing ministry's in the four cities selected were asked to complete questionnaire #1. The initial response from this group was positive and therefore a high response rate involving many installations was expected from the maintenance directors.

Over 300 questionnaires were mailed to property managers and developers. It was hoped that a response rate of about 10%, covering about 200 installations, would be obtained. It was also hoped that all four maintenance directors would complete the questionnaire and due to the number of public housing buildings in Montreal and Toronto, it was expected that about 300 installations would be covered by those responses. Therefore, it was expected that about 500 installations would be sampled using questionnaire #1.

When the questionnaires were returned, only about 5% of the property managers and developers returned useful replies which covered 184 installations. (Another 5% returned the questionnaires stating that they are interested in the results however they could not provide any useful information). The maintenance directors in Toronto and Halifax also completed the questionnaire, accounting for 156 installations. Therefore, a total of 340 installations were sampled using questionnaire #1. Unfortunately, about 90% of the installations sampled were brick veneer/concrete masonry, resulting in a small sample size for installations of other types.

Only nine of the installations sampled were brick veneer/steel stud claddings, making it difficult to reliably compare the two brick masonry systems. To increase the sample size for BV/SS claddings, seven buildings across Canada were added to the sample which were observed on-site by the principal consultant of this study. Two were located in St. John's, two in Toronto and three in Calgary. For each city, an additional questionnaire was completed to document relevant information for each cladding. These buildings did not have a higher incidence of repair than the BV/SS installations sampled and therefore did not artificially increase the repair incidence for BV/SS systems. Another questionnaire was later completed to include a building in Halifax which was addressed by the second questionnaire. In total, 21 replies to questionnaire #1 were obtained which sampled 348 cladding installations.

2.2.2 Type, Incidence and Costs of Repairs

Approximately 200 property management and development firms in Halifax, Montreal, Toronto and Calgary were contacted in an attempt to locate individuals who were willing to complete questionnaire #2. Of these, only 10 people in Halifax and Toronto stated that they could (or would) provide information. In fact, only three of these individuals provided useful information involving a total of four replies to Questionnaire #2. Since cladding repairs are required at two of the buildings in Calgary which were inspected by the principal consultant, repair costs were estimated for these buildings and a questionnaire was completed for each one. Also, two buildings investigated by the principal consultant in Ottawa which require or are undergoing repairs were included in the survey. The addition of these four buildings doubled the number of installations sampled to a total of eight.

In an attempt to obtain additional useful information for the study, several building owners and a masonry restoration specialist in Calgary was contacted. Also, further attempts were made to establish contacts with individuals in Toronto who might be able to provide useful information. These attempts were unsuccessful in providing additional useful information.

Since no further progress was made in increasing the number of installations sampled, it was decided that other housing authorities would be contacted. Maintenance officials at housing authorities in several other cities across Canada were contacted and asked to provide information that could be useful to this study. Most of the officials contacted were willing to assist in the study. However, several of the housing authorities did not own any mid to high-rise buildings which have required cladding repairs. In the few cases where the housing authorities owned buildings which could be sampled, the officials stated that the information was not available or it would be too difficult to dig out of the files. Therefore, none of the housing authorities contacted were able to provide replies to questionnaire #2.

After unsuccessful attempts to obtain additional information from Toronto and Calgary, it was also decided to add the Ottawa/Hull area to the survey. The principal consultant for this study is based in Ottawa and therefore it was felt that it would be easiest to obtain further information from the Ottawa/Hull area.

Two developers, three property managers, and three building restoration contractors were contacted in order to locate buildings in the Ottawa/Hull area which have undergone cladding repairs. Although the property managers and restoration contractors tried to be of assistance by directing the consultant to buildings which were repaired, none were able to provide a complete set of information and therefore no useful information was obtained from these contacts.

The Ottawa-Carleton Regional Housing Authority and the Eastern Regional Housing Programs Office of the Ministry of Housing were then visited to obtain relevant information by searching through files and reviewing drawings and investigation reports. A review of available information enabled eight more installations in Eastern Ontario to be sampled. In total 16 buildings were sampled with Questionnaire #2.

However, these questionnaires did not provide enough information, on their own, to allow the type, incidence and costs of repairs to be accurately assessed. Therefore, hypothetical cases were also examined and engineering judgements were made as to the likely incidence and types of repairs that would be required for various cladding systems. Past experience with cladding repairs was also used to estimate repair costs.

2.2.3 Selection of Cladding Systems

Through-the-wall masonry (TTW), glass curtain walls and stone panels were not included in this study since they are not likely to be among the most cost effective and are not common systems. TTW was fairly common in the past but it is known to have a high incidence of repair in most of Canada. For this reason, TTW is no longer used frequently in most areas of Canada. Since TTW is no longer frequently used and because it is not one of the cheaper systems to install, TTW is not included in this study.

Glass curtain walls and stone panels are uncommon on residential buildings and therefore they were not included in the study. Due to the high installation costs of stone panels they are mainly used on prestige commercial buildings or museums. Glass curtain walls are mainly used in commercial applications.

The results of questionnaire #1 indicate that conventional stucco is not one of the more common systems installed on apartment buildings, likely due to its limited aesthetic appeal in such applications. However, stucco is not uncommon either as it is inexpensive and is frequently used in small quantities on a building dominated by another cladding to provide a contrast to the main cladding. Since stucco is relatively inexpensive and is used fairly often, conventional stucco systems were examined in this study. The polymer modified stucco system was included in the report as a comparison to conventional stucco and because it is gaining popularity as an alternative to metal claddings in retrofit applications and as an alternative to precast concrete in new construction. In this study, however, it is being examined as an original installation over concrete masonry or steel stud support walls, not as a retrofit cladding.

Therefore, only those systems which are fairly common and/or are inexpensive to install are examined. These include brick veneer/concrete masonry, brick veneer/steel stud, precast concrete, metal siding, metal panels, conventional stucco and polymer modified stucco. The stucco systems were examined with concrete masonry and steel stud backup walls.

2.2.4 Installation Costs

A quantity surveyor in Ottawa completed Questionnaire #3, providing original installation costs for the BV/CM, BV/SS, precast concrete, metal siding and metal panel cladding systems. These five systems were selected for questionnaire #3 since they were found to be the most common cladding/wall systems. Installation costs were then estimated for the conventional and polymer modified stucco systems using past experience with cladding repairs or replacement involving these systems as well as cost information provided with questionnaire #3 for the other systems.

2.2.5 Life Cycle Costs

Upon obtaining and analyzing data regarding installation costs, and average repair costs, the overall life-cycle costs could be calculated. In determining life-cycle costs, several assumptions, as detailed in Section 7, were made in regards to discounting, inflation and the residual value of the cladding system. The overall life-cycle costs were calculated using the present value method. In order to calculate life-cycle costs using the present value method, it was necessary to estimate:

- installation costs
- repair costs
- residual values
- discounting rate
- inflation rate

General comments and conclusions were made based on the analysis of the data obtained from the questionnaires and cost estimates as well as on the life-cycle costs calculations.

3. LIMITATIONS OF STUDY

In reviewing the survey findings, certain limitations should be realized. The quality (or accuracy) of a survey depends on:

- sample size
- number of responses
- clarity of questions
- respondents' interpretation of questions
- interpretation of answers
- assumptions made while analyzing data

Specifically, limitations to this survey and the findings of this report include:

1. An insufficient number of replies to the first two questionnaires was received, therefore:
   - not all cladding systems were examined.
   - the incidence of repairs may not be accurate for some claddings
   - some repair costs may not be accurate
   - the life-cycle costs may not be truly representative of average conditions for each cladding type (however, the rating which was established is likely accurate)

2. The building age is not known for installations which did not require repairs.

3. The cladding systems described to obtain the installation costs may not be of identical construction as the claddings examined to obtain repair costs. Therefore, the repair costs obtained for each cladding may not apply entirely to the systems described to obtain installation costs.

4. INITIAL INSTALLATION COSTS

The initial installation costs of the five most common systems were obtained from a quantity surveyor who completed questionnaire #3. The five systems are brick veneer/concrete masonry, brick veneer/steel stud, precast concrete, metal panels, and metal siding. To ensure that the costs obtained generally represent the average system that is constructed today, the most common method of construction for each system was specified. Since the construction costs may vary for different building sizes, two hypothetical buildings of different shape and size were described. In addition, the quantity surveyor provided input as to what construction is most common for precast concrete and metal claddings. Installation costs for conventional stucco and polymer modified stucco (over rigid insulation) were estimated using known unit prices for these finish systems as well as costs for the concrete masonry and steel stud support walls provided by the quantity surveyor for the other cladding systems.

The initial installation costs for each system were obtained on a unit cost basis (i.e. cost per unit area of wall cladding) since the overall life-cycle costs were to be determined on a unit cost basis. These costs represent the average initial cost of construction of each cladding system for mid-rise and high-rise buildings, and are summarized in Table 1.

Table 1: Average Installation Costs of Cladding Systems (March 31, 1990)

Cladding System	Mid-rise	High-rise
Brick Veneer/Concrete Masonry	$216/m^2$	$206/m^2$
Brick Veneer/Steel Stud	$174/m^2$	$166/m^2$
Precast Concrete	$264/m^2$	$251/m^2$
Metal Panels	$184/m^2$	$175/m^2$
Metal Siding	$166/m^2$	$158/m^2$
Conventional Stucco		
- on concrete masonry walls	$170/m^2$	$162/m^2$
- on steel stud walls	$131/m^2$	$125/m^2$
Polymer Modified Stucco on Insulation		
- on concrete masonry walls	$216/m^2$	$206/m^2$
- on steel stud walls	$184/m^2$	$175/m^2$

Examination of Table 1 reveals that the unit prices for the mid-rise installations, with lower cladding quantities, are consistently about 5% higher than for the high-rise installations. Since the difference in costs are consistent as a result of the quantities being the main variable between the two situations, there is no need to examine both mid-rise and high-rise examples. Therefore, only high-rise installations are examined in the remainder of this report.

5. GENERAL DURABILITY

A sample of 348 cladding installations was obtained through the 21 responses to questionnaire #1. The responses indicate that the brick veneer/concrete masonry system is presently much more common than any other cladding system. The responses also indicate that the brick veneer/steel stud system has a high incidence of repair while brick veneer/concrete masonry, precast concrete and metal cladding systems have lower repair rates. Other claddings are not as common and insufficient data is available to draw any conclusions regarding the incidence of repairs for other systems. Table 2 summarizes part of the findings regarding the more common claddings. Metal siding and metal panels were combined since insufficient data was obtained to examine the repairs to these systems separately.

Table 2: Summary of Responses Regarding Incidence of Repairs

Cladding System	Number of Installations	Number Repaired	Percentage Repaired (rounded)
Brick Veneer/ Concrete Masonry	304	47	15
Brick Veneer/ Steel Stud	16	9	55
Precast Concrete	14	2	15
Metal	10	1	10

Since significantly fewer installations were sampled for the BV/SS, precast concrete and metal systems, the results are not as reliable as those obtained for the BV/CM system.

5.1 Definition of Maintenance and Repairs

For the purpose of the survey, maintenance and various degrees of repairs were defined in terms of the type of repair work that could be carried out on various cladding systems. The approximate costs, in terms of per cent of the wall systems' installation costs, were also determined. Maintenance generally involves regular repairs intended to rectify minor problems and to prevent further deterioration so that more extensive repairs will not be required at a later date. Repairs other than maintenance are intended to remedy more serious distress problems and are generally required only once, provided that the cause of distress is fully addressed.

Costs for maintenance work are typically equivalent to about ½% to 1% of the installation costs about every five to ten years. Examples of maintenance work are:

- minor repointing of masonry
- minor concrete or stucco patching
- minor crack repairs
- reinstatement of loose siding or trim in a few isolated locations

Costs for moderate repairs are generally equivalent to about 5% to 20% of the installation costs. Some examples are:

- substantial repointing of masonry
- replacement of numerous bricks
- constructing control joints
- tightening many fasteners on metal siding
- resetting isolated metal or concrete panels
- substantial crack repairs and patching of concrete panels
- substantial patching or stucco replacement
- significant refinishing of polymer modified stucco

Costs for extensive repairs are generally equivalent to about 20% to 40% of the installation costs. Some examples are:

- major repointing
- reconstruction of about 5% of masonry facade
- major repairs to shelf angles
- resetting a large number of panels or siding
- replacing a moderate number of panels or siding
- major crack repairs and patching of concrete panels
- retrofit over a small portion of the cladding
- major replacement of conventional stucco
- significant amounts of major refinishing of polymer modified stucco
- any combination of two or three moderate repairs

Costs for severe repairs are generally equivalent to over 40% of the installation costs. In some cases, the repairs may be worth as much as 120% of the installation costs, i.e. the repairs to the wall system may cost 20% more than typical installation costs for the system on a new building. Some examples of severe repairs are:

- reconstruction of over 10% of the masonry facade, combined with significant repairs
- complete repointing combined with other miscellaneous repairs
- replacing large amounts of panels or siding

- retrofit over a substantial portion of the cladding
- major patching of polymer modified stucco
- replacing large amounts of modified stucco cladding
- any combination of a few extensive repairs

Costs for complete replacement are generally equivalent to over 60% of the installation costs. In some cases, the repairs may be worth as much as 300% of the installation costs, i.e. the repairs to the wall system may cost three times more than typical installation costs for the system on a new building. Repairs at the lower end of the scale generally apply to simple retrofits of a weatherscreen over the original cladding while repairs at the upper end would involve complete reconstruction of the wall system. Some examples of complete replacement are:

- complete reconstruction of the masonry facade which, in some cases, also involves reconstructing the back-up walls
- complete replacement of panels, siding or stucco
- complete retrofit, which may include repairs to existing cladding

5.2 Brick Veneer/Concrete Masonry

For many years, one of the most common cladding systems has consisted of clay brick masonry veneer and concrete masonry back-up walls. The brick veneer/concrete masonry system is still popular and it has gained a reputation of being quite durable.

The survey confirms that the system is durable since only about 15% of the 304 installations sampled have required repairs other than general maintenance. In many cases BV/CM installations required only moderate repairs after 15 to 20 years of service.

Although the system is generally durable, the performance of the cladding varies greatly from installation to installation. Some buildings required cladding repairs early in their service life while others did not require repairs for many years. Table 3 summarizes the key findings relating to the extent of repairs to brick veneer/concrete masonry claddings. Note that the average age of the repaired installation generally increases as the extent of repairs increases. The height of the building appears to have no relation to the extent of repairs or the age of the installation when repairs are required.

Table 3: Summary of BV/CM Installations According to Extent of Repairs

Extent of Repairs	Number of Installations	Average Height of Building (Storeys)	Average Age of Building at Time of Repair (Years)
Moderate	21	13	15
Extensive	15	13	17
Severe	3	6	21
Complete Replacement/ Retrofit	8	10	20
All Repairs	47	12	16

Figure 1 illustrates the percentage of installations which have experienced the various types of repairs. Buildings which required moderate cladding repairs ranged in age from 6 to 31 years. The breakdown of the age of the installations is shown in Figure 2. Similarly, the breakdown of installations with extensive repairs and complete retrofits/replacements is shown in Figures 3 and 4, respectively. Only three buildings with severe cladding repairs were sampled and they were five, 25 and 32 years old.

