SURVEY OF BUILDING ENVELOPE FAILURES IN THE COASTAL CLIMATE OF BRITISH COLUMBIA

Presented to:

Mr. D. Hazleden, MAIBC, MRAIC
Senior Advisor
Research and Technology Transfer

Mr. J. Rousseau
Manager, Innovation Centre for
High-Rise and Multiples
Technical Policy and Research

CMHC - B.C. & Yukon Regional Office
450 - 999 Canada Place
Vancouver, B.C.
V6C 3E1

Submitted By:

Morrison Hershfield Limited

Suite 247
4299 Canada Way
Burnaby, B.C.
V5G 1H3

November 22, 1996

EXECUTIVE SUMMARY

The purpose of this study was to correlate building envelope performance problems which are currently being experienced in low rise wood frame residential buildings in the coastal climate of the BC Lower Mainland, with sources of moisture, and design and construction features. This study has facilitated the identification of key aspects of the design, construction, operations and maintenance processes leading to the problems, which in turn provides the construction industry with focal points for the development of solutions to the current problems.

Forty six buildings were studied, 37 which had experienced performance problems and 9 which had not experienced problems. The buildings contained three cladding types (stucco, vinyl and wood), and a range of sheathing paper, sheathing, insulation and framing materials and configurations.

The results of the study indicate that the primary source of moisture leading to the performance problems was exterior water ingress rather than interior sources or construction moisture. Walls with roof overhangs were shown to have fewer problems than those without overhangs. The water was found to enter the wall assemblies at interface details; primarily at windows, at the perimeter of decks, balconies and walkways, and at saddle locations. The problems with these details were found to be related to aspects of the design and construction rather than operations or maintenance, or the materials themselves. The study was not able to identify significant differences in performance for walls with OSB or plywood sheathing, nor was there sufficient data to indicate differences in performance between walls with housewrap or building paper.

It was found that there was confusion in the design and construction of the wall assemblies with respect to water management principles. In addition to the presence of exterior moisture sources, drainage and drying potential were identified to be significant variables in determining the ability of a wall to perform. In all cases the problem walls failed to effectively balance moisture ingress, drainage and drying mechanisms. Once wetted, the potential for drying of walls in the coastal climate of the lower mainland during the winter months is very limited.

Based on the results of the study it was concluded that in the coastal climate area, face sealed wall assemblies are very sensitive to design and construction variables and it therefore may not be possible to achieve acceptable performance with face sealed systems. Concealed barrier systems may provide adequate levels of performance, however significant improvement must

occur in the design and construction of interface details. Rainscreen wall assemblies offer the best opportunity to achieve acceptable performance.

Recommendations for improvement in design and construction practices include the provision of greater clarity in design strategies, improvement in details (show more key details, larger scale, 3-D), development of guidance documents with respect to these details, communication of the design intent through mock-ups, establishment of an envelope quality management protocol, and training of trade personnel with respect to the construction of envelope materials and systems.

Several aspects of the envelope performance problems were identified as requiring further investigative work or development. These included cost effective remedial work strategies, supportive development and testing work for new rainscreen assemblies, drying characteristics of wall assemblies in the Lower Mainland environment, modifications in the application of the A440 window performance standard to installed window assemblies, and guidance on maintenance issues with respect to exterior walls.

RÉSUMÉ

Le but de cette étude était d'établir une corrélation entre les problèmes de performance de l'enveloppe des petits bâtiments résidentiels à ossature de bois de la région côtière du Lower Mainland de Colombie-Britannique, les sources d'humidité et les caractéristiques de conception et de construction. Cette étude a contribué à cerner les aspects clés des procédés de conception, de construction, d'exploitation et d'entretien à l'origine des problèmes, un processus qui a par la suite permis de fournir à l'industrie de la construction des indications pour régler les problèmes actuels.

Quarante-six bâtiments ont été étudiés, dont 37 qui avaient connu des problèmes de performance et 9 pour lesquels on n'avait observé aucun problème. Ces bâtiments présentaient trois types de parement (stucco, vinyle et bois) et comportaient des papiers de revêtement, des isolants et des matériaux et configurations d'ossature divers.

Les résultats de l'étude révèlent que la principale source d'humidité causant des problèmes de performance est l'infiltration d'eau provenant de l'extérieur plutôt que l'humidité provenant de l'intérieur ou de la construction elle-même. Les murs pourvus de débords de toit se sont avérés moins sujets aux problèmes que ceux qui en étaient dépourvus. On s'est aperçu que l'eau s'infiltrait dans les murs à la jonction de certains éléments d'assemblage, principalement aux fenêtres, autour des plates-formes, des balcons et des allées ainsi qu'à la hauteur du dos d'âne. Les problèmes inhérents à ces détails découlaient davantage de certains aspects de la conception et de la construction que de l'exploitation ou de l'entretien ou même des matériaux proprement dits. L'étude n'a pas pu relever de différences de performance significatives entre les murs constitués de panneaux OSB ou de contreplaqué, et les données recueillies n'ont pas suffit à établir des différences de performance entre les murs possédant un revêtement textile continu et ceux où l'on avait utilisé du papier de construction.

On a constaté qu'il existait une certaine confusion dans la conception et la construction des assemblages muraux quant aux principes de gestion des infiltrations d'eau. Outre la présence de sources d'humidité extérieure, on a déterminé que le potentiel de drainage et de séchage de l'eau constituaient d'importantes variables agissant sur la performance d'un mur. Dans tous les cas, les murs présentant des problèmes n'étaient pas parvenus à équilibrer efficacement les mécanismes d'infiltration d'humidité, de drainage et de séchage. Lorsque les murs sont mouillés, leur potentiel de séchage durant les mois d'hiver du climat côtier du Lower Mainland est très limité.

Les résultats de l'étude permettent de conclure que les murs à complexe étanche externe en climat côtier sont très sensibles aux variables de conception et de construction et qu'il n'est peut-être pas possible d'obtenir une performance acceptable de ce genre d'assemblage. Les complexes étanches internes pourraient offrir une performance acceptable, mais il faudrait que des améliorations considérables soient apportées à la conception et à l'exécution des détails de jonction des assemblages. Les murs à écran pare-pluie offrent les meilleures perspectives en matière de performance.

Pour améliorer les méthodes de conception et de construction, on recommande une plus grande clarté pour les stratégies de conception, l'amélioration des détails (montrer plus de détails clés, présenter les documents à plus grande échelle ou en trois dimensions), la rédaction de guides ayant

trait à ces détails, la transmission de l'objectif recherché par un détail particulier au moyen de maquettes, l'établissement d'un protocole de gestion de la qualité de l'enveloppe et la formation des gens de métier pour la mise en oeuvre des matériaux et éléments de l'enveloppe. On a déterminé que plusieurs aspects des problèmes de performance de l'enveloppe relevés nécessitaient de plus amples études ou devaient être approfondis. On suggère entre autres l'élaboration de stratégies correctives efficientes, la mise au point et l'essai de nouveaux assemblages d'écrans pare-pluie, l'étude des caractéristiques de séchage des assemblages muraux dans le contexte du Lower Mainland et la modification de l'application, aux fenêtres installées, de la norme A440 régissant la performance des fenêtres et des directives sur l'entretien des murs extérieurs.

CMHC SCHL
Helping to house Canadians
Question habitation, comptez sur nous

National Office
700 Montreal Road
Ottawa, Ontario
K1A 0P7

Bureau national
700 chemin de Montréal
Ottawa (Ontario)
K1A 0P7

Puisqu'on prévoit une demande restreinte pour ce document de recherche, seul le sommaire a été traduit.

La SCHL fera traduire le document si la demande le justifie.

Pour nous aider à déterminer si la demande justifie que ce rapport soit traduit en français, veuillez remplir la partie ci-dessous et la retourner à l'adresse suivante :

Le Centre canadien de documentation sur l'habitation
La Société canadienne d'hypothèques et de logement
700, chemin de Montréal, bureau C1-200
Ottawa (Ontario)
K1A 0P7

TITRE DU RAPPORT : ______________________________

____

Je préférerais que ce rapport soit disponible en français.

NOM ______________________________

ADRESSE ______________________________
rue app.

____
ville province code postal

No de télephone ( ) ____________

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TERMINOLOGY

This report describes problems of water leakage and damage to exterior walls of wood-frame multi-unit residential buildings in the Lower Mainland of British Columbia. The data from the field survey which forms the basis of this report are contained in an electronic database. A number of the terms which are used in the report and in the database have specific meaning in the context of this report and are therefore defined below:

Balcony refers to a horizontal surface exposed to outdoors, but projected from the building so that it is not located over a living space.

Cladding refers to a material or assembly which forms the exterior skin of the wall and is exposed to the full force of the environment. Cladding types included in this study are stucco, wood siding, and vinyl siding.

Deck refers to a horizontal surface exposed to outdoors, located over a living space, and intended for moderate use but not for access to other areas of the building.

Envelope refers to those parts of the building which separate inside conditioned space from unconditioned or outside space, such as windows, doors, walls, roofs, and foundations.

Horizontal Movement Joint refers to a horizontal joint on a wall which provides capability for differential movement of portions of the building structure (expansion joint) or prevents or localizes cracking of brittle materials such as stucco, where any leakage due to the cracking or movement can be controlled (control joint).

Housewrap refers to a sheet plastic material which is used as a sheathing paper, generally between the wall sheathing material and the exterior cladding. Although recognized as a proprietary term, in this report housewrap is used to represent a generic group of materials. One common type of housewrap consists of Spun-Bonded Polyolefin (SBPO), another is made of perforated polyethylene. Their resistance to liquid water is high, but resistance to water vapour is lower than many common "vapour barrier" materials.

Maintenance refers to a regular process of inspection of envelope and exterior systems such as roof, walls, windows, gutters, downspouts and drains, cleaning of those items that need it on a regular basis (such as leaves from gutters and drains in the fall, and lint from dryer vents), and correction of minor defects such as small areas of failed caulking.

Operation of the building or envelope refers to normal occupancy of the building where the envelope is affected by interior space conditioning, changes to light fixtures, signs, vegetation and planters, and accidental damage or vandalism.

Penetration refers to a hole passing through the opaque wall structure in which ducts, electrical wires, pipes, and fasteners are run between inside and outside.

Problems: Each investigator was asked to describe the cause of each set of symptoms submitted. These "causes" were then grouped into 17 categories of "problems". Buildings and walls which have a "symptom report" are called "problem buildings" and "problem walls".

Saddle refers to the transition of small horizontal surfaces, such as the top of a balcony guardrail or parapet wall, with a vertical surface, such as a wall.

Sheathing refers to a material (OSB or plywood) used to provide structural stiffness to the wall framing and to provide structural backing for the cladding and sheathing paper.

Sheathing Paper refers to a material or combination of materials in an exterior wall whose purpose is to retard penetration of water further into the structure once past the cladding. Commonly-used materials are building paper and housewrap.

Symptoms: A performance problem within the exterior wall of a building will become evident by the development of a number of "symptoms", such as staining and wetting of surfaces, loss of strength, delamination or cracking of materials, peeling paint and debonded coatings, etc. In the database "symptom reports" are provided which describe the set of symptoms found. These are then classified under "problem categories"; most "symptoms" are the result of only one problem, but occasionally two related problems contribute to the same set of symptoms.

Walkway refers to a corridor exposed to outdoors which provides access between suites and stairwells or elevators.

1. INTRODUCTION

1.1 Background

Over the past ten years there has been a residential building boom in the Lower Mainland of British Columbia. The building construction has included single family residential, high rise non-combustible construction, and low rise multi-unit wood frame construction. While some envelope performance problems have been experienced with all of these types of construction, the problems have been more prevalent, more severe, and have appeared earlier in low rise multi-unit wood frame construction. The problems have included water penetration, damage to cladding systems, and rotting and decay of wood components (siding, framing members and sheathing). The extent and severity of these performance problems has been well publicized through the media.

The industry, the marketplace, and the regulatory agencies have responded to the increased incidence of problems and the negative publicity. The City of Vancouver has responded to these problems by introducing Bulletins that attempt to ensure greater quality in envelope construction. The first two Bulletins have dealt with EIFS construction; one published in 1989 and the second in early 1996. The City has recently introduced a new Bulletin dealing with all cladding types, with some extra clauses dealing with the use of stucco as cladding.