5.3 Brick Veneer/Steel Stud

The brick veneer/steel stud cladding system has existed for about 20 years and has become very popular during the past decade. The system's popularity is mainly due to the following factors:

- aesthetic appeal of brick masonry veneer
- the system is relatively inexpensive to construct
- steel stud walls occupy less space than masonry walls
- lower dead loads result in lighter structural framing
- the building can be enclosed more quickly

The disadvantages of the system is that there appears to be much uncertainty at this time regarding the safety, serviceability and durability of the system. Previous studies have demonstrated that the potential for serious performance problems exists, mainly because the system is often inadequately designed and constructed.

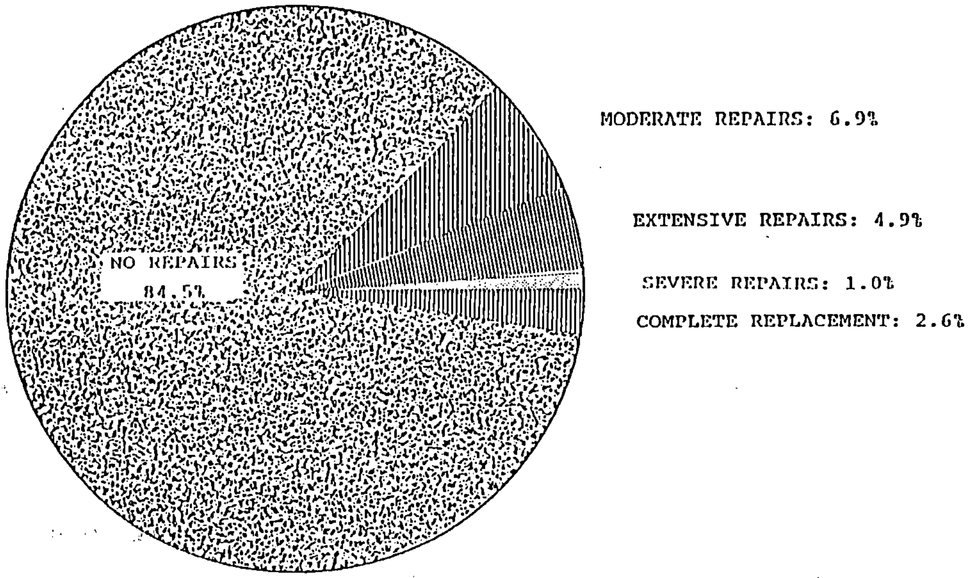

Figure 1 - Performance Summary for BV/CM Installations

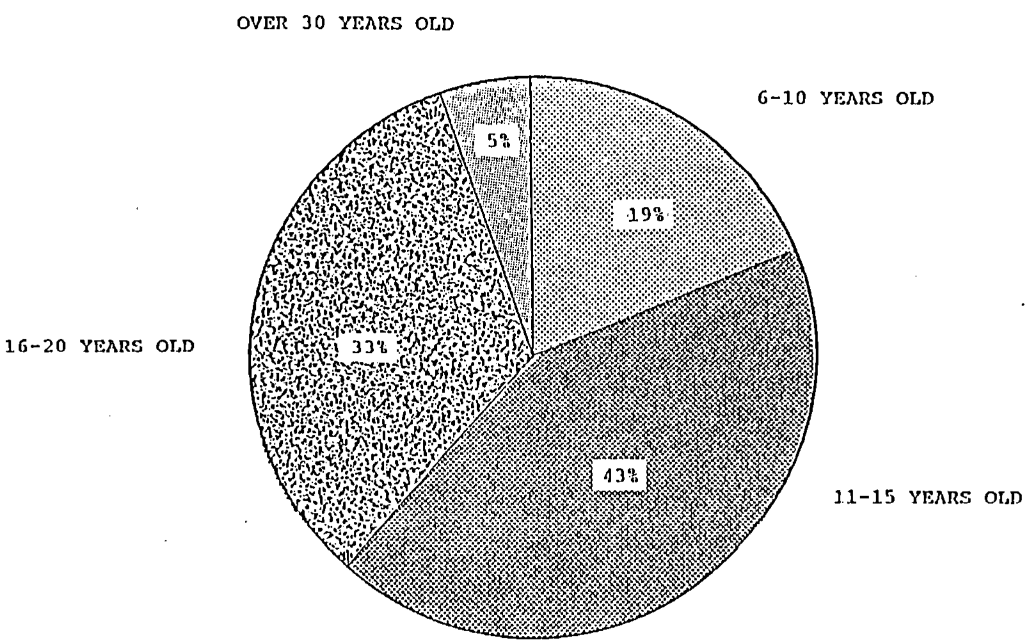

Figure 2 - Age of BV/CM Installations with Moderate Repairs

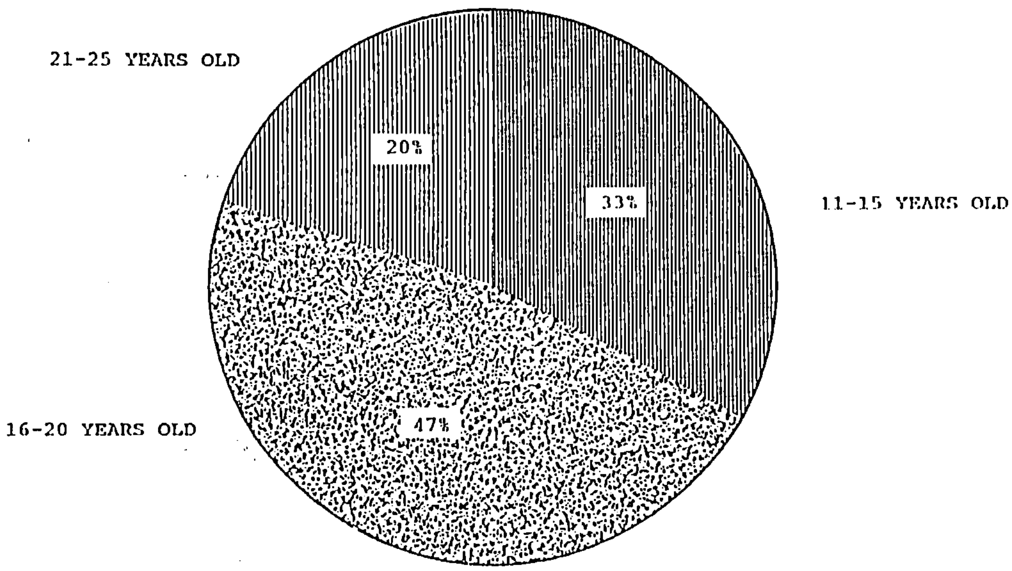

Figure 3 - Age of BV/CM Installations with Extensive Repairs

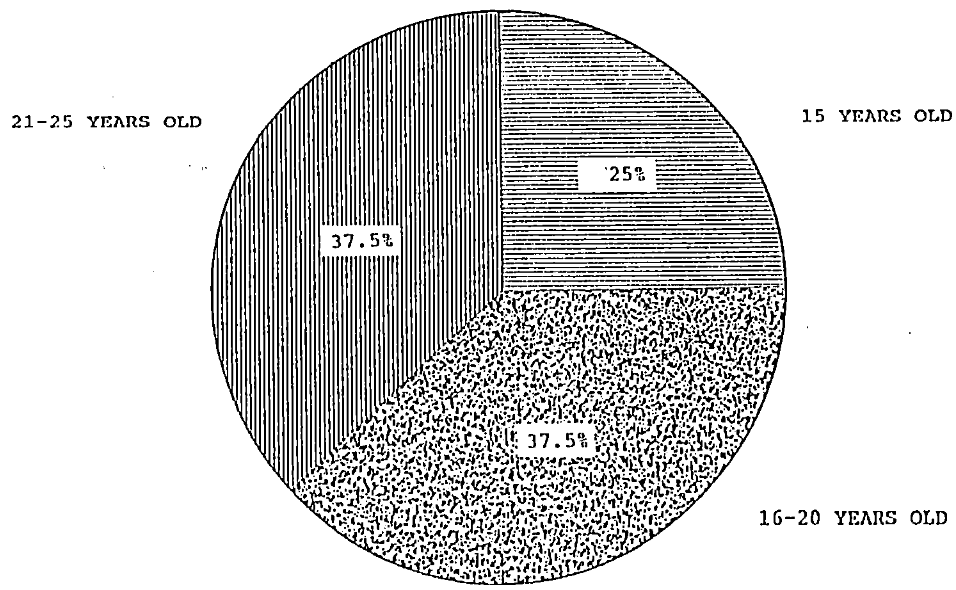

Figure 4 - Age of BV/CM Installations with Complete Replacements/Retrofits

The survey confirms that the BV/SS system does have a higher potential for serious problems. The incidence of repairs of the system was found to be much higher than that of other common systems. Table 4 summarizes the data obtained regarding BV/SS claddings which have been (or are about to be) repaired. Since the age of the claddings when various repairs are required varies widely, there appears to be little correlation between the extent of repairs and the age of the installation. Two installations required only moderate repairs after about 15 years of service, yet one BV/SS cladding required complete reconstruction after only a few years of service. Figure 5 illustrates the percentage of installations which have experienced the various types of repairs.

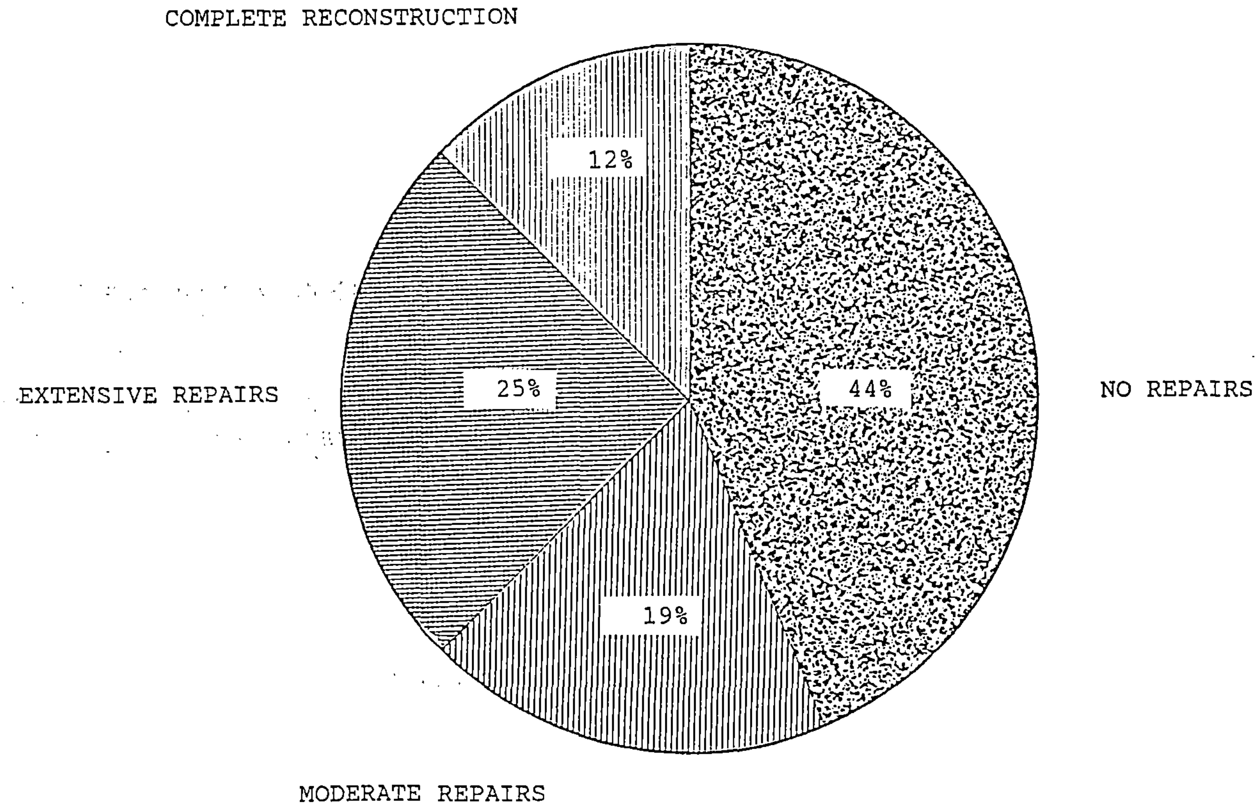

Figure 5 - Performance Summary for BV/SS Installations

Table 4: Summary of Repairs to BV/SS Installations

Building No.	Height (storeys)	Age When Repaired (years)	Extent of Repairs
1	17	15	Moderate
2	21	16	Moderate
3	10	2	Extensive
4	4	1	Moderate
5	5	9	Extensive
6	7	10	Complete
7	11	9	Extensive
8	17	8	Extensive
9	5	4	Complete

The wide variation in cladding performance is likely due to inconsistencies in the method of constructing BV/SS walls. The main reasons the BV/SS cladding system has a poor performance record appear to be:

- poor detailing of the steel stud wall and connections to the brick veneer
- poor detailing of brick veneer, especially at the shelf angle locations
- general lack of knowledge of the cladding system on the part of designers, contractors and inspectors
- lack of proper supervision
- poor workmanship

While the BV/SS system does require repairs more frequently than other common systems, one must remember that certain masonry distress problems are not related to the type of back-up wall. Deficiencies such as a lack of control joints can cause serious performance problems in any brick veneer facade, regardless of which type of back-up walls are used. Three of the buildings listed in Table 4 were closely examined on site and the repairs that are required in two of the buildings bear little relation to the steel stud back-up walls. The main cause of distress for the two buildings was poor detailing of the brick veneer and it is very likely that the same repairs would have been required if concrete masonry back-up walls had been used. Without additional information regarding the cause of distress to the BV/SS installations, the reason for the higher incidence of repairs cannot be fully explained.

5.4 Precast Concrete

Precast concrete claddings have been used for many years and today the system is one of the more popular claddings. One of the main advantages of the system is that the cladding consists of large wall panels, which can be constructed in a variety of shapes and sizes to suit the building application. Another key advantage of precast concrete panels is that they are factory built, generally under strict quality control. Also, the panels can often be installed more quickly than masonry cladding systems, enabling the building to be enclosed in less time. Finally, a variety of aesthetic effects can be created through the use of concrete panels. Overall, the use of wall panels has made the precast concrete system a popular alternative to masonry systems.

The survey indicates that precast concrete claddings have a low incidence of repair; only 2 of 14 buildings sampled required repairs. Pertaining to the two installations which were repaired, one required extensive repairs after 21 years and the other required moderate repairs after 5 years of age. This survey indicates that about 7% require moderate repairs while another 7% require extensive repairs and that the remaining 86% do not require repairs. However, recladding of precast concrete claddings is not uncommon and therefore it assumed that this is required for 5% of the precast concrete installations. Therefore, a total of 19% of the installations assumed to require repairs at some time during the 25 year life cycle.

5.5 Metal Siding and Panels

Metal cladding systems have been used for many years on low-rise commercial and industrial buildings. Over the last 10 years or so, metal claddings have become fairly popular for use on mid to high-rise residential buildings. Metal claddings are popular because they are generally one of the least expensive claddings to install and the products used over the last 10 years generally require minimal maintenance. Metal claddings are particularly popular for recladding applications, where the original cladding has suffered much deterioration. The metal cladding can be anchored to most wall systems and it generally provides a good weather screen. The main disadvantage of the system is its limited aesthetic appeal, especially on high-rise apartment buildings.

Metal claddings can be divided into two generic groups, panels and siding. Metal panels consist of sheet metal steel or aluminum which is pressed into a variety of shapes and sizes to suit the building application. Panels can have a variety of finishes, from enamel paint to porcelain. Metal siding, on the other hand, consists of either steel or aluminum sheet metal which is pressed into strips with varying profiles and are generally finished with baked-on enamel paint.

This survey indicates that the metal cladding system has a low incidence of repair since only 1 of 10 buildings sampled required repairs. However, these results cannot be assumed to be completely reliable since this data represents only a small sample and the repaired cladding likely represents an unusual case since extensive repairs were required after only two years of service. Since the results obtained for metal claddings do not likely represent average conditions, engineering judgements are made regarding what repairs are likely to be typical. It is very likely that the cladding which was repaired after only two years of service was improperly installed. Since improper installation of a metal cladding is likely to be rare, it is assumed that extensive repairs are generally not required after 2 years of service. Instead, it is assumed that, on average, moderate repairs are required to about 10% of all metal cladding installations after about 15 years of service.

5.6 Conventional Stucco

Very little data was obtained from the questionnaires regarding the general durability, i.e. the type and incidence of repairs, for conventional stucco systems. As a result, assumptions based on engineering judgement and past experience are used to estimate the incidence of repairs for stucco as well as the type of repairs and when they are likely required.

Based on past experience, stucco applied to concrete masonry support walls generally appears to have a higher incidence of repair than BV/CM, precast concrete or metal cladding systems. As such, it is assumed that repairs will be required to 25% of all stucco/concrete masonry installations within the first 25 years of service, as follows:

- 5% will require moderate repairs after 10 years
- 10% will require extensive repairs after 15 years
- 10% will require retrofits after 20 years.

When stucco is applied to steel stud support walls, the incidence and extent of repairs is expected to be higher. The steel stud walls will experience greater thermal movements than concrete masonry walls and more stresses will be induced to the stucco than in concrete masonry installations. Higher stresses will therefore cause more cracking and spalling of the stucco and hence the incidence and costs of repairs will be higher for stucco on steel stud walls. To be conservative, it is assumed that the incidence of repairs will be 50% higher than for stucco applied to concrete masonry. Therefore, repairs for stucco on steel/stud walls are assumed to be as follows:

- 7.5% will require moderate repairs after 10 years
- 15% will require extensive repairs after 15 years
- 15% will require retrofits after 20 years.

5.7 Polymer Modified Stucco

Polymer modified stucco products are relatively new to Canada although they have been used in some parts of the United States for about a decade. These systems utilize a polymer modified stucco which is applied over rigid insulation and reinforcing mesh. The insulation is attached to the support walls using either glue or mechanical fasteners. The support walls may be constructed using concrete masonry or steel studs.

The modified stucco systems which are available appear to vary significantly in their design, installation costs and quality. The first type utilizes mechanical fasteners which secure extruded polystyrene insulation to the support walls. A polymer modified base coat is then applied over fibreglass reinforcing mesh to provide the hardness and durability of the system. A thin, yet hard, polymer modified finish coat is then applied over the base coat to provide the colour and texture desired. There are two products of this type currently on the market. However, one of the products has been produced for over 10 years and a 10-year warranty may be obtained whereas the other product is relatively new and offers only a one-year warranty. Although the second product appears similar to the established product, little information is available from the manufacturer regarding its durability.

The second type of polymer modified stucco system utilizes expanded polystyrene (a lower quality insulation) and is glued to the support wall instead of being mechanically fastened. The coats of stucco are similar to the mechanically fastened systems. Since this system uses a lower quality insulation and is only glued to the substrate, it is less expensive to install. However, the system is known to experience problems in certain weather conditions which cause the glue to fail. The principal consultant knows of two installations in the Ottawa area where this cladding system has failed shortly after installation due to failure of the glue. These problems may not occur in other climates however this system does not appear to be as suitable to the Central Canada climate as the mechanically fastened system.

Only the well established, mechanically fastened type of polymer modified stucco system will be examined by this report for the following reasons:

- an abundance of information on the system is available
- the principal consultant has experience with the system
- little information is available for the newer product which is mechanically fastened to the substrate
- the glued - type system appears to be unreliable in certain weather conditions and therefore repair costs cannot be reasonably predicted.

The polymer modified stucco system being examined by this study will not likely require significant maintenance or repairs within the first 25 years of its life cycle for the following reasons:

- all materials are of very good quality
- the stucco appears very durable and capable of providing many years of service
- the manufacturer generally pays close attention to its applications to ensure it is properly designed
- only approved applicators are authorized to install the system.

However, problems can occur with any system due to a wide variety of factors. Therefore it is assumed that 10% of these installations will require moderate repairs after 15 years.

6. REPAIR COSTS

Originally, it was intended that all repair costs would be obtained using replies to questionnaire #2. However, insufficient data was obtained in this manner and therefore experience and engineering judgements were used to estimate repair costs. As discussed previously, maintenance costs could not be estimated and therefore were not included in the calculation of life cycle costs. Omitting maintenance work from the calculations will not greatly affect the overall results since many cladding installations receive no maintenance and these costs, when incurred, likely represent minor costs in comparison to average repair costs.

Using a combination of data from replies, cost estimates for hypothetical cases, and engineering judgement, the average repair costs were estimated for BV/CM, BV/SS, precast concrete, metal, conventional stucco, and polymer modified stucco systems. All repair costs were estimated on a unit cost basis and represent costs as of March 31, 1990.

It was assumed that the BV/CM and BV/SS systems experience similar moderate and extensive repairs. Cladding repairs of this extent for these systems usually involve only the masonry. Also, the distress is usually caused by severe exposure to detrimental weather conditions or poor detailing and/or construction practices. Therefore, these types of repairs are independent of the types of backup walls utilized and the BV/CM and BV/SS systems will incur similar costs for moderate and extensive repairs.

Since the brick masonry systems have similar moderate and extensive repair costs, replies to questionnaire #2 for moderate and extensive repairs to BV/CM and BV/SS installations were applied to both systems.

6.1 Brick Veneer/Concrete Masonry

As shown in Section 5, various types of repairs are required to BV/CM claddings with varying frequency. The average cost of each extent of repair was calculated by examining specific repair cases. To determine the average costs of moderate repairs, three replies involving moderate brick masonry repairs were examined. For extensive repairs, only hypothetical cases were analyzed to determine the average cost of repairs. For severe repairs and complete reconstruction/retrofit, the possible range of repair costs was examined.

6.1.1 Moderate Repairs

For moderate repairs, the following three cases were examined:

Case 1: Reply #5 to questionnaire #2; it was estimated that about $135,000 in repair costs will be incurred in 1990. The area of the brick veneer is about 4475 m^2, therefore the unit costs of those repairs will be approximately $30/$m^2$.

Case 2: Reply #6 to questionnaire #2; it was estimated that about $50,000 in repair costs will be incurred in 1990. The area of the brick masonry veneer is approximately 3230 m^2 and therefore the unit costs of these repairs will be approximately $15/$m^2$

Case 3: Reply #7 to questionnaire #2; it was found that about $25,000 was spent on repairs in 1982. In 1990 dollars, that is about $38,000 for approximately 1350 m^2 of brick veneer. Therefore, the unit cost of repairs is approximately $28/$m^2$.

On average, the unit cost of repairs for the above 3 cases is $24/$m^2$. Each case represents a typical situation for moderate repairs however Case 2 is likely on the lower end of the range for moderate repairs. Therefore, it was assumed that the average cost of moderate repairs to BV/CM claddings is $26/$m^2$.

6.1.2 Extensive Repairs

For the cost estimates presented below, the following hypothetical building was used:

- 16-storey residential building
- dimensions are about 23 m x 46 m
- shelf angles at every floor level
- brick veneer area = 2800 m^2
- total shelf angle length = 1320 m

For extensive repairs, the following three cases were examined:

Case 1: Using the hypothetical building above, assume 50% of the brick veneer is to be repointed and about 500 bricks need to be replaced in several different areas. The unit costs for repointing and brick replacement are approximately $97/m^2$ and $15/brick, respectively. Therefore, the total cost of repairs is $143,300, or approximately $51/m^2$ for the entire cladding area.

Case 2: Using the hypothetical building, assume 5% of the brick veneer (or 140 m^2) required brick replacement, mostly in isolated sections and about 20% of the brick masonry required repointing. Using a unit cost of about $12/brick and 65 bricks/$m^2$ for brick replacement and $104/$m^2$ for repointing, the total cost is $167,440, or approximately $50/$m^2$.

Case 3: Using the hypothetical building, assume that about 50% of the shelf angles require repairs which involve removing and reconstructing the brick veneer around the shelf angle. Also assume that about 100 bricks require replacement and minor repointing worth about $5,000 is required. With unit costs for the shelf angle repairs and brick replacement of $250/m, $15/brick respectively, the total cost is $178,100. Therefore, the unit cost of repairs is approximately $64/$m^2$.

The average of the above three cases is $58/$m^2$. Each case represents a typical situation for extensive repairs and therefore an average unit cost of $58/$m^2$ was assumed for extensive repairs.

6.1.3 Severe Repairs, Retrofits & Reconstruction

The cost of severe repairs, such as reconstruction of large wall sections, could cost between $80/$m^2$ and $160/$m^2$ for the entire cladding area. Such repairs are not common and are usually caused by deficient design and construction, and/or severe weathering conditions. Complete reconstruction of brick veneer due to severe distress would cost between $165/$m^2$ and $285/$m^2$. A complete retrofit of a new cladding would cost between $120/$m^2$ and $200/$m^2$. Installing some variety of new cladding over deteriorated brick veneer is a fairly common remedial solution for claddings in poor condition. The above values are summarized in Table 5 in a comparison of costs with BV/SS installations, which are discussed in the next section.

6.2 Brick Veneer/Steel Stud

Brick veneer/steel stud cladding systems generally have the same type of maintenance and moderate to extensive repairs as brick veneer/concrete masonry claddings. Problems such as poor detailing, poor construction or severe weathering can cause distress in both systems which is very similar in nature. Repointing, replacement of bricks, and shelf angle repairs, can occur in both claddings and the repair costs are generally equal for both systems. Therefore, it was assumed that the average costs for moderate and extensive repairs determined for BV/CM systems also apply for BV/SS systems. A complete retrofit of a new cladding system over a BV/SS installation would generally involve the same work as a retrofit over BV/CM. Therefore the costs for this type of repair would also be between $\$120/m^2$ and $\$200/m^2$.

The average costs for severe repairs to BV/SS installations were estimated at $\$80/m^2$ to $\$200/m^2$. There is a very large range of repair costs for severe repairs to BV/SS claddings since the types of repair could vary from major brick veneer repairs (similar to that for the BV/CM system) to reconstruction of entire wall sections, including the steel stud backup walls.

It is estimated that reconstruction of BV/SS installations would generally cost between $\$165/m^2$ and $\$400/m^2$ although the costs could exceed $\$400/m^2$, as indicated by reply #8 to questionnaire #2. The upper end of the range of installations costs is much higher for BV/SS installations than it is for BV/CM installations. The possibility of higher costs exists because the BV/CM system rarely requires remedial work to the backup walls whereas poor steel stud backup walls are often the reason why BV/SS installations require reconstruction. The average repair costs for the BV/SS system are summarized in Table 5 in a comparison of costs with the BV/SS system.

Table 5: Typical Repair Costs of BV/CM and BV/SS Installations

Extent of Repairs	Typical Repair Costs (1990 dollars)	
	BV/CM	BV/SS
Moderate	$\$26/m^2$	$\$26/m^2$
Extensive	$\$58/m^2$	$\$58/m^2$
Severe	$\$80/m^2$ - $\$160/m^2$	$\$80/m^2$ - $\$200/m^2$
Complete Retrofit	$\$120/m^2$ - $\$200/m^2$	$\$120/m^2$ - $\$200/m^2$
Complete Reconstruction	$\$165/m^2$ - $\$285/m^2$	$\$165/m^2$ - $\$400/m^2$

6.3 Precast Concrete

Replies to questionnaire #2 only provided data regarding costs associated with a retrofit of metal siding over deteriorated concrete panels. These replies covered installations which were reclad at unit costs (in 1990 dollars) of $166/m^2$ and $254/m^2$. The building which experienced repairs costing $254/m^2$ required major repairs to the precast concrete cladding system prior to the retrofit and therefore it likely represents an unusually costly example. However, the responses for precast concrete claddings are useful in demonstrating the possible range of retrofit costs. Normal retrofit applications likely cost between about $150/m^2$ and $225/m^2$. Complete replacement of an entire precast concrete cladding would likely cost about $400/m^2$, or 60% more than the original construction costs.

Replies to questionnaire #1 indicated that 7% of precast concrete cladding require moderate repairs while another 7% require extensive repairs. The unit costs for these types of repairs is required in order to calculate life cycle costs. Costs for moderate and extensive repairs to precast concrete cladding systems were estimated using a hypothetical repair case on a high-rise building for each type of repair. For the cost estimates presented below, the following hypothetical building was used:

- 16-story residential building
- dimensions are about 23 m x 46 m
- precast concrete panel area = 2800 m^2

For moderate repairs, it was assumed that 5% of the precast concrete cladding would require patching at a unit cost of $400/m^2$. The total costs of these repairs would be $56,000 and therefore these repairs would cost $20/m^2$ over the entire cladding area.

For extensive repairs, it was assumed that 15% of the precast concrete would require patching and about 100 m of crack repairs would also be required. Assuming unit repair costs of $350/m^2$ and $50/m for the patching and crack repairs, respectively, the total costs of these repairs would be $54/m^2$.

Since the above hypothetical case likely represents typical situations, the unit costs for moderate and extensive repairs to precast concrete installations are assumed to be $20/m^2$ and $54/m^2$, respectively, as calculated above.

The above costs apply to conventional precast concrete cladding systems only. There are a large variety of precast panels used on residential buildings and the newer ones are quite different from panels installed 10 or 20 years ago. Some older panels did experience performance problems whereas manufacturers of the newer panels claim that these new panels require no routine maintenance.