The National Standing Committee on Small Buildings has identified these unique problems in the coastal climate of B.C. as an issue that may require special attention in codes and guideline documents. An industry group supported by the Canadian Home Builders' Association (CHBA BC), New Home Warranty of British Columbia and the Yukon (NHW), and the Wall and Ceiling Association has developed a seminar on Stucco Cladding, which has been delivered to industry tradespeople since 1995. The Architectural Institute of British Columbia (AIBC), along with Canada Mortgage and Housing Corporation (CMHC), was instrumental in creating the Building Envelope Research Consortium (BERC), the group of stakeholders comprising members of development industry, the architectural and engineering professions, government agencies involved in the housing industry, and contractors and trade organizations. The BERC played an advisory role in the field survey work described in this report.

The problems have persisted despite continuing advances in the understanding of the behaviour of building envelopes, the presence and efforts of the various industry associations, and changes in codes and standards. Why do these problems persist? The responses to that question are many: poor design, poor construction, poor coordination of trades, poor performance of building materials, unique climate of the Lower Mainland, high initial moisture content of the wood, lack of knowledgeable owners and property managers leading to poor inspection and maintenance, and the list goes on. The simple fact that there are so many opinions may be inhibiting our collective ability to focus on the key sources of the problems and take appropriate action to improve performance.

There is clearly a need to objectively determine the prevalent cause(s) of envelope performance problems in low rise multi-unit wood frame buildings and to provide some focus to efforts to resolve the problems. The current study is the first step in a process that will hopefully help the construction community turn the corner towards improved building envelope performance. BERC sees the role of this study as the first step in a three-step process; following from this work, it intends to develop a Best Practices Guide for building envelopes in the Lower Mainland environment, and develop a Quality Assurance Program which will provide some structure for measuring and improving the performance of envelopes in new buildings.

It is estimated that the stock of new buildings constructed and occupied during the period 1985-1991 in the Lower Mainland numbers about 600. This field survey is not intended to provide a statistical representation of the overall population of target buildings; both because of the small size of the sample, and because of the non-random method of selecting buildings for inclusion in the sample. Thus statistics generated from the sample data should not be extended to apply to the entire population of low-rise multi-unit buildings in the Lower Mainland.

1.2 Objectives

The primary objective of the study is to correlate potential causal factors with the building envelope problems which wood-frame residential buildings are experiencing in the coastal climate of the B.C. Lower Mainland and Vancouver Island. This will facilitate the identification of the key aspects of the design, construction, operations and maintenance processes leading to the problems, which will in turn present focal points for the development of solutions. Specific questions addressed include:

- How is water getting into exterior wall assemblies of buildings?
- Are there differences in the performance of walls with various claddings?
- Do currently used sheathing papers work effectively?
- Are there differences in the performance of walls constructed with OSB or plywood?
- Are other detail elements of the wall a factor - windows, doors, vents, etc.?
- How much of wall problems are really related to roofing defects?
- Is the envelope water management strategy used for each wall system appropriate for the Lower Mainland climate zone?
- What stage(s) in the development process most affect the eventual success or failure of the envelope water management strategy?
- What elements of 4-storey wood frame envelopes should be addressed in the development of locally-relevant details for the Best Practice Guide planned by CMHC as follow-up to this work?
- What aspects of the building envelope failures are most relevant to improving construction quality control processes and should therefore be addressed in a Quality Assurance Protocol planned for development by CMHC ?

1.3 Project Team

The project team was led by Morrison Hershfield Limited (MH). Other team members included Constructive Building Solutions (CBS), Sheltair Scientific (SS), and New Home Warranty of British Columbia and the Yukon (NHW). Although NHW is not a consulting firm, the nature of their business requires investigating the causes of claims against their warranties; they therefore have a wide range of investigative files of building failures which were available for analysis. All team members contributed data to the study and participated in the analysis of the data and development of recommendations.

2. METHODOLOGY

2.1 Study Design

The study methodology consisted of the following tasks:

- Develop a list of criteria for buildings to be included in the study.

- Develop a list of buildings meeting those criteria.

- Develop a data collection instrument to gather, under consistent conditions, the information desired about the buildings and the problems encountered.

- Establish consistent evaluation criteria and standards within the data collection team and familiarize personnel in the use of the data collection instruments.

- Develop a computer database to automate the input of data, to store it in an organized fashion, and to provide simple access for analysis of data relationships.

- Carry out the data collection on the buildings.

- Analyze the data collected to identify and test the strength of relationships between problems encountered and wall design, materials, construction, and maintenance.

- Develop recommendations which provide direction with respect to the next steps in the process of alleviating the deterioration problems in future buildings of this type.

- Write a final report which presents the results of the study.

2.2 Criteria for Sample Buildings

Some of the specific attributes of the buildings included in the study are described as follows:

- Three and four-storey wood frame, residential buildings located in the Coastal area of B.C. The coastal area has been further defined as including the B.C. Lower Mainland and Vancouver Island, within 30 km. of the coast of the Strait of Georgia. Both market (Strata title) and non-market social housing have been included in the study.

- Age of no more than eight years. The purpose of this is to restrict the study to the perceived problem population of recent buildings which have experienced rapid deterioration. This criterion was relaxed to a first occupancy date of 1985 or later, after a preliminary check of investigation files revealed that a number of relevant buildings would be eliminated solely on the basis of age. Age is a substitute criterion for the use of designs, materials, and construction representative of the problem population, in that extensive use of stucco and Oriented Strand Board (OSB) became common during that period, and a building boom in the types of buildings exhibiting problems also began at that time.

- Cladding types were restricted to stucco (excluding EIFS systems), wood siding, and vinyl siding. EIFS systems were excluded because they are the subject of a separate study, not because buildings with EIFS cladding are considered problem-free. Other types of cladding such as masonry are rare in this class of building in the Lower Mainland.

- The buildings to be studied were to include examples of each of two exterior sheathing papers: asphalt-impregnated building paper, and housewrap (either spun-bonded polyolefin sheet or perforated polyethylene sheet).

- The buildings to be studied were to include examples of the use of OSB exterior sheathing as well as exterior grade plywood sheathing.