6.4 Metal Siding and Panels

Replies to the questionnaires did not provide information regarding typical repair costs for metal cladding systems and therefore unit costs for repairs are estimated. Only moderate and extensive repair costs need to be examined for the metal system since it appears that it is unusual for metal claddings to require more substantial repairs.

It is assumed that moderate repairs cost about 15% of the average installation costs of $\$165/m^2$ for metal claddings (both siding and panels). Therefore, moderate repairs cost about $\$25/m^2$. These cost estimates are coarse however the repair costs will likely be a small portion of the overall life-cycle costs of the cladding and therefore inaccuracies in the repair costs will not significantly affect the life-cycle costs of cladding systems.

6.5 Conventional Stucco

Similarly to metal claddings, repair costs for stucco must be estimated since replies to the questionnaires did not provide enough information regarding typical repair costs. It is assumed that moderate repairs for stucco on concrete masonry cost about 10% of the installation costs while extensive repairs cost about 20% of the installation costs. Since the installation costs for stucco on concrete masonry is $\$162/m^2$, moderate and extensive repairs cost $\$16/m^2$ and $\$33/m^2$ respectively. As discussed previously, the incidence and costs of repairs are expected to be higher when stucco is applied over steel stud walls. To be conservative, it is assumed that those repair costs are about 25% higher. Therefore, moderate and extensive repairs to conventional stucco applied to steel stud walls are assumed to cost $\$20/m^2$ and $\$40/m^2$ respectively. From response #12 to questionnaire #2, which involves a retrofit application in Ottawa, it is estimated that a typical retrofit of a new cladding over stucco costs about $\$140/m^2$.

6.6 Polymer Modified Stucco

This system is expected to experience only moderate repairs in about 10% of the installations. Since repair costs cannot be determined by examining actual cases, they are estimated by assuming that moderate repairs will cost about 10% of the original installation costs, or $\$21/m^2$. Repair costs are not expected to vary depending on the support walls used. When polymer modified stucco is applied over steel stud walls, exterior insulation is used and this results in less thermal movements in the stud walls than in the case where conventional stucco is applied to exterior wall sheathing over steel studs. Also, there is a lot of attention paid to control joints and other detailing with this system and therefore the possibility of repairs is further reduced.

6.7 Summary of Repairs to Cladding Systems

The incidence and type of repairs to the various claddings examined by this study are discussed in Section 5 while the costs associated with these repairs is discussed in subsections 6.1 to 6.6. Table 6 summarizes the findings regarding incidence and costs of repairs as well as the age of the system when these repairs are normally required. Where a range of costs is listed in earlier sections, an average value within the range is used in the summary. For example, the range of costs for retrofits or reconstruction work involving BV/CM systems is between $\$120/m^2$ and $\$285/m^2$. The most probable average costs for this type of work is about $\$175/m^2$ and therefore this value is used. Table 6 summarizes retrofits and replacement work for the BV/CM system by listing that 2.6% of all BV/CM installations require this type of work when they are 20 years of age, at an average unit cost of $\$175/m^2$.

7. LIFE-CYCLE COSTS

The life-cycle costs of an asset are the overall costs incurred in the use of the asset throughout the time period of the asset's life which is being examined. For a cladding system, the life-cycle costs depend on the initial construction costs, financing costs, maintenance and repair costs, heating costs for the building, inflation, interest rates and the residual value of the cladding system.

As discussed in previous sections, maintenance costs are not included since they are likely a very small percentage of the overall costs and heating costs are not a factor since all systems examined have similar thermal resistance characteristics. For this study, the present value approach is used to analyze the life cycle costs and therefore financing costs do not enter into the calculation of the life cycle costs. Financing charges do not have to be calculated since all costs are being analyzed as if one lump sum will be set aside at the beginning of the time period to account for all costs and therefore the initial costs are not being financed.

With the above elements removed, the main factors which affect the total life cycle costs of the claddings are the installation costs (principal), the repair costs (operating costs), and the residual value of the systems, as well as inflation and the interest rate.

Table 6 - Summary of Cladding Repairs

Repair Types	BV/CM	BV/SS	Precast Concrete	Metal	Conventional Stucco on Concrete Masonry	Conventional Stucco on Steel Studs	Polymer Modified Stucco
No Repairs	84.5%	41%	81%	90%	75%	62.5%	90%
Moderate	6.9% $\$26/m^2$ age - 15	24% $\$26/m^2$ age - 11	7% $\$20/m^2$ age - 5	10% $\$25/m^2$ age - 15	5% $\$16/m^2$ age - 10	7.5% $\$20/m^2$ age - 10	10% $\$21/m^2$ age - 15
Extensive	4.9% $\$58/m^2$ age - 17	31% $\$58/m^2$ age - 13	7% $\$54/m/^2$ age - 21	----	10% $\$32/m^2$ age - 15	15% $\$40/m^2$ age - 15	----
Severe	1.0% $\$120/m^2$ age - 21	----	----	----	----	----	----
Retrofit or Reconstruction	2.6% $\$175/m^2$ age - 20	4% $\$200/m^2$ age - 20	5% $\$190/m^2$ age - 20	----	10% $\$140/m^2$ age - 20	15% $\$140/m^2$ age - 20	----

7.1 Inflation and Interest Rates

Inflation is an important factor in determining life-cycle costs since all costs incurred except for the principal, are affected by inflation. If an asset is known to incur certain costs (in present day dollars), say in five years, then the actual costs at year 5 must be estimated by adjusting the present day dollars by the expected amount of inflation over the next five years.

Over the last six years, which were years of generally moderate inflation, the average inflation rate varied from 4% to 5%. Most years inflation is generally moderate however there are years when the inflation rate is high, such as when it was over 10% in the early 1980's. To account for those periods where the inflation rate is high, an average rate of 6% was assumed to adjust the repair costs, which are estimated in 1990 dollars, to future repair costs. The assumed inflation rate represents the likely average inflation rate over the next 25 years.

Interest rates have also varied significantly in past years, with the prime lending rate ranging from about 6%, nearly 20 years ago, to about 20% in 1981. In recent years, the prime lending rate has generally been between 5% and 8% higher than the inflation rate. As an average, a 6% differential between the inflation and interest rates was assumed and therefore the interest rate used for the calculation of life-cycle costs is 12%.

For the present value method of analyses, the interest rate is used to determine the present value of future costs. The process of equating future costs to present value is called discounting and is actually the reciprocal of compounding. For example, if $1,000 was invested in such a way that 10% interest is paid each year for three years, the future value of the original $1,000 due to the compounded interest, would be $1,310. The reverse is also true and therefore $1,310 in three years from now, discounted to the present is $1,000 at an interest rate of 10%.

The 6% inflation rate is used to adjust unit costs in 1990 dollars to expected unit costs in future years. The 12% interest rate is used to determine the present value of these future costs. For example, repairs to a cladding system which cost $50,000 in 1990 dollars will cost about $120,000 in 15 years (in 2005 dollars). Using an interest rate of 12% and discounting to 1990, the present value of the $120,000 expenditure is about $22,000, in 1990 dollars. The latter calculation involves the use of a present worth factor which will be explained in Section 7.4 "Calculation of Life-Cycle Costs".

A sensitivity check was carried out to determine if the results would vary significantly if different values were used for the inflation and interest rates. It was found that the present value of repair costs and residual values varied somewhat when rates were increased or decreased within ranges that could reasonably occur over a 25 year period. However, the increase or decrease was proportional for all systems and the differences between systems did not vary significantly. The present value of the total life-cycle costs only varied in the actual cost values and the relative cost-effectiveness of the cladding systems did not vary significantly.

7.2 Initial and Residual Value

The principal is the original sum of money invested or the original cost of the asset (initial value), not including financing charges or other charges indirectly related to the asset. The principal costs are incurred at the beginning of the life cycle, and they are in present value terms. Therefore, when using the present value method, the principal costs do not need to be calculated using economic procedures involving a present worth factor. For the cladding systems examined in this study, the principal is the initial installation costs discussed in Section 4.

The residual value of any asset depends on the asset's life expectancy, depreciation and amount of service the asset has provided. The life expectancy of the asset is mainly related to the obsolescence of the asset. Obsolescence can be defined as physical, economic, functional, technological, social or legal, as follows:

Physical - the asset can no longer physically function, i.e. the asset is seized-up or is about to collapse

Economic - it is no longer cost-effective to continue using the asset

Functional - the asset can physically be used however it can no longer serve the purpose for which it was designed

Technological - the asset is technologically inferior to most alternatives

Social - society will no longer accept the use of the asset

Legal - legal requirements dictate replacement of the asset for reasons other than those listed above

When calculating the present value of an asset's residual value, the future value must be discounted to the present using a present worth factor which accounts for the interest rate and the number of years between the present and the time when the residual value of the asset is recovered.

For the study, all claddings were assumed to have a service life of 50 years since that is the normal design life for residential buildings and 50 years is the industry accepted standard for the life expectancy of the wall systems being examined. Not all installations will provide 50 years of trouble-free service however repair costs, including cladding replacement, are covered by the calculations regarding the operating costs of the claddings. Since each cladding is assumed to have a service life of 50 years, the claddings would be considered to obsolete at the 50-year point and therefore have no residual value at that point.

Since this study examines a 25-year life cycle, the residual value of each cladding is analyzed at the 25-year point of the cladding's service life. Since straight-line depreciation is used and the residual value for each cladding is being analyzed when the claddings have provided service for exactly 50% of their intended life, the residual value for each cladding in 25 years will be 50% of the initial installation costs (in 1990 dollars). Once the residual value in 25 years is known in 1990 dollars, inflation is used to estimate the residual value when this value is to be recovered in 2015. The future residual value is then discounted to the present to obtain the present value of the cladding's residual value.

For example, the initial installation costs for the BV/CM system are $\$206/m^2$ and therefore the residual value at year 25 is $\$103/m^2$, in 1990 dollars. Assuming 6% inflation per year, the residual value for the system in 25 years is $\$442/m^2$, in 2015 dollars. Assuming an interest rate of 12% and discounting to the present, the present worth of the residual value of the system is $\$26/m^2$, in 1990 dollars.

7.3 Maintenance, Repair and Energy Costs

The operating costs of an asset are the costs incurred during the use of the asset, i.e. all costs that occur between the time the asset is purchased and the time the asset is disposed of. For a cladding system, these costs involve maintenance and repairs to the cladding as well as heating costs for the building. When analyzing life cycle costs using the present value method, all future operating costs are discounted to the present in the same manner that the future residual value is discounted to the present. As discussed in previous sections, maintenance costs are a minor portion of the operating costs and there are not significant differences between the heating costs associated with the different systems. Therefore, repair costs are the only operating costs which were analyzed. Average repair costs for the systems are based on the findings summarized in Sub-section 6.7.

It is assumed that the systems which were not repaired to date will not require repairs during the 25-year period being examined. This assumption may result in repair costs which are underestimated however the future performance of walls which were not repaired cannot be predicted for the masonry and concrete systems. It is unlikely that the relative cost-effectiveness of the cladding systems will be affected significantly by this assumption since it only applies to the precast concrete and brick veneer systems. The repairs to the metal and stucco systems are mainly based on engineering judgements which involve assumptions regarding repairs over the entire 25-year life cycle examined.

7.4 Life-Cycle Costs Calculations

The initial installation costs, residual value, inflation and interest rates discussed in previous sections are used in the calculation of life-cycle costs. Economic analyses, involving transforming all costs at the time when they were incurred to a present value, were carried out to compare the life-cycle costs of the various claddings.

The following symbols were used to represent various terms in the calculation of life-cycle costs:

PV: Total present value of all life cycle costs

P: Initial installation costs of the cladding

R: Residual value of the cladding

F: Future repair costs experienced by an installation (for a particular type of repair)

PVR: Present value of the residual value

PVF_{rep}: Present value of future repairs to an installation (for a particular type of repair)

PVF_{ave}: Present value of average repair costs experienced by a cladding system (for a particular type of repair)

PVF: Total present value of all repairs experienced by a cladding system

i: Inflation rate

r: Interest rate

n: Number of years

$PWF_{r,n}$: Present Worth Factor for a future cost to be incurred (or salvaged) n years from the present, considering an interest rate, r.

PC: Per Cent of installations affected by a particular type of repair.

The present value of the residual value of a cladding is calculated as follows:

$$PVR = R \times [1/(1 + r)^n] = R \times (PWF_{r,n})$$

Similarly, the present value of future repair costs experienced by an installation is calculated as follows:

$$PVF_{rep} = F \times (PWF_{r,n})$$

Since only a percentage, PC, of installations are affected by particular repair costs, the average costs of these repairs to the cladding systems are required. This quantity is calculated as follows:

$$PVF_{ave} = (PC) \times (PVF_{rep})$$

The above calculation is carried out for each type of repair (moderate, extensive, severe and retrofit/reconstruction) and the total present value of all repairs is the summation of the present value for each category of repairs, i.e.

$$PVF = PVF_{ave}$$

The total present value of life cycle costs equals the principal costs plus the total repair costs minus the residual value of the cladding, i.e.

$$PV = P + PVF - PVR$$

Table 7 summarizes the results of the life cycle costs analyses using an inflation rate of 6% and an interest rate on installation of 12%. (More detailed tables appear in Appendix C.)

Table 7 - Comparison of the Present Value of the Life-Cycle Costs for Various Cladding Systems over a 25-Year Life-Cycle ($/m^2)

Type of Cost Incurred (or Recovered)	BV/CM	BV/SS	Precast Concrete	Metal Siding	Metal Panels	Conventional Stucco on: Concrete Masonry	Conventional Stucco on: Steel Studs	Polymer Modified Stucco on: Concrete Masonry	Polymer Modified Stucco on: Steel Studs
Installation Costs	206	166	251	158	175	162	125	206	175
Repair Costs	3.80	14.90	5.40	1.10	1.10	6.50	11.20	0.90	0.90
Residual Value	(26.00)	(20.95)	(31.81)	(19.94)	(22.09)	(20.47)	(15.76)	(26.00)	(22.09)
Total Life-Cycle Costs (Rounded)	184	160	225	139	154	148	120	181	154

8. SUMMARY AND CONCLUSIONS

8.1 Findings

The key findings of this study are as follows:

- The least expensive cladding system to install is conventional stucco applied to steel stud backup walls.

- Conventional stucco applied to steel studs is also the most cost-effective over the 25-year life cycle examined.

- Precast concrete panel claddings are the most expensive to install and the least cost-effective over the life cycle examined.

- Polymer modified stucco and metal claddings have the lowest average repair costs of the nine claddings examined.

- Brick veneer/steel stud claddings have the highest average repair costs, followed by conventional stucco applied to steel stud backup walls.

- The claddings which are least expensive to install are generally (but not always) the most cost-effective over the life cycle examined.