- Buildings which appear to be performing well and exhibit no outward signs of moisture problems within their walls; these are termed "control" buildings. The criteria for eligibility of these buildings to be included in the study was defined to be as above, with a further requirement that they be completed no later than 1991; this provides a minimum five year time period during which no problems have become evident.

2.3 Building Sample Characteristics

The choice of buildings to be included in the study has a major impact on the validity of the conclusions drawn from the analysis of the buildings and their problems. The criteria for selection of buildings has attempted to ensure that the sample is representative of the population of buildings we want to address, that is, wood-frame residential buildings located in the coastal climate region of B.C. and built in the last 10 years. However, the nature of the selection process is not random, and statistics from the sample group are not necessarily applicable to the entire population of buildings.

One objective of this project is to provide an indication of whether there are specific differences in materials, design, construction, or maintenance between buildings which have problems and buildings which do not. The sample of buildings is therefore divided into two major types, "problem" buildings and "control" buildings.

"Problem" buildings are defined as those in which a moisture problem within the walls, decks, or exterior framing has resulted in damage requiring $10,000 or more to repair (this may include expenses for repairs which did not solve the problem). "Control" buildings are those buildings which, over a period of at least five years, have not experienced such moisture problems.

Table 2.1 shows the distributions of buildings in the initial project plan as well as the totals which were achieved by the project team.

TABLE 2.1
DISTRIBUTION OF BUILDING TYPES

Building Type		Initial Plan	Actual
Control	Market	Not Specified	5
	Non-market	Not Specified	4
	Total	**12**	**9**
Problem	Market	Not Specified	33
	Non-market	Not Specified	4
	Total	**28**	**37**

2.3.1 "Control" Buildings

In order to identify eligible "non-market" buildings, CMHC provided the project team with a list of all CMHC subsidized projects for the years 1985 to 1990. From this list, 6 primary sample buildings and 6 alternates were submitted to CMHC Portfolio Management for vetting of problems and to provide the names of contacts who could provide plans and access to the buildings. Of these twelve, only three were found to meet the criteria for inclusion in the survey as "control" buildings by CMHC Portfolio Management. We also contacted the Greater Vancouver Housing Authority and the Affordable Housing Association, who were able to provide us with four more qualifying buildings. Further discussion indicated that only five of the seven buildings qualified, and we were unable to obtain the plans for one of these; the final database thus contains only four "non-market" buildings in the "control" group.

For "control market" buildings, the project team contacted several developers and architects and asked them to each identify 3 appropriate buildings from their projects completed between 1985 and 1991. We were able to identify, visit for inspection, and obtain the plans for a total of four confirmed "control market" buildings. A fifth building was contributed from the files of a study team member, who had investigated the building for a fire sprinkler problem and found it met the requirements for a "control" building in this study. In order to complete the project, the team closed the search for "control" candidate buildings on August 30, and proceeded with analysis of the sample of 9 completed at that time.

2.3.2 "Problem" Buildings

The four team member firms identified and provided data for a total of 37 different buildings which meet the eligibility criteria and for which significant problems have been investigated over the past few years. Although 50 "problem" buildings were expected to be available from the team members' files; the strict eligibility criteria and overlaps between the different firms have reduced the numbers.

The distribution of cladding, sheathing, and sheathing paper types within the sample problem buildings differs from the desired sample distribution of the initial plan. Table 2.2 below compares the distribution of primary wall types represented among the 37 problem buildings which are in the study sample. Note that for those buildings having more than one wall type defined, only the wall with the largest area (the primary wall) appears in the table. The distribution of cladding types in the sample is quite comparable with the initial plan; however we have a great oversupply of walls using building paper and OSB, and we are short on examples of the less-common housewrap sheathing paper, and plywood sheathing. In fact there are no examples of walls using both housewrap and plywood in the data, neither "problem" nor "control". It appears that we are short on these types because of the rarity of use of these types in the overall population of buildings, not because of the nature of the population of problem buildings.

2.4 Data Input Form and Guide

A copy of the final Data Input Form, and a Guide to the completion of the Data Input Form, are included in Appendix A. The Guide contains definitions of a number of the building details, materials, and condition assessments used in the form and in this report.

TABLE 2.2
COMPONENT DISTRIBUTION OF PRIMARY WALLS
IN PROBLEM BUILDINGS

	STUCCO		WOOD		VINYL		OTHER		TOTAL	
	Initial Plan	Actual Sample	Initial Plan	Actual Sample	Initial Plan	Actual Sample	Initial Plan	Actual Sample	Initial Plan	Actual Sample
Building Paper & OSB	5	18	1	2	1	4	0	0	7	24
Building Paper & Plywood	5	8	1	1	1	0	0	0	7	9
Housewrap & OSB	5	3	1	0	1	1	0	0	7	4
Housewrap & Plywood	5	0	1	0	1	0	0	0	7	0
Other	0	0	0	0	0	0	0	0	0	0
Totals	**20**	**29**	**4**	**3**	**4**	**5**	**0**	**0**	**28**	**37**

2.5 Pilot Surveys

Personnel of the four study team organizations participated in a group training session in which the data input forms were filled out for one example problem in one building. The session extended for approximately 8 hours spread over two days. The purpose of this session was to fine-tune the data collection methodology and forms, and to establish consistent standards for the evaluation of the buildings and their problems. A large number of valuable comments and concerns were raised during the session, and the data input form and guide were modified after the session to incorporate a number of changes. The representatives of each firm expressed confidence that they would be able to complete the forms consistent with the definitions and procedure described on the forms and in the guide.

2.6 Database

The database which stores the information relating to the buildings and provides reporting and analysis capability, was implemented using the Microsoft Access 2.0 database software, and the data input forms for all 46 buildings were input. The database architecture mirrors the input forms in that all information is stored by the major key of "Building ID", with sub-keys of "Wall ID", and "Performance Problem ID". Further identifier keys of "Wall Type ID" and "Problem Category" have been developed. The Wall Type ID identifies the type of cladding, sheathing paper, sheathing, and wall structure used in each wall. The Problem Category key sorts each symptom into 17 categories which generally reflect how water enters the wall.

2.7 Data Collection

After the August 24 meeting of the steering committee, three new data fields were added to all the database records. These were "Number of Living Units", "Wall Section Type", and "Problem Category". The number of living units in each building is required in order to normalize the "Cost of Repair" data in a form which accounts for the size of the building. The other two fields make data analysis much simpler by grouping the various wall sections and problems represented in the database.

The ages of the control buildings are fairly evenly spread over the eligibility period of 1985-1991. The great majority of the buildings are three and four-storey; there are a few lower buildings included, but all are wood frame except one which is wood post and beam. The problem buildings' exposure to the wind shows a greater exposure to north and south directions than to east and west; on average the north and south elevations are less protected from driving rain than the east and west. In comparison, the control buildings are less-exposed to wind on the north, east, and south elevations than the problem buildings.

Nearly all the buildings were originally equipped with windows having aluminum frames without thermal break. These windows typically have a drained frame design; the frame joints are often reported to be unsealed, as are the joints between the frame and the cladding; and the frame placement is close to flush with the exterior face of the cladding. All of these factors tend to increase the volume of water passing over and around the window, and the potential for water to enter the window opening. Information on window opening type, whether fixed, awning, casement or slider, was not collected as it was beyond the scope of the study to identify and investigate specific issues related to window components.

Table 3.2 presents data on the cost of the work required to repair each building having problems, normalized for size by dividing by the number of living units in the building, and shows how the cost varies by cladding type. Cost per unit is a good proxy variable for severity and extent of damage to each building. Included in the repair costs are some incidences of multiple attempts to resolve the same problem.

TABLE 3.2
COST OF REPAIRING PROBLEMS

Cladding	Count	Mean Cost/Unit	Median Cost/Unit	Standard Deviation
ALL	37	$ 7,152	$ 3,333	$ 10,918
STUCCO	28	$ 8,552	$ 5,100	$ 12,208
VINYL	5	$ 1,818	$ 1,417	$ 1,148
WOOD	8	$ 4,635	$ 4,666	$ 3,178

NOTE: The sum of the three cladding types is more than the total number of buildings because some buildings have problem walls of more than one type, and their data is included for walls of each cladding type which have problems

3.1 Wall Construction Statistics

A total of 72 walls are defined for the 46 buildings. There are a number of examples of the same wall construction on different buildings. The distinctive elements of wall construction are the cladding, the sheathing paper, the sheathing, the framing thickness, and the presence of insulation. Walls which are completely exposed to exterior conditions (parapets, balcony dividers, and solid guardrails) are not insulated. Table 3.3 describes the 27 unique wall section types in the database.

Of the 72 walls defined, 21 are of one specific construction, consisting of stucco cladding, building paper, OSB sheathing, 89 mm wood frame with glass fibre insulation, interior vapour barrier and drywall. This is by far the most common wall section of this group of buildings, appearing on one half of the problem buildings in the database. In contrast, there are no walls which combine housewrap and plywood.

Table 3.4 shows the occurrence of details on the 51 problem walls defined in the database. Shading has been used to emphasize those details where design, materials, or installation are rated poor in a substantial fraction of the total. Those details where between 30% and 50% were rated "poor" are lightly shaded; those where more than 50% were rated "poor" have heavier shading. In general each of these details occur on about half of the wall types; they are not rare situations and their design and construction is an integral part of the wall design and construction. However, the treatment of these details is highly variable in quality. All flat roof parapets and most window and door heads are flashed, and most of these flashings and details are rated acceptable. In contrast, only 29% of saddle details are flashed, and 77% of saddle details are rated poor in design, materials, and/or installation. Note that window sills are considered to be an outward projection from the plane of the wall, not simply the bottom of a window.

Table 3.5 shows the same information for the 21 walls in the database which do not have reported problems. Five of these walls are problem-free walls found on buildings having other walls with problems; the other 16 walls are found on the "control" buildings. Comparison of Table 3.5 with Table 3.4 shows that the design of details on performing walls was rated poor in a substantial fraction of cases, but that materials and installation were generally not rated poor. This indicates either that good construction practise can overcome design inadequacies in the details, or that wall performance was not sensitive to that detail.

TABLE 3.3
UNIQUE WALL CONSTRUCTIONS IN STUDY BUILDINGS

Wall Section Type ID	Cladding	Sheathing Paper	Sheathing	Framing, Insulation	"Control" Examples	"Problem" Examples
OHO140I	Other	Housewrap	OSB	140 mm, yes	2	0
OON89I	Other	Other	None	89 mm, yes	0	2
OPO89I	Other	Bldg. Paper	OSB	89 mm, yes	1	0
OPP89I	Other	Bldg. Paper	Plywood	89 mm, yes	1	0
SHO140I	Stucco	Housewrap	OSB	140 mm, yes	1	1
SHO89I	Stucco	Housewrap	OSB	89 mm, yes	0	2
SPO140I	Stucco	Bldg. Paper	OSB	140 mm, yes	2	2
SPO140X	Stucco	Bldg. Paper	OSB	140 mm, no	0	1
SPO89I	Stucco	Bldg. Paper	OSB	89 mm, yes	2	19
SPO89X	Stucco	Bldg. Paper	OSB	89 mm, no	0	2
SPOXXX	Stucco	Bldg. Paper	OSB	other, yes	0	1
SPP140I	Stucco	Bldg. Paper	Plywood	140 mm, yes	1	3
SPP89I	Stucco	Bldg. Paper	Plywood	89 mm, yes	3	4
SPP89X	Stucco	Bldg. Paper	Plywood	89 mm, no	1	0
VHO140I	Vinyl	Housewrap	OSB	140 mm, yes	0	1
VPN140I	Vinyl	Bldg. Paper	Other	140 mm, yes	0	1
VPN89X	Vinyl	Bldg. Paper	Other	89 mm, no	0	1
VPO140I	Vinyl	Bldg. Paper	OSB	140 mm, yes	0	2
VPO89I	Vinyl	Bldg. Paper	OSB	89 mm, yes	2	1
VPP140I	Vinyl	Bldg. Paper	Plywood	140 mm, yes	2	1
VPP140X	Vinyl	Bldg. Paper	Plywood	140 mm, no	1	0
VPP89X	Vinyl	Bldg. Paper	Plywood	89 mm, no	1	0
WHO140I	Wood	Housewrap	OSB	140 mm, yes	1	1
WPO140I	Wood	Bldg. Paper	OSB	140 mm, yes	0	1
WPO140X	Wood	Bldg. Paper	OSB	140 mm, no	0	1
WPO89I	Wood	Bldg. Paper	OSB	89 mm, yes	0	4
WPP89I	Wood	Bldg. Paper	Plywood	89 mm, yes	0	2
				TOTAL:	**21**	**51**