The rankings of the wall systems included in this study in regards to their installation, repair and life-cycle costs are listed in Table 8. Note that the least expensive cladding system in each category of costs is given a ranking of "1" while higher numbers refer to more expensive systems.

Other important findings of this survey are:

- The three most popular cladding systems are, in decreasing order, brick veneer/concrete masonry, brick veneer/steel stud, and precast concrete. Of these, the brick veneer/steel stud system is the least expensive to install.

- The brick veneer/steel stud system appears to have a higher incidence of repair, and therefore higher average repair costs, than the brick veneer/concrete masonry cladding system.

- While brick veneer/steel stud claddings have become very popular in recent years, it appears that there are currently still more apartment buildings on the market which utilize the brick veneer/concrete masonry system.

Table 8 - Ranking of Cladding Systems in Regards to Costs

Cladding System	Installation Costs	Repair Costs	Life-Cycle Costs
Conventional Stucco Applied to Steel Stud Walls	1	8	1
Metal Siding	2	3	2
Conventional Stucco Applied to Concrete Masonry Walls	3	7	3
Metal Panels	5	3	4
Polymer Modified Stucco Applied to Steel Stud Walls	5	1	4
Brick Veneer/Steel Stud	4	9	6
Polymer Modified Stucco Applied to Concrete Masonry Walls	7	1	7
Brick Veneer/Concrete Masonry	7	5	8
Precast Concrete	9	6	9

Note: The least expensive cladding in each category of costs is given a ranking of "1" while successively more expensive systems are given successively higher ranking numbers.

- Although conventional stucco systems and metal siding are the least expensive to install, they are not as commonly used for mid to high-rise residential buildings, likely due to their limited aesthetic appeal in such applications.
  - Stucco is mainly used for small applications, such as around windows and doors at balconies.
  - Metal siding is becoming popular as a weatherscreen in retrofit applications due to its low installation and maintenance costs.
- Through-the-wall masonry, glass curtain walls, and stone panels are not commonly used in residential applications.

8.2 Discussion of Findings

Based on the available information from this study, it appears that in general the most cost-effective claddings are those which are the least expensive to install. This is so because repair costs account for a relatively small percentage of life cycle costs. According to the information presented in Table 7, repair costs for the 25-year life cycle represent only 1% to 7% of the life cycle costs.

The results of this study indicate that the BV/SS walls have a much higher incidence of repair than the BV/CM walls. Since the key difference between these two wall systems is the backup wall, this finding initially appears to imply that much of the reported distress is attributable to the steel stud backup wall. Furthermore, a comparison of the two brick masonry wall systems indicates that the BV/SS walls require repairs at a much earlier age than BV/CM walls. Except for the cases of complete reconstruction, little information was received which would explain the reasons for the dramatic differences in the time and incidence of repairs. However, based on the authors' extensive experience in the performance investigation of BV/SS wall systems across Canada, the cause of distress in the majority of the cases was not related to the presence of the steel stud backup walls, but rather to poor detailing and poor construction of the brick veneer.

Only in the cases of complete reconstruction of the BV/SS wall systems was the major cause of distress attributable to the steel stud backup walls. On the other hand, observations have shown that the steel stud wall system is vulnerable to deterioration due to corrosion in the presence of moisture. Design and construction provisions must ensure that moisture due to exfiltration or infiltration does not expose metal components to repeated wetting conditions. It is estimated that detailed inspection work and quality control for the BV/SS wall system would provide reasonable assurance of adequate construction conditions at a cost of about 3% of the installation costs. It should be kept in mind that already more stringent supervision by professional engineers is required for precast concrete claddings. Similar inspection and quality control requirements for the BV/SS wall system would substantially improve the longterm performance of the steel stud backup system, and hence improve the life cycle costs of the BV/SS system.

8.3 Concluding Remarks

The results of this survey are limited to the amount of data received through replies to questionnaires #1 and #2. Much of the repair costs were based on estimates and hypothetical situations and these conditions have likely introduced some errors into the calculations of average repair costs. Since average repair costs account for only a small portion of the life-cycle costs, it is believed that these errors are not significant and therefore only minor inaccuracies in the life-cycle costs exist. The most important aspect of this study is the relative cost-effectiveness of the cladding systems and not the actual values for life-cycle costs.

The difficulty in obtaining adequate information for this study has demonstrated that projects requiring detailed information for research analysis purposes of this type cannot be carried out effectively based on a mail-out survey. It is recommended that similar studies in the future include sufficient funds for visiting actual buildings and to carry out a detailed search of the pertinent files. Such a file search would include the review of drawings, consultants reports and repair information.

Pertaining to the BV/SS system, further work is required to confirm whether or not the BV/SS wall system actually has as high an incidence of repair as indicated by this survey and whether these repairs are related to the presence of steel stud backup walls. A separate detailed study should be undertaken on the BV/SS wall systems to obtain more accurate information on incidence, type and costs of repairs. The study should also determine the most common causes of distress.

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APPENDIX A: Sample Questionnaires

GENERAL SURVEY
OF CLADDING REPAIRS
IN CANADA

This questionnaire forms part of a CMHC study to define the most cost effective cladding system for medium and high-rise apartment buildings.

For your guidance, a sample response from a hypothetical organization has been provided at the end of the questionnaire. Please review the sample response and complete the questionnaire as accurately as possible.

You need not identify yourself, your organization nor the buildings in question. However, if you wish to receive a copy of the survey results, please indicate your name, phone number and business address below, or attach your card.

Please return this questionnaire within 2 weeks to:

Mr. Jim White
Canada Mortgage and Housing Corporation
Cladding Repair Survey
Research Division
National Office
682 Montreal Road
Ottawa, Ontario
K1A 0P7

GENERAL SURVEY OF
CLADDING REPAIRS
IN CANADA

Special Note:

If the original cladding of a building has been completely replaced or covered up by a new cladding, please respond to the questions with respect to the original cladding. For example, assume brick veneer with concrete block back-up was covered by a retrofit of metal siding. In question 2, the building would be counted as brick veneer/concrete block. In the last column of Table 2, the new cladding (i.e. metal siding) would be indicated as the replacement cladding.

QUESTIONNAIRE:

1. In which of the following cities are the majority of the medium and high-rise apartment buildings (i.e. 5 storeys or more) that your organization owns or manages?

   check one: ☐ Halifax ☐ Montreal ☐ Toronto ☐ Calgary ☐ Ottawa

2. For each cladding system, indicate the total number of installations and the number of installations which have required repairs:

		Number of Installations	Number Repaired
2.1	Brick veneer with concrete block back-up ...	________	________
2.2	Brick veneer with steel stud backup	________	________
2.3	Pre-cast concrete panels	________	________
2.4	Stone panels	________	________
2.5	Insulated metal panels	________	________
2.6	Metal siding	________	________
2.7	Through-the-wall brick or concrete masonry..	________	________
2.8	Standard stucco or architectural plasterwork	________	________

Note: Where several cladding systems are used on one building, each system should be counted as one installation in the above count.

The remainder of the questionnaire applies to past cladding repairs, excluding normal maintenance items.

3. For each building, please provide specific repair information by completing Table 2. Use the applicable cladding "Type Code" shown below:

Type Code	Cladding type
BV/CB	brick veneer with concrete block back-up
BV/SS	brick veneer with steel stud back-up
CP	pre-cast concrete panels
SP	stone panels
MP	insulated metal panels
TTW or CM	through-the-wall or split-rib concrete masonry
S	stucco or architectural plasterwork
O	other - please specify

Note 1: Identify the extent of repairs by entering "M", "E", "S", or "C" for moderate, extensive, severe or complete replacement, respectively.

Note 2: If complete replacement or retrofit was required, indicate the type of replacement cladding.

Questionnaire #1

Table 2 Details of Cladding Repairs

*Building	Cladding Repaired	Building Height (storeys)	Present Building Age (years)	Age When Repaired (years)	Extent of Repairs	Replacement Cladding

* You are not required to identify the building. This space is provided only to help the respondent to remember which buildings have been covered by the survey.

SAMPLE

XYZ Developments in Toronto owns 7 buildings as described below:

Building #1: 14-year old, 12-storey building with a brick veneer/steel stud exterior wall system. No repairs were undertaken except for minor tuck-pointing every 5 years.

Building #2: 22-year old, 20-storey building. Cladding consists of 45% split-rib masonry, 35% pre-cast concrete panels and 20% granite panels. The granite panels were installed 6 years ago over deteriorated stucco. Minor repointing of split-rib masonry and a replacement of a few concrete panels were carried out 2 years ago.

Building #3: 2-year old, 6-storey building. Cladding consists of 80% brick veneer/concrete block and 20% is high-strength, insulation backed stucco. No cladding repairs have been undertaken

Building #4: 10-year old, 35-storey building consisting entirely of brick veneer/steel stud exterior wall system. Next year, major repairs will be undertaken that include extensive repointing, rebuilding sections of veneer with existing brick and replacing spalled bricks with new brick.

Building #5: 6-year old, 27-storey building. Cladding consists of 60% insulated metal panels and 40% marble panels. Minor adjustments were made to some panels one year after construction.

Building #6: 30-year old, 5-storey building consisting entirely of brick veneer with concrete block back-up walls. Minor repointing has been carried out every 6 years. No other repairs have been undertaken.

Building #7: 25-year old, 16-storey building. Original cladding was stucco on concrete block. Insulated metal panels were installed over the stucco 7 years ago.

—//—

Sample Tabular Response:

Table 2 Details of Cladding Repairs

*Building	Cladding Repaired	Building Height (storeys)	Present Building Age (years)	Age When Repaired (years)	Extent of Repairs	Replacement Cladding
BUILDING #2	S	20	22	16	C	SP
BUILDING #2	CP	20	22	20	M	—
BUILDING #7	S	16	25	18	C	MP

* You are not required to identify the building. This space is provided only to help the respondent to remember which buildings have been covered by the survey.

Questionnaire #2

GENERAL SURVEY
OF CLADDING REPAIRS
IN CANADA

This questionnaire forms part of a CMHC study to define the most effective cladding system for medium and high-rise apartment buildings.

Over the years, many different claddings/wall systems have been used on residential buildings and various opinions exist regarding which system is most economical. This debate has been unresolved due to a lack of information regarding the overall life cycle costs of cladding systems. This questionnaire is intended to resolve the debate and your participation is hereby solicited. Please take the time to complete the questionnaire (particularly part 3) and return it to the address below at your earliest convenience.

If any part of the questionnaire needs to be clarified, please feel free to direct questions to Mr. Steve Laviolette at (613) 224-1594.

Please return this questionnaire to :

Mr. Steve Laviolette
Suter Keller Inc.
1390 Prince of Wales Drive, Suite 107
Ottawa, Ontario
K2C 3N6

RT 1 - GENERAL INFORMATION

.1 In which of the following cities is the building located?

☐ Halifax ☐ Montreal ☐ Toronto ☐ Calgary

.2 What percentage of the cladding is:

	%
brick veneer with concrete masonry back-up?...........	______
brick veneer with steel stud back-up?.................	______
pre-cast concrete panels?.............................	______
stone panels?...	______
insulated metal panels?...............................	______
metal siding?...	______
through-the-wall brick (TTW) or concrete masonry?......	______
standard stucco or architectural plasterwork?.........	______

.3 How tall is the building?...................... ______ storeys

.4 What is the area of a typical floor?

☐ under 4,000 $ft.^2$ ☐ 7,000-10,000 $ft.^2$
☐ 4,000-7,000 $ft.^2$ ☐ over 10,000 $ft.^2$

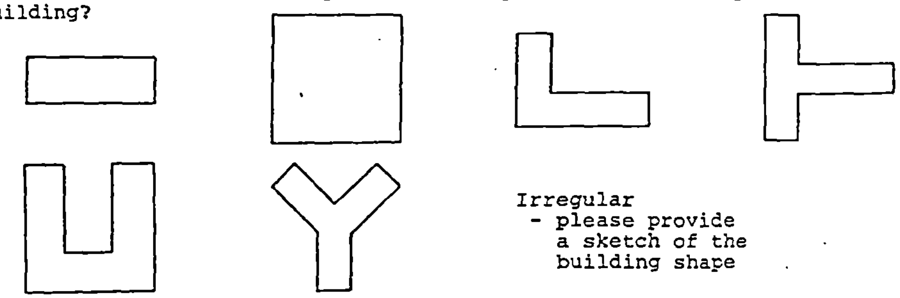
.5 What is the total area, including windows and doors, of the exterior walls?

☐ under 15,000 $ft.^2$ ☐ 45,000-59,999 $ft.^2$
☐ 15,000-29,999 $ft.^2$ ☐ 60,000-74,999 $ft.^2$
☐ 30,000-44,999 $ft.^2$ ☐ over 75,000 $ft.^2$

.6 What percentage of the exterior walls is composed of windows and doors?

☐ Under 10% ☐ 10-19% ☐ 20-29% ☐ 30-39% ☐ 40-50% ☐ over 50%

.7 Which of the following figures best represents the shape of the building?



Irregular
- please provide a sketch of the building shape

.8 Indicate, on the figure checked off in question 6, which direction is north by drawing an arrow pointing north.

.9 What term below best describes the building's exposure to wind?

☐ well protected ☐ partially exposed ☐ fully exposed

.10 How old is the building?

☐ less than 10 years ☐ 25-34
☐ 10-14 ☐ 35-50
☐ 15-19 ☐ over 50 years
☐ 20-24

.11 Which of the following major structural elements does the building consist of?

☐ reinforced concrete floor slabs
☐ concrete slabs on steel joists
☐ precast concrete floor slabs
☐ reinforced concrete columns
☐ structural steel columns
☐ reinforced concrete beams
☐ structural steel beams
☐ reinforced concrete shear walls
☐ masonry shear walls
☐ load-bearing masonry walls

.12 Does the building typically have cantilevering floor slabs?

☐ yes ☐ no

ART 2 - ORIGINAL BUILDING DETAILS

.1 <u>Brick Veneer with Concrete Masonry Back-up Walls</u>:

.1 Which type of ties (shown on the next page) are used to connect the brick veneer to the concrete masonry back-up?

☐ corrugated strip ties
☐ Z-ties
☐ rigid adjustable ties
☐ other
☐ rectangular (or rigid) ties
☐ horizontal reinforcement
☐ non-rigid adjustable ties

.2 Are the back-up walls load bearing or non-load bearing?

☐ load bearing ☐ non-load bearing

.3 Are control joints used between the building frame and non-load bearing back-up walls?

☐ not applicable (i.e. walls are load bearing)
☐ yes ☐ no

.4 How are the walls insulated?

☐ walls are not insulated
☐ insulated on interior of masonry back-up
☐ insulated on exterior of masonry back-up
☐ insulated on both sides of masonry back-up

.5 Where is the vapour barrier located?

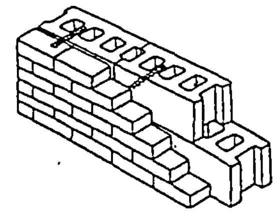
☐ no vapour barrier used
☐ on interior of masonry back-up
☐ on exterior of masonry back-up

.6 Which spacing of vertical control joints is used in the veneer?