TABLE 3.4
STATISTICS ON WALL DETAILS ON PROBLEM WALLS

Detail Type	% of Walls Having Detail	% of Details Flashed	% of Details Poor Design	% of Details Poor Material	% of Details Poor Installation
BUILDING FEATURES					
Flat Roof Parapet	63	94	31	3	31
Inverted Soffit	0	NA	NA	NA	NA
Roof/Wall Junction	37	58	26	5	16
Saddle (Guardrail, etc)	69	29	77	29	46
Decks	43	55	32	9	18
Balconies	57	41	48	14	38
Patios	49	24	24	8	8
Exterior Walkways	43	36	59	27	36
Exposed Columns	73	32	35	8	16
Material Transitions	47	25	33	4	13
Horizontal Movement Jts.	39	25	15	0	20
Door Sills	75	18	26	8	13
Door Heads	76	77	10	3	21
Window Sills	49	72	24	8	24
Window Heads	86	91	14	2	30
PENETRATIONS					
Dryer Vents	63	19	47	13	28
Other Vents and Intakes	49	16	24	12	20
Guardrail Attachments	71	8	67	14	28
Electrical Fixtures	59	10	40	3	10
Scuppers	51	46	35	31	42
Water, Power, Gas Lines	6	0	33	33	50
Other	4	50	100	50	100
EAVESTROUGHS	67	NA	26	6	32

TABLE 3.5
STATISTICS ON WALL DETAILS ON PROBLEM-FREE WALLS

Detail Type	% of Walls Having Detail	% of Details Flashed	% of Details Poor Design	% of Details Poor Material	% of Details Poor Installation
BUILDING FEATURES					
Flat Roof Parapet	29	100	0	0	0
Inverted Soffit	0	NA	NA	NA	NA
Roof/Wall Junction	33	71	14	0	0
Saddle (Guardrail, etc)	43	22	67	0	0
Decks	48	60	10	0	0
Balconies	48	50	20	0	0
Patios	48	40	20	0	0
Exterior Walkways	5	100	0	0	0
Exposed Columns	43	11	44	0	11
Material Transitions	33	29	14	0	0
Horizontal Movement Jts.	29	0	0	0	0
Door Sills	67	13	13	0	0
Door Heads	67	86	21	0	0
Window Sills	62	6	19	0	0
Window Heads	71	80	20	0	0
PENETRATIONS					
Dryer Vents	62	31	31	0	8
Other Vents and Intakes	52	36	36	0	18
Guardrail Attachments	71	7	60	13	20
Electrical Fixtures	57	25	33	16	16
Scuppers	33	71	43	0	0
Water, Power, Gas Lines	0	0	0	0	0
Other	5	100	100	0	0
EAVESTROUGHS	71	NA	20	0	7

Lack of overhangs above walls is suggested by some industry members as a contributing factor to moisture damage in wood frame walls. The data on overhangs confirms this view; Figure 3.1 shows that the proportion of walls with problems drops consistently with increase in the width of overhang above them.

FIGURE 3.1
EFFECT OF OVERHANGS ON WALL PERFORMANCE

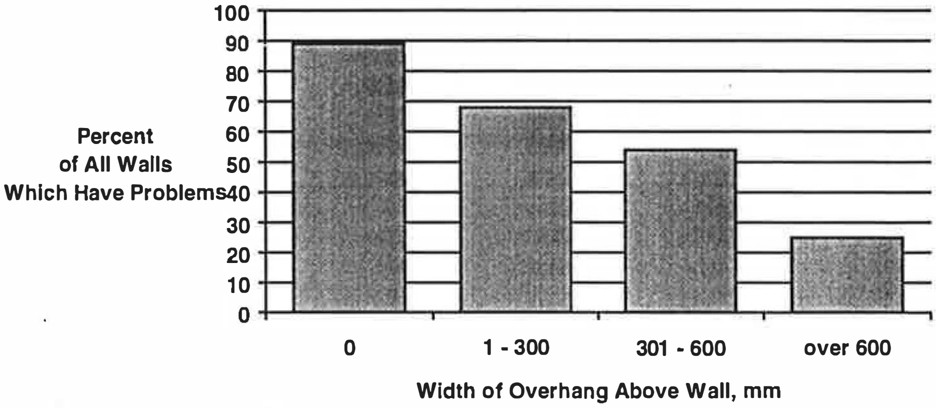


Table 3.6 shows the distribution of overhang widths by the cladding type installed on each wall. Since stucco is used on over 70 % of the walls defined in the database, the overhangs typically found on stucco walls affect the totals substantially. The data for wood siding walls is similar to that for stucco, but the data for vinyl walls indicates that they commonly have a larger overhang than the other cladding types. This may account for the reduced numbers of problems found in vinyl-clad walls in comparison with the other cladding types.

TABLE 3.6
DISTRIBUTION OF OVERHANG WIDTHS BY CLADDING TYPE

Overhang Width Range (mm)	0	1 - 300	301 - 600	over 600
Stucco - Clad Walls	44 %	35 %	16 %	5 %
Vinyl - Clad Walls	23 %	8 %	54 %	15 %
Wood - Clad Walls	50 %	30 %	20 %	0 %
Other Clad Walls	17 %	50 %	33 %	0 %
All Cladding Types	**39 %**	**31 %**	**25 %**	**6 %**

3.2 Problem Statistics

A total of 166 symptom reports covering a total of 193 problems are reported in the database. They have been categorized and summarized by building element affected; the results are shown in Table 3.7. Note that the total number of problems in the various categories is greater than 166, due to assigning some symptom reports to more than one category of problem.

Table 3.7 shows that there are some specific details that are involved in a high proportion of problems. The first four categories of problems relate to windows, and together they represent nearly 1/4 of the total reported problems. Each building in the database has on average more than one window-related problem. One major cause of window problems is poor sealing of mitre joints, a product assembly characteristic.

The next two categories relate to waterproof membranes on decks, balconies, and exterior walkways, and account for 17 % of the reported problems. It is rarely the application of the membrane on the substrate that causes problems; it is usually the lack of appropriate design or construction of its joints with penetrations and walls.