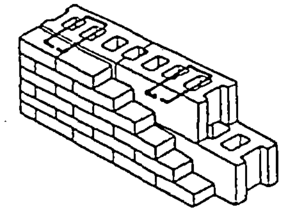
☐ vertical control joints not used
☐ every 4.5-6m (15-20 ft)
☐ every 6-8m (20-26 ft)
☐ every 8-10m (26-33 ft)
☐ every 10-12m (33-39 ft)
☐ other

.7 Are vertical control joints used within 3m (10 ft) of wall corners?

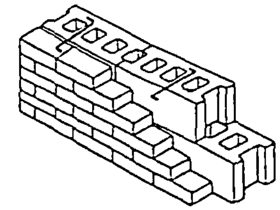
☐ yes ☐ no



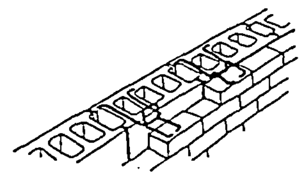
corrugated strip tie



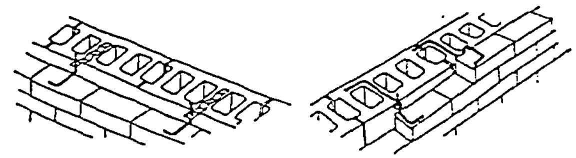
rectangular tie



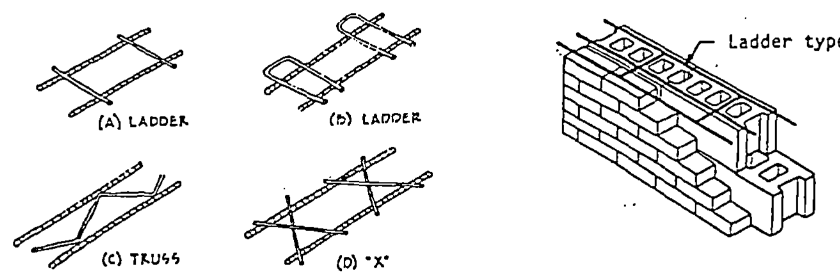
Z-tie



rigid adjustable tie



non-rigid adjustable ties



horizontal reinforcement

TYPES OF TIES

.8 How is the brick veneer supported?

- ☐ veneer supported at foundation wall level only
- ☐ supported by shelf angles on every fourth floor
- ☐ supported by shelf angles on every third floor
- ☐ supported by shelf angles on every second floor
- ☐ supported by shelf angles on every floor
- ☐ supported by floor slabs directly
- ☐ Other. Please specify

.9 Are horizontal control joints used at each shelf angle?

☐ not applicable ☐ yes ☐ no

.2 <u>Brick Veneer with Steel Stud Back-up Walls</u>:

.1 Which stud size is used?

- ☐ 92 mm (3 5/8 in.); 0.91 mm (20 ga.) thick
- ☐ 92 mm; 1.2 mm (18 ga.) thick
- ☐ 92 mm; 1.5 mm (16 ga) thick
- ☐ 152 mm (6 in.); 0.74 mm (22 ga.) thick
- ☐ 152 mm; 0.91 mm (20 ga) thick
- ☐ 152 mm; 1.2 mm (18 ga.) thick
- ☐ 152 mm; 1.5 mm (16 ga.) thick
- ☐ Other

.2 Which stud spacing is used?

☐ 300 mm (12 in.) o.c. ☐ 400 mm (16 in.) o.c.
☐ 600 mm (24 in.) o.c. ☐ Other

3. How are the studs connected to the ceiling track?

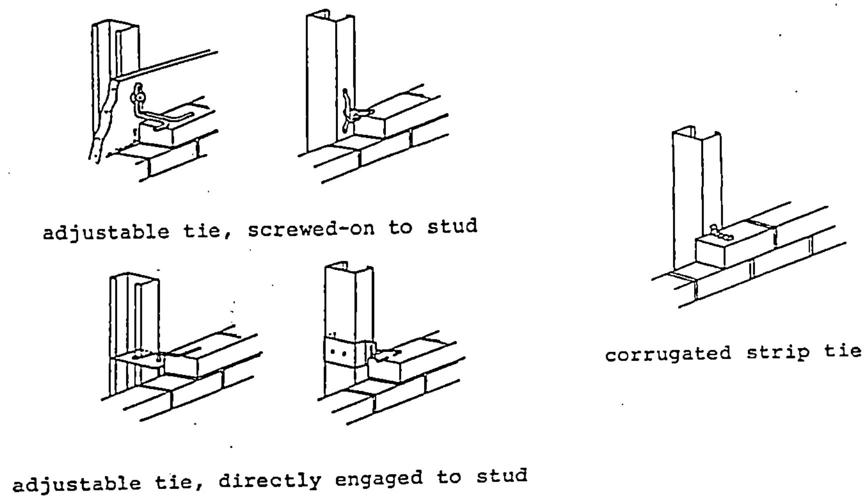
- ☐ fixed stud-track connections
- ☐ connections which permit slab movement

.4 Which type of ties (shown on the following page) connect the brick veneer to the back-up walls?

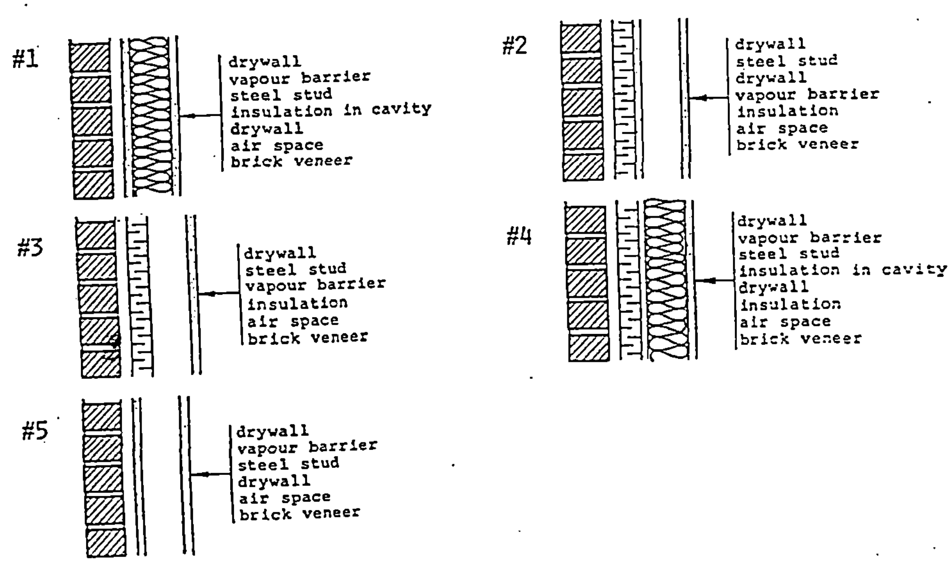
- ☐ corrugated strip ties
- ☐ adjustable tie, screwed to stud
- ☐ adjustable tie, directly engaged to stud
- ☐ other

.5 Which building envelope components (shown on the following page) are used?

☐ #1 ☐ #2 ☐ #3 ☐ #4 ☐ #5 ☐ other



TYPES OF TIES



BUILDING ENVELOPE COMPONENTS

6 Which spacing of vertical control joints is used?

☐ vertical control joints not used ☐ every 8-10m (25-33 ft)
☐ every 4.5-6m (15-20 ft) ☐ every 10-12m (33-39 ft)
☐ every 6-8m (20-26 ft) ☐ other

.7 Are vertical control joints used within 3m (10 ft) of wall corners?

☐ yes ☐ no

.8 How is the brick veneer supported?

☐ veneer supported at foundation wall level only
☐ supported by shelf angles on every fourth floor
☐ supported by shelf angles on every third floor
☐ supported by shelf angles on every second floor
☐ supported by shelf angles on every floor
☐ supported by floor slabs directly
☐ Other. Please specify

9 Are horizontal control joints used at each shelf angle?

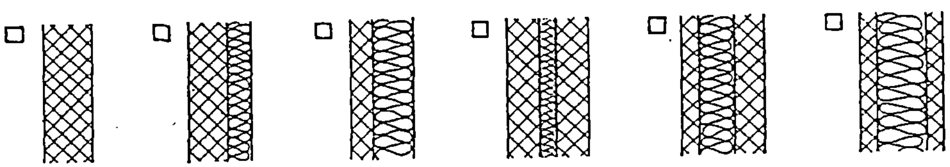
☐ not applicable ☐ yes ☐ no

3 Pre-cast Concrete Panels:

1 Which function do the panels perform?

☐ load-bearing
☐ stiffening (i.e. shear wall)
☐ space enclosing only (i.e. curtain wall)

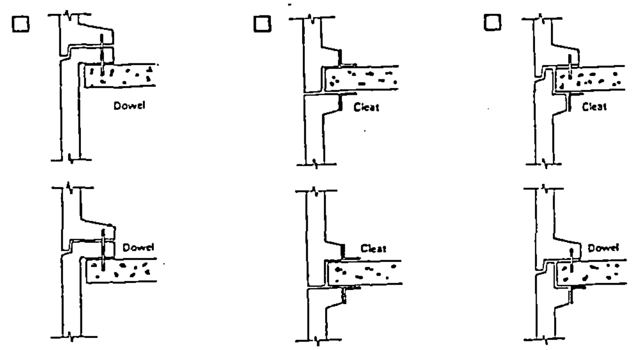
2 Which type of panels are used?



Note:  - represents pre-cast concrete

 - represents insulation

.3 How are panels attached to the building?



.4 Are control joints used:

4.1 vertically between each panel? ☐ yes ☐ no
4.2 at each floor level? ☐ yes ☐ no

.5 What type of back-up walls are used?

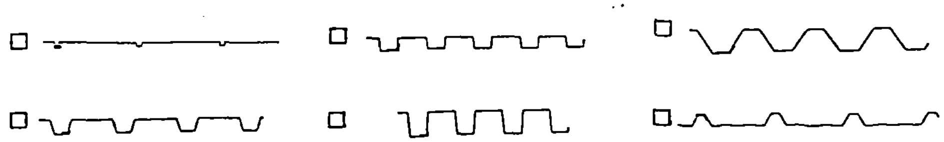
☐ back-up walls not used ☐ load bearing masonry
☐ non-load bearing masonry ☐ steel studs ☐ other

2.4 Metal Cladding:

.1 What type of metal cladding is used?

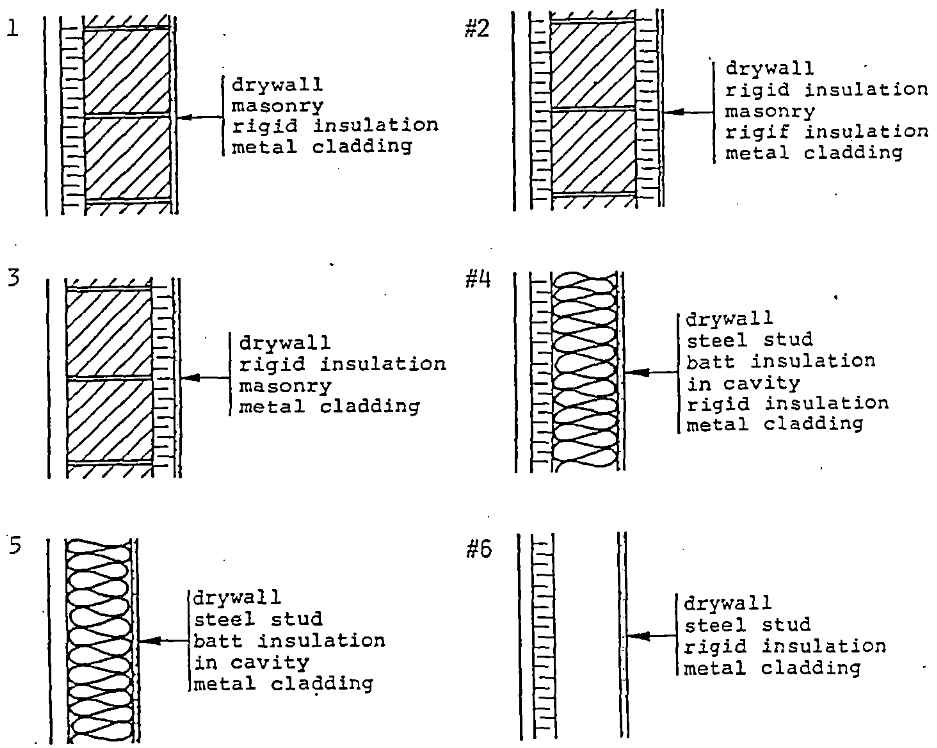
☐ steel panels ☐ steel siding ☐ aluminum siding ☐ other

.2 What type of profile does the cladding have?



.3 Which building envelope components (shown on the following page) are used?

☐ #1 ☐ #2 ☐ #3 ☐ #4 ☐ #5 ☐ #6 ☐ other



BUILDING ENVELOPE COMPONENTS

.4 Where is the vapour barrier located?

☐ no vapour barrier used
☐ on interior of back-up walls
☐ on exterior of back-up walls

.5 How is the cladding connected to the building?

☐ connected directly to back-up walls
☐ cladding connected to Z-channels (or similar standard anchorage) which are connected to back-up walls
☐ cladding connected to Z-channels (or similar standard anchorage) which are connected to building frame
☐ Other. Please specify

2.5 <u>Through-the-Wall Brick and Concrete Masonry</u>:

.1 Is the masonry load bearing or non-load bearing?

☐ load bearing ☐ non-load bearing

.2 How thick are the majority of the masonry units?

☒ 150 mm (6 in.) ☐ 250 mm (10 in.)
☐ 200 mm (8 in.) ☐ 300 mm (12 in.)

.3 Is there any allowance for movement between structural elements and masonry infill walls?

☐ not applicable (i.e. walls are load bearing)
☐ yes ☐ no

.4 Are the slabs typically exposed or concealed by the masonry?

☐ exposed ☐ concealed by masonry

.5 Does the wall system contain a vapour barrier?

☐ yes ☐ no

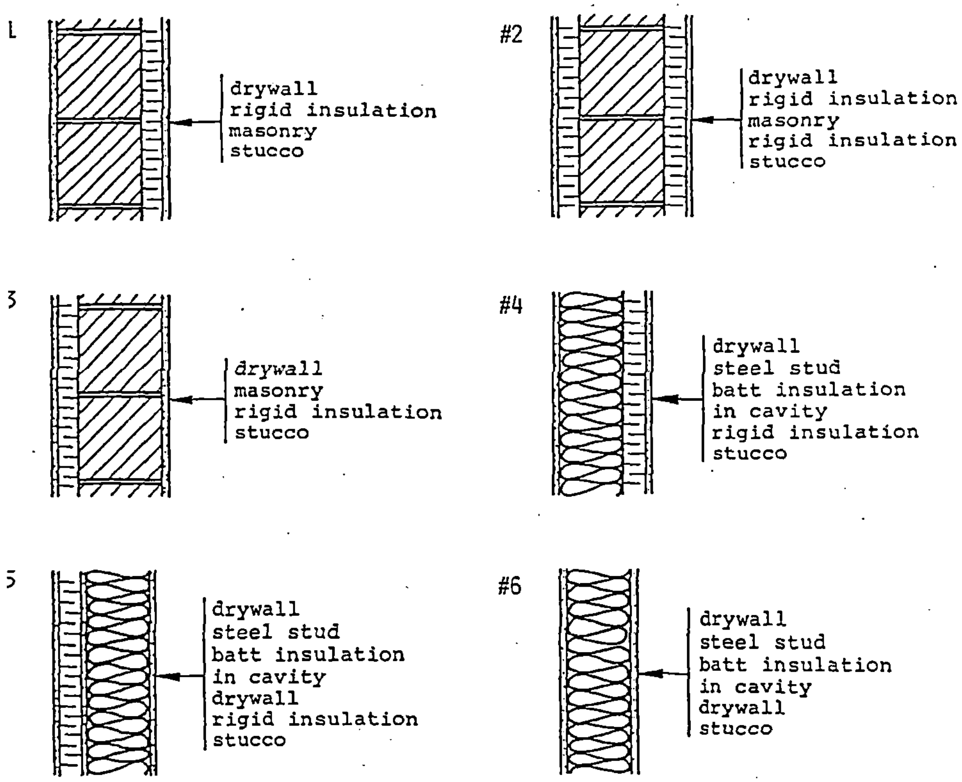
2.7 <u>Stucco or Architectural Plasterwork</u>:

.1 Which exterior wall system (shown on the next page) is used?

☐ #1 ☐ #2 ☐ #3 ☐ #4 ☐ #5 ☐ #6 ☐ other

.2 Where is the vapour barrier located?

☐ no vapour barrier used
☐ on interior of back-up walls
☐ in exterior of back-up walls



BUILDING ENVELOPE COMPONENTS

.3 Is the stucco/plaster applied on lath?

☐ yes ☐ no

.4 Are control joints used at slab levels?

☐ yes ☐ no

.5 Which spacing of vertical control joints is used?

☐ vertical control joints not used
☐ every 4.5-6m (15-20 ft) ☐ every 6-8m (20-26 ft)
☐ every 8-10m (26-33 ft) ☐ every 10-12m (33-39 ft)

.6 Are vertical control joints used within 3m (10 ft) of wall corner?

☐ yes ☐ no

.7 Is there any allowance for movement between structural elements and the back-up walls?

☐ not applicable (i.e. walls are load bearing)
☐ yes ☐ no

ART 3 - LIFE CYCLE COSTS

pecial Note: Respond to questions regarding repair work with respect to the original cladding system. If a cladding system underwent repairs more than once, provide answers for the first set of repairs.

.1 EXTERIOR FINISHES

.1.1 Masonry

.1 How often are maintenance repairs (e.g. minor tuck-pointing, minor replacement of bricks) carried out on the masonry veneer?

- ☐ not regularly carried out
- ☐ every 4 or 5 years
- ☐ every 6 or 7 years
- ☐ every 8 or 9 years
- ☐ every 10-12 years

.2 What is the usual cost of maintenance work?

- ☐ not applicable
- ☐ less than $1,000
- ☐ $1,000 - $2,000
- ☐ $2,000 - $4,000
- ☐ $4,000 - $6,000
- ☐ $6,000 - $8,000
- ☐ $8,000 - $10,000
- ☐ over $10,000

.3 Has repair work other than maintenance been undertaken?

☐ yes ☐ no

Answer questions 4 through 10 only if you have answered yes to question 3.

.4 What type(s) of repairs were undertaken?

- ☐ extensive tuck-pointing of TTW brick or exterior concrete masonry
- ☐ extensive tuck-pointing of veneer
- ☐ reconstruction of less than 10% of veneer
- ☐ reconstruction of 10 to 20% of veneer
- ☐ reconstruction of over 20% of veneer
- ☐ partial retrofit over existing cladding using new cladding system
- ☐ complete retrofit over existing cladding using new cladding system
- ☐ complete removal and reconstruction of masonry veneer
- ☐ complete removal of veneer and replacement with a new cladding system
- ☐ Other. Please specify

.5 How much did the repairs cost?

- ☐ less than $5,000
- ☐ $5,000 - $10,000
- ☐ $10,000 - $15,000
- ☐ $15,000 - $20,000
- ☐ $20,000 - $30,000
- ☐ $30,000 - $50,000
- ☐ $50,000 - $100,000
- ☐ $100,000 - $300,000
- ☐ $300,000 - $500,000
- ☐ $500,000 - $750,000
- ☐ $750,000 - $1,000,000
- ☐ over $1,000,000

.6 How old was the building when the repairs were carried out?

- ☐ less than 5 years
- ☐ 5-9 years
- ☐ 10-14 years
- ☐ 15-19 years
- ☐ 20-24 years
- ☐ 25-29 years
- ☐ 30-39 years
- ☐ 40-50 years
- ☐ over 50 years

.7 Please give a brief description of the cause(s) of distress:

____
____
____
____
____

.8 Who determined the cause of distress?

- ☐ Engineer
- ☐ Architect
- ☐ Contractor
- ☐ Other. Please specify

.9 Have additional cladding repairs (other than maintenance) been carried out since the first set of repairs?

☐ yes ☐ no

.10 How extensive were the subsequent repairs in comparison to the first set of repairs?

- ☐ not applicable
- ☐ less severe
- ☐ about the same
- ☐ more severe

3.1.2 Precast Concrete Panels:

.1 How often are maintenance repairs (e.g. minor patching, minor crack repairs) carried out on the concrete panels?

- ☐ not regularly carried out
- ☐ every 4 or 5 years
- ☐ every 8 or 9 years
- ☐ every 10-12 years

.2 What is the usual cost of maintenance work?

- ☐ not applicable
- ☐ less than $1,000
- ☐ $1,000 - $2,000
- ☐ $2,000 - $4,000
- ☐ $4,000 - $6,000
- ☐ $6,000 - $8,000
- ☐ $8,000 - $10,000
- ☐ over $10,000

.3 Has repair work other than maintenance been undertaken?

☐ yes ☐ no

nswer questions 4 through 10 only if you have answered yes to question 3.

.4 What types of repairs were undertaken?

☐ repair of cracked concrete panels
☐ patching of spalled concrete panels
☐ removal and resetting of a few panels
☐ removal and resetting of many panels
☐ replacement of a few panels
☐ replacement of many panels
☐ complete replacement of all panels with new concrete panels
☐ complete replacement of all panels with a different cladding system
☐ Other. Please specify

.5 How much did the repairs cost?

☐ less than $5,000	☐ $20,000 - $30,000	☐ $300,000 - $500,000
☐ $5,000 - $10,000	☐ $30,000 - $50,000	☐ $500,000 - $750,000
☐ $10,000 - $15,000	☐ $50,000 - $100,000	☐ $750,000 - $1,000,000
☐ $15,000 - $20,000	☐ $100,000 - $300,000	☐ over $1,000,000

.6 How old was the building when the repairs were carried out?

☐ less than 5 years	☐ 15-19 years	☐ 30-39 years
☐ 5-9 years	☐ 20-24 years	☐ 40-50 years
☐ 10-14 years	☐ 25-29 years	☐ over 50 years

.7 Please give a brief description of the cause(s) of distress:

____
____
____
____
____

8. Who determined the cause of distress?

☐ Engineer ☐ Architect ☐ Contractor
☐ Other. Please specify

.9 Have additional cladding repairs (other than maintenance) been carried out since the first set of repairs?

☐ yes ☐ no

.10 How extensive were the subsequent repairs in comparison to the first set of repairs?

☐ not applicable
☐ less severe ☐ about the same ☐ more severe

3.1.3 Metal Cladding:

.1 Has it been necessary to undertake repairs?

☐ yes ☐ no

Answers questions 2 through 8 only if you have answered yes to question 1.

.2 What type of repairs were undertaken?

☐ reattachment of loose siding or trim
☐ removal and resetting of a few panels
☐ removal and resetting of many panels
☐ replacement of less than 15% of the cladding
☐ replacement of 15 to 29% of the cladding
☐ replacement of 30 to 44% of cladding
☐ replacement of 45 to 65% of the cladding
☐ replacement of more than 65% of the cladding
☐ complete replacement of all cladding with new metal cladding
☐ complete replacement of all cladding with a different cladding
☐ system
☐ Other. Please specify

.3 How much did the repairs cost?

less than $5,000	☐ $20,000 - $30,000	☐ $300,000 - $500,000
☐ $5,000 - $10,000	☐ $30,000 - $50,000	☐ $500,000 - $750,000
☐ $10,000 - $15,000	☐ $50,000 - $100,000	☐ $750,000 - $1,000,000
☐ $15,000 - $20,000	☐ $100,000 - $300,000	☐ over $1,000,000

.4 How old was the building when the repairs were carried out?

☐ less than 5 years	☐ 15-19 years	☐ 30-39 years
☐ 5-9 years	☐ 20-24 years	☐ 40-50 years
☐ 10-14 years	☐ 25-29 years	☐ over 50 years

.5 Please give a brief description of the cause(s) of distress:

____
____
____
____
____

.6 Who determined the cause of distress?

☐ Engineer ☐ Architect ☐ Contractor
☐ Other. Please specify

.7 Have additional cladding repairs (other than maintenance) been carried out since the first set of repairs?

☐ yes ☐ no

.8 How extensive were the subsequent repairs in comparison to the first set of repairs?

☐ not applicable
☐ less severe ☐ about the same ☐ more severe

.1.4 Stucco/Architectural Plasterwork:

.1 Has minor patching of stucco/plaster been undertaken?

☐ yes ☐ no

nswer questions 2 and 3 only if you answered yes to question 1.

.2 How much did minor patching cost?

☐ not applicable ☐ $2,000-$4,000 ☐ $8,000-$10,000
☐ under $1,000 ☐ $4,000-$6,000 ☐ over $10,000
☐ $1,000-$2,000 ☐ $6,000-$8,000

.3 How old was the stucco/plaster when minor patching was undertaken?

☐ less than 4 years ☐ 7-9 years ☐ 13-15 years
☐ 4-6 years ☐ 10-12 years ☐ over 15 years

.4 Has more extensive removal and replacement of deteriorated stucco been undertaken?

☐ yes ☐ no

.nswer questions 5 through 12 only if you have answered yes to question 4.

.5 What percentage of the stucco/plaster required replacement?

☐ less than 15% ☐ 30-44% ☐ 55-69% ☐ 85-99%
☐ 15-29% ☐ 45-54% ☐ 70-84% ☐ 100%

.6 How much did the repairs cost?

☐ less than $5,000 ☐ $20,000 - $30,000 ☐ $300,000 - $500,000
☐ $5,000 - $10,000 ☐ $30,000 - $50,000 ☐ $500,000 - $750,000
☐ $10,000 - $15,000 ☐ $50,000 - $100,000 ☐ $750,000 - $1,000,000
☐ $15,000 - $20,000 ☐ $100,000 - $300,000 ☐ over $1,000,000

.7 How old was the building when the repairs were carried out?

☐ less than 5 years ☐ 15-19 years ☐ 30-39 years
☐ 5-9 years ☐ 20-24 years ☐ 40-50 years
☐ 10-14 years ☐ 25-29 years ☐ over 50 years

.8 Please give a brief description of the cause(s) of distress:

____
____
____
____
____

.9 Who determined the cause of distress?

☐ Engineer ☐ Architect ☐ Contractor
☐ Other. Please specify

.10 What was used to replace deteriorated stucco?

☐ stucco without lath ☐ stucco on lath
☐ a different cladding system

.11 Have additional cladding repairs (other than maintenance) been carried out since the first set of repairs?

☐ yes ☐ no

.12 How extensive were the subsequent repairs in comparison to the first set of repairs?

☐ not applicable
☐ less severe ☐ about the same ☐ more severe

3.2 BACK-UP WALLS

.1 Have repairs been undertaken to any elements of the back-up walls?

☐ no ☐ yes. Please specify

.2 How much did the repairs cost?

☐ not applicable ☐ $10,000-$15,000 ☐ $25,000-$35,000
☐ less than $2,000 ☐ $15,000-$20,000 ☐ $35,000-$50,000
☐ $2,000-$5,000 ☐ $20,000-$25,000 ☐ over $50,000
☐ $5,000-$10,000

Questionnaire #3

GENERAL SURVEY
OF CLADDING REPAIRS
IN CANADA

INSTRUCTIONS:

In the table that follows, please estimate the unit cost of each cladding alternative for the two hypothetical buildings listed below. Assume that both buildings:

- are to be constructed on easily accessible sites
- have balconies at every unit
- have approximately 30% of the exterior walls consisting of windows and patio doors
- have only one type of cladding system on the entire building envelope
- are similar in all other ways except those listed below.

Building No. 1

A 5-storey, square building measuring 25m (82 ft) on each side. The total cladding area is about 900 m^2 (9675 ft^2)

Building No. 2

A 16-storey, rectangular building measuring 20m (66 ft) by 50m (164 ft). The total cladding area is about 5800 m^2 (62,350 ft^2).