The largest single category of problems occurs at the saddle joints of balcony/walkway guardrails with surrounding walls. Twenty-two instances of problems caused by poor detailing of these joints are reported, in only 35 wall types where they occur. These, combined with the defects on balcony rail cap flashings and the problems with waterproof membranes, make the balconies, decks, and walkways a key problem generator identified through the survey.

A key observation is that nearly all the problem categories relate to details such as windows, decks, and penetrations found on walls rather than to the basic construction of the wall assembly. Category 17 contains problems relating directly to cladding, sheathing paper, and sheathing; they represent less than 10 % of the total. The wall as an assembly necessarily involves field areas and interfaces with other materials and components. Although the leakage occurred at interfaces, the damage extended to adjacent field areas. The field areas were not able to drain or dry rapidly enough to prevent damage from occurring.

TABLE 3.7
CATEGORIZATION OF PROBLEMS BY AFFECTED BUILDING ELEMENT

Category ID	Description	Number of Problems				Total # of Problems
		Stucco	Vinyl	Wood	Other	
1	Windows: No sealants at frame/cladding joint	9	1			10
2	Windows: No sealants at corner mitre joints	10	1	1		12
3	Windows: Poor flashing at head or sill	13		3		16
4	Windows: Poor building paper installation	6	1			7
	Subtotal Windows	**38**	**3**	**4**	**0**	**45**
5	Poor Deck/Walkway/Balcony Waterproofing: Field	12	3	1		16
6	Poor Deck/Walkway/Balcony Waterproofing: Junction with walls	16		1		17
	Subtotal Deck/Walkway/Balcony	**28**	**3**	**2**	**0**	**33**
7	Poor Guardrail Saddle Joints	13	3	5	1	22
8	Poor Guardrail Cap Flashings	8	1	4		13
9	Poor Parapet Cap Flashings	7	1			8
	Subtotal Horizontal Surface Flashings	**28**	**5**	**9**	**1**	**43**
10	Poor Base/Transition/Control Joint Flashings	14		1		15
11	Poor Roof/Wall Joint Flashings	3				3
12	Poor Eavestroughs / Downspouts	3	1	1		5
13	Poor Concrete Slab / Wall Joints	3		1	1	5
14	Poor Dryer Vents: Lint plugged, leaking in wall	6		2		8
15	Poor Vents: No sealing or flashing at hood	5	1	2		8
16	Poor Other Details	8	2	1	1	12
17	Material / Installation Defects: Cladding, Weather Barrier, Sheathing	10	2	4		16
	TOTALS	**146**	**17**	**27**	**3**	**193**

The above problem categories were developed from the assessment of what caused the water problem within the wall. In general, investigators focused on the path taken by the water to pass through the cladding in describing and categorizing problems. The path taken by the water to pass through the sheathing paper was described in much less detail, although in order to cause leakage on the interior of the building or deterioration of sheathing and structure, **both** layers must be compromised regardless of the design philosophy utilized. Table 3.8 summarizes how the water penetrated past the sheathing paper in the 166 reported symptoms:

TABLE 3.8
PENETRATION PAST SHEATHING PAPER

Path Through Sheathing Paper	Percent of Total Symptoms
No exterior sheathing paper	14 %
Discontinuities	30 %
Material Degradation	11 %
No or reversed lap	10 %
At flashing	16 %
At penetration	16 %
Other	3 %

Table 3.9 shows the evaluators' allocation of responsibility for each problem reported to design, construction, maintenance, and operating procedures. The majority of responsibility was allocated to "design and construction"; 100 cases or about 60 % of the total. The role of maintenance was rated as minimal, with 13 cases of "poor" maintenance and 18 cases of "not-maintainable" details contributing to 12 % of the problems. Design was held to be the sole cause of 17 problems (10 % of the total), while construction was held to be the sole cause in 44 problems, or over 25% of the total.

Maintenance was not held to be the sole cause of any problems. It is acknowledged that some repair or maintenance to failed materials or joints may have reduced the damage that occurred due to initial design or construction related problems. However, since these failures occurred early in the life of the building they were considered to be premature. The study evaluation team therefore generally regarded the necessity for this work to be related to design or construction deficiencies rather than routine maintenance. Furthermore, minor repair or maintenance activities would generally not have eliminated the problems, only reduced the severity of the damage.

Operational characteristics of the buildings, including damage to wall cladding caused by residents attaching planters to the walls, were identified as an issue in only one case.

TABLE 3.9
OVERALL CAUSES OF PROBLEMS

Rating	Design		Construction		Maintenance		Operation	
	# of Ratings	# of Problems Contributed	# of Ratings	# of Problems Contributed	# of Ratings	# of Problems Contributed	# of Ratings	# of Problems Contributed
Acceptable	47	0	17	0	133	0	162	0
Poor	90	90	149	149	13	13	1	1
Not Designed	29	27	NA	NA	NA	NA	NA	NA
Not Maintainable	NA	NA	NA	NA	18	6	NA	NA
Not Rated	0	0	0	0	2	0	3	0
TOTALS	166	**117**	166	**149**	166	**19**	166	**1**

3.3 Correlations between Problems and Selected Building Characteristics

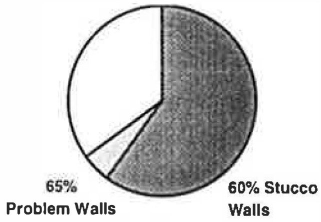
In this section we examine subsets of the data which share a common characteristic and compare them to the remainder of the data to determine if there are substantial differences between the two sets. This indicates whether the presence or absence of these characteristics is a good indicator of problems and provides direction for looking for cause-effect relationships. However in many cases, the range of values for each statistic is large; this means that the statistical significance of the "average" is relatively poor. We report these figures simply as indications rather than as statistically significant data. We focus on common hypotheses circulating in the construction industry about the causes of problems.