Building	Cladding System	Unit Cost of Construction
#1 (5-storey)	Brick Veneer/Steel Stud - standard clay brick - 6 in., 18 g.a. galvanized studs - R20 batt insulation in stud space - drywall both sides of studs - studs screw fastened - adjustable ties screwed to studs	
#1 (5-storey)	Brick Veneer/Concrete Masonry - standard clay brick - 8 in. hollow core masonry infill - infill grouted every 32 in. - ladder ties used - 2 in. rigid insulation on interior and in cavity (R20)	
#1 (5-storey)	Precast Concrete - 6 in. thick panels using normal density concrete - 6 in., 20 ga. galvanized studs - R20 batt insulation in stud space	
#1 (5-storey)	Metal Panels - rectangular, flush face steel panels - 6 in., 20 ga. galvanized studs - R20 batt insulation in stud space	
#1 (5-storey)	Metal Siding - deep rib steel siding - 6 in., 20 ga. galvanized studs - R20 batt insulation in stud space	
#2 (16-storey)	Brick Veneer/Steel Stud (as above)	
#2 (16-storey)	Brick Veneer/Concrete Masonry (as above)	
#2 (16-storey)	Precast Concrete (as above)	
#2 (16-storey)	Metal Panels (as above)	
#2 (16-storey)	Metal Siding (as above)	

APPENDIX B: Summary of Responses to Questionnaire #1 and #2

LEGEND FOR APPENDIX B

Cladding Systems:

BV/CM:	Brick Veneer/Concrete Masonry
BV/SS:	Brick Veneer/Steel Stud
CP:	Precast Concrete Panels
MP:	Metal Panels
MS:	Metal Siding
TTW:	Through-the-wall Masonry
S:	Stucco
SP:	Stone Panels
O:	Other
N/A:	Not Applicable

Extent of Repairs:

M:	Moderate Repairs
E:	Extensive Repairs
S:	Severe Repairs
C:	Complete Reconstruction/Replacement of Cladding or Complete Retrofit of New Cladding Over Existing

SUMMARY OF REPLIES TO QUESTIONNAIRE #1 (questions 1 and 2)

QUESTION / REPLY #	1		2		3		4	
1. City	Toronto		Toronto		Calgary		Toronto	
2. Cladding Repairs	Installed	Repaired	Installed	Repaired	Installed	Repaired	Installed	Repaired
2.1 BV/CM	30	3	1	0	1	0	6	2
2.2 BV/SS	2	2					2	0
2.3 Precast Concrete	3	0					3	0
2.4 Stone Panels								
2.5 Metal Panels								
2.6 Metal Siding								
2.7 TTW								
2.8 Stucco								

QUESTION / REPLY #	5		6		7		8	
1. City	Toronto		Halifax		Toronto		Halifax	
2. Cladding Repairs	Installed	Repaired	Installed	Repaired	Installed	Repaired	Installed	Repaired
2.1 BV/CM					16	3		
2.2 BV/SS			2	2			1	1
2.3 Precast Concrete	1	1	1	1				
2.4 Stone Panels								
2.5 Metal Panels			1	1	4	0		
2.6 Metal Siding								
2.7 TTW								
2.8 Stucco	1	1						

SUMMARY OF REPLIES TO QUESTIONNAIRE #1 (questions 1 and 2)

QUESTION / REPLY #	9		10		11		12	
1. City	Toronto		Toronto		Toronto		Montreal	
2. Cladding Repairs	Installed	Repaired	Installed	Repaired	Installed	Repaired	Installed	Repaired
2.1 BV/CM	1	1	18	7	75	1	1	0
2.2 BV/SS								
2.3 Precast Concrete			2	0				
2.4 Stone Panels								
2.5 Metal Panels			1	0				
2.6 Metal Siding			4	0				
2.7 TTW	1	0						
2.8 Stucco								

QUESTION / REPLY #	13		14		15		16	
1. City	Montreal		Halifax		Calgary		Toronto	
2. Cladding Repairs	Installed	Repaired	Installed	Repaired	Installed	Repaired	Installed	Repaired
2.1 BV/CM			2	0	1	0	150	28
2.2 BV/SS					1	0		
2.3 Precast Concrete			4	0				
2.4 Stone Panels								
2.5 Metal Panels								
2.6 Metal Siding								
2.7 TTW	1	0						
2.8 Stucco								

SUMMARY OF REPLIES TO QUESTIONNAIRE #1 (questions 1 and 2)

QUESTION / REPLY #	17		18		19		20	
1. City	Unknown		Toronto		St. John's		Calgary	
2. Cladding Repairs	Installed	Repaired	Installed	Repaired	Installed	Repaired	Installed	Repaired
2.1 BV/CM	2	2						
2.2 BV/SS			2	1	2	0	3	2
2.3 Precast Concrete								
2.4 Stone Panels								
2.5 Metal Panels								
2.6 Metal Siding								
2.7 TTW	1	0						
2.8 Stucco								

QUESTION / REPLY #	21							
1. City	Halifax							
2. Cladding Repairs	Installed	Repaired	Installed	Repaired	Installed	Repaired	Installed	Repaired
2.1 BV/CM								
2.2 BV/SS	1	1						
2.3 Precast Concrete								
2.4 Stone Panels								
2.5 Metal Panels								
2.6 Metal Siding								
2.7 TTW								
2.8 Stucco								

SUMMARY OF REPLIES TO QUESTIONNAIRE #1 (Question #3)

Reply Number	Building Number	Cladding Repaired	Building Height (storeys)	Present Building Age (years)	Age When Repaired (years)	Extent of Repairs	Replacement Cladding
1	1	BV/CM	17	21	8	M	N/A
1	2	BV/SS	17	20	15	M	N/A
1	3	BV/SS	21	20	16	M	N/A
1	4	BV/CM	8	30	20	E	S (partial)
1	5	BV/CM	16	19	10	M	N/A
4	1	BV/CM	11	20	13	E	N/A
4	2	BV/CM	11	20	13	E	N/A
5	1	CP	16	25	21	E	N/A
5	2	S	14	27	27	C	UNKNOWN
6	1	BV/SS	10	16	2	E	N/A
6	2	BV/SS	4	1	1	M	N/A
6	3	CP	8	18	5	M	N/A
6	4	MP	10	16	2	E	N/A
7	1	BV/CM	7	23	16	M	
7	2	BV/CM	6	18	15	M	
7	3	BV/CM	4	23	18	M	
8	1	BV/SS	5	15	9	E	BV/SS
9	1	BV/CM	11	15	15	M	
10	1	BV/CM	7	26	23	C	S (Insulcrete)
10	2	BV/CM	11	27	25	E	BV
10	3	BV/CM	8	25	25	S	BV
10	4	BV/CM	30	18	18	M	BV
10	5	BV/CM	22	23	23	E	BV & MP
10	6	BV/CM	7	24	20	E	BV
10	7	BV/CM	12	28	24	C	S & MP
11	1	BV/CM	14	24	16	E	MP
16	1	BV/CM	18	20	19	M	MP
16	2	BV/CM	3	22	22	C	S/MP

SUMMARY OF REPLIES TO QUESTIONNAIRE #1 (Question #3)

Reply Number	Building Number	Cladding Repaired	Building Height (storeys)	Present Building Age (years)	Age When Repaired (years)	Extent of Repairs	Replacement Cladding
16	3	BV/CM	19	18	16	E	S
16	4	BV/CM	7	23	21	E	S
16	5	BV/CM	10	20	15	E	S
16	6	BV/CM	11	20	16	E	S
16	7	BV/CM	11	16	11	E	S
16	8	BV/CM	10	16	10	E	S
16	9	BV/CM	18	19	18	C	S
16	10	BV/CM	17	20	16	E	S
16	11	BV/CM	2	23	19	C	S
16	12	BV/CM	25	20	15	C	
16	13	BV/CM	17	20	15	C	
16	14	BV/CM	9	20	12	E	S
16	15	BV/CM	8	19	16	M	S
16	16	BV/CM	4	20	19	E	S
16	17	BV/CM	13	18	16	M	
16	18	BV/CM	14	19	12	M	S
16	19	BV/CM	18	16	12	M	
16	20	BV/CM	27	16	10	E	S
16	21	BV/CM	8	24	19	M	S
16	22	BV/CM	4	14	5	S	S
16	23	BV/CM	15	17	13	M	S
16	24	BV/CM	14	16	6	M	S
16	25	BV/CM	19	15	13	M	S
16	26	BV/CM	14	20	10	M	MP
16	27	BV/CM	20	18	17	E	MP/SP
16	28	BV/CM	4	32	31	M	MP
17	1	BV/CM	6	35	32	S	BV
17	2	BV/CM	6	9	9	M	N/A
18	1	BV/SS	7	10	10	C	BV/SS

SUMMARY OF REPLIES TO QUESTIONNAIRE #2 (PART 1)

Building Number	Building Location	Cladding Used			Wall Area (sq. m)	Window Coverage	Cladding Area (sq. m)	Cladding Quantities (sq. m)		
		#1	#2	#3				#1	#2	#3
#1	Ottawa	60% TTW	30% BV/CM	10% O	3,430	15%	2,915	1,750	875	290
#2	Ottawa	80% PC	20% O	N/A	4,785	20%	3,825	3,060	765	N/A
#3	Ottawa	75% BV/CM	25% PC	N/A	3,535	40%	2,120	1,590	530	N/A
#4	Ottawa	93% PC	7% CM	N/A	4,790	35%	3,110	2,895	220	N/A
#5	Calgary	100% BV/SS	N/A	N/A	7,105	30%	4,975	4,975	N/A	N/A
#6	Calgary	100% BV/SS	N/A	N/A	4,610	30%	3,230	3,230	N/A	N/A
#7	Toronto	70% BV/CM	30% S	N/A	3,485	45%	1,915	1,340	575	N/A
#8	Halifax	100% BV/SS	N/A	N/A	3,485	25%	2,615	2,615	N/A	N/A
#9	Toronto	100% BV/CM	N/A	N/A	1,025	25%	770	770	N/A	N/A
#10	Toronto	59% BV/CM	26% M	15% SP	7,100	25%	5,325	3,140	1,385	800
#11	Ottawa	70% TTW	20% S	10% O	5,260	45%	2,895	2,025	580	290
#12	Ottawa	70% TTW	30% S	N/A	5,840	15%	4,965	3,475	1,490	N/A
#13	Prescott	100% O	N/A	N/A	1,620	25%	1,215	1,215	N/A	N/A
#14	Kingston	100% TTW	N/A	N/A	Unknown	Unknown	1,970	1,970	N/A	N/A
#15	St. Mary's	100% TTW	N/A	N/A	Unknown	Unknown	1,325	1,325	N/A	N/A
#16	Ottawa	100% TTW	N/A	N/A	Unknown	Unknown	7,430	7,430	N/A	N/A

SUMMARY OF REPLIES TO QUESTIONNAIRE #2 (PART 3)

Building Number	Building Location	Type of Repair	Cladding Repaired	Area Repaired (sq. m)	Year Repaired	Repair Costs (at repair year)	Repair Costs (1990 dollars)	Unit Cost (1990 dollars per sq. m)
#1	Ottawa	Retrofit	TTW	1,750	1986	$222,000	$264,000	$151
#2	Ottawa	Retrofit	PC	3,100	1984	$401,000	$516,000	$166
#3	Ottawa	Reconstruction	BV/CM	2,120	1990	$600,000	$600,000	$283
#4	Ottawa	Retrofit	PC	2,895	1989	$700,000	$735,000	$254
#5	Calgary	Moderate	BV/SS	4,475	1990	$135,000	$150,000	$30
#6	Calgary	Moderate	BV/SS	3,230	1990	$50,000	$50,000	$15
#7	Toronto	Moderate	BV/CM	1,350	1982	$25,000	$38,000	$28
#8	Halifax	Reconstruction	BV/SS	2,625	1989	$1,000,000	$1,000,000	$400
#9	Toronto	Retrofit	BV/CM	770	1988	$150,000	$164,000	$213
#10	Toronto	Partial Retrofit	BV/CM	5,325	1988	$400,000	$437,000	$82
#11	Ottawa	Retrofit	S	580	1988	$93,000	$102,000	$175
#12	Ottawa	Retrofit	S	1,490	1990	$220,000	$220,000	$141
#13	Prescott	Retrofit	O	1,215	Unknown	$188,000	Unknown	Unknown
#14	Kingston	Retrofit	TTW	1,970	1985	$195,000	$241,000	$122
#15	St. Mary's	Retrofit	TTW	1,325	1984	$140,000	$181,000	$136
#16	Ottawa	Retrofit	TTW	7,430	1989-91	$1,500,000	$1,800,000	$202

APPENDIX C: Detailed Life Cycle Cost Tables

Life Cycle Costs for Brick Veneer/ Concrete Masonry
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	206	100.0	1.00000	206.00
Moderate Repairs	15	62	6.9	0.18270	0.78
Extensive Repairs	17	156	4.9	0.14564	1.11
Severe Repairs	21	408	1.0	0.09256	0.38
Retrofits/ Reconstruction	20	561	2.6	0.10367	1.51
Residual Value	25	-442	100.0	0.05882	-26.00
				total =	183.79

PRESENT VALUE OF LIFE CYCLE COSTS = $184/sq. m

Life Cycle Costs for Brick Veneer/ Steel Stud
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	166	100	1.00000	166.00
Moderate Repairs	11	49	24	0.28748	3.38
Extensive Repairs	13	124	31	0.22917	8.81
Retrofits/ Reconstruction	20	641	4	0.10367	2.66
Residual Value	25	-356	100	0.05882	-20.94
				total =	159.91

PRESENT VALUE OF LIFE CYCLE COSTS = $160/sq. m

Life Cycle Costs for Metal Siding
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	158	100	1.00000	158.00
Moderate Repairs	15	60	10	0.18270	1.10
Residual Value	25	-339	100	0.05882	-19.94
				total =	139.16

PRESENT VALUE OF LIFE CYCLE COSTS = $139/sq. m

Life Cycle Costs for Metal Panels
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	175	100	1.00000	175.00
Moderate Repairs	15	60	10	0.18270	1.10
Residual Value	25	-376	100	0.05882	-22.12
				total =	153.98

PRESENT VALUE OF LIFE CYCLE COSTS = $154/sq. m

Life Cycle Costs for Conventional Stucco on Masonry Walls
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	162	100	1.00000	162.00
Moderate Repairs	10	29	5	0.32197	0.47
Extensive Repairs	15	77	10	0.18270	1.41
Retrofits/ Reconstruction	20	449	10	0.10367	4.65
Residual Value	25	-348	100	0.05882	-20.47
				total =	148.06

PRESENT VALUE OF LIFE CYCLE COSTS = $148/sq. m

Life Cycle Costs for Conventional Stucco on Steel Stud Walls
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	125	100.0	1.00000	125.00
Moderate Repairs	10	43	7.5	0.32197	1.04
Extensive Repairs	15	115	15.0	0.18220	3.14
Retrofits/ Reconstruction	20	449	15.0	0.10367	6.98
Residual Value	25	-268	100.0	0.05882	-15.76
				total =	120.40

PRESENT VALUE OF LIFE CYCLE COSTS = $120/sq. m

Life Cycle Costs for Polymer Modified Stucco on Steel Stud Walls
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	175	100	1.00000	175.00
Moderate Repairs	15	50	10	0.18220	0.91
Residual Value	25	-376	100	0.05882	-22.12
				total =	153.79

PRESENT VALUE OF LIFE CYCLE COSTS = $154/sq. m

Life Cycle Costs for Polymer Modified Stucco on Masonry Walls
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	206	100	1.00000	206.00
Moderate Repairs	15	50	10	0.18220	0.91
Residual Value	25	-442	100	0.05882	-26.00
				total =	180.91

PRESENT VALUE OF LIFE CYCLE COSTS = $181/sq. m

Life Cycle Costs for Precast Concrete Panels
(High-rise bldg., i=6%, r=12%)

Type of Cost	Year Cost Incurred	Cost at Incurrence ($/sq. m)	Per Cent Affected	Combined Economic Factors	Present Value of Cost ($/sq. m)
Principal	0	251	100	1.00000	251.00
Moderate Repairs	5	27	7	0.56743	1.07
Extensive Repairs	21	184	7	0.09256	1.19
Retrofits/ Reconstruction	20	609	5	0.10367	3.16
Residual Value	25	-541	100	0.05882	-31.82
				total =	224.60

PRESENT VALUE OF LIFE CYCLE COSTS = $225/sq. m