3.3.1 Wall Cladding

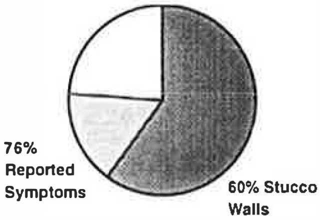
One common hypothesis holds that stucco as an exterior cladding is not appropriate for this climate and/or that the building industry is not able to produce stucco clad buildings which do not leak. In order to test this thesis we have divided the database records into those which use stucco as a cladding, and those which do not. The following statistics result:

- 43 of 72, or **60 %** of walls described in the database have stucco cladding.

- 33 of 51, or **65 %** of problem walls defined in the database have stucco cladding. There are **8% more** (65/60) problem stucco walls than expected based on their proportion of the database.



- 126 of 166, or **76 %** of reported symptoms were on stucco-clad walls. There are **27 % more** (76/60) symptoms reported on stucco walls than expected based on their proportion of the database.

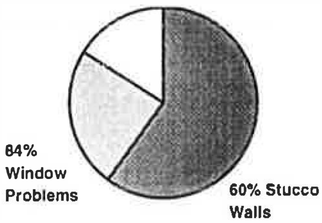


- The average number of symptoms reported per problem stucco-clad wall is **3.8** (126/33), while the average number of symptoms reported on other-clad walls is **2.2** (40/18). Poor performance in stucco walls is often the result of a substantial number of different defects; there is a greater variety of defects in stucco walls than in other walls.

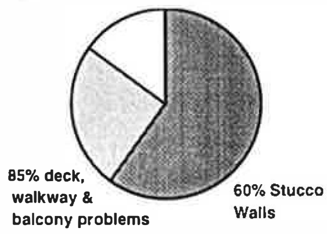
- The mean Time to Problem Noticed is 3.2 years for stucco-clad walls, 1.4 years for vinyl-clad walls, and 4.1 years for wood-clad walls. This may reflect the fact that it is relatively easy to investigate and repair vinyl-clad walls because the siding is easy and inexpensive to remove and reinstate.

- The mean repair cost/unit of buildings with problems on stucco-clad walls is $8,552, more than twice as much as the mean of $3,551 for buildings with problems on walls using other types of cladding. Stucco is difficult to remove and must be completely replaced; siding is often reuseable. Also the damage discovered to sheathing paper, sheathing, and structure may be more extensive under stucco than under other claddings.

- 38 of 45, or **84 %** of all window-related problems occur on stucco-clad walls. There are **40 % more** (84/60) window problems on stucco walls than expected based on their proportion in the database. This indicates that the interface detail of windows to stucco cladding is a more frequent problem than connection of windows to other cladding types.



- 28 of 33, or **85 %** of all deck/walkway/balcony waterproofing problems occur on stucco-clad walls. There are **40 % more** (85/60) deck/walkway/balcony problems on stucco walls than expected based on proportion. This may reflect construction sequencing problems in addition to detailing issues, where the deck waterproofing is applied after the stucco is on the wall, and the membrane cannot be properly lapped under the sheathing paper behind the stucco.

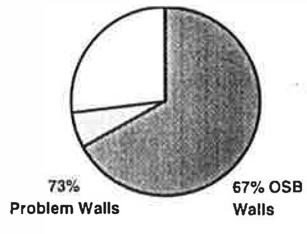


- The only problem categories where frequency on stucco-clad walls is proportional to the frequency of stucco cladding are "other details", "material/installation defects", and "guardrail saddle joints".

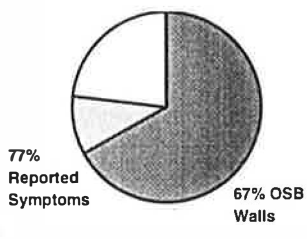
3.3.2 Sheathing

Another hypothesis frequently put forward to explain unusual numbers of problems on recent buildings is that OSB sheathing has much poorer resistance to the cycles of wetting and drying which occur in the coastal climate. By examining OSB-sheathed walls, we can determine if problems on these walls differ significantly from those on walls having other sheathing (a mixture of plywood, gypsum board, and no sheathing). The following statistics result:

- 48 of 72, or **67 %** of walls in the database have OSB sheathing.
- 37 of 51, or **73 %** of problem walls in the database have OSB sheathing. There are **9 % more** (73/67) problem OSB walls than expected based on their proportion of the database.



- 128 of 166, or **77 %** of symptoms were reported on OSB-sheathed walls. There are **15% more** (77/67) symptoms on OSB-sheathed walls than expected, based on their proportion in the database.

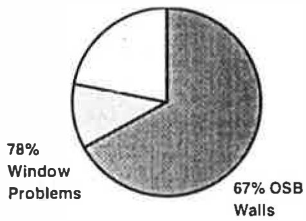


- The mean number of symptoms on OSB-sheathed walls is **3.5**, while the mean on other-sheathed walls is **2.7.**

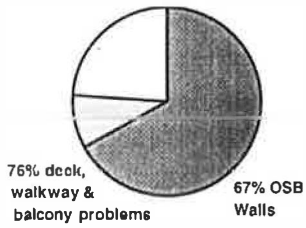
- The average cost/living unit to repair problem walls having OSB sheathing is $6,638, while the average cost/living unit to repair walls having other types of sheathing is $8,726. However, the standard deviations on these statistics are high; the range of costs are from less than $1000/unit to greater than $20,000/unit, indicating that the validity of this comparison of averages is questionable.

- The mean Time to Problem Noticed is 3.2 years for OSB-sheathed walls and 3.1 years for other-sheathed walls. This indicates that the speed of deterioration of different types of sheathing is not related to the time taken for a problem to be noticed.

- 35 of 45, or **78 %** of window-related problems in the database are on OSB-sheathed walls. There are **16 % more** (78/67) window problems on OSB-sheathed walls than expected based on their proportion in the database.



- 25 of 33, or **76 %** of deck/balcony/walkway problems are on OSB-sheathed walls.



- All of the 16 problems relating to vents are on OSB-sheathed walls.

Because of the wide ranges of values in these statistics, a large data set is required to provide reliability of comparisons of averages. There is not enough data to draw significant conclusions from the above statistics, but it appears that the frequencies of problems on OSB-sheathed walls are slightly more than proportional to the number of OSB-sheathed walls. While it appears that OSB-sheathed walls have more symptoms per problem wall, the symptoms do not appear sooner nor do they cost more to repair. Thus it appears that there is no direct correlation between use of OSB sheathing and the cause or size of problems.

3.3.3 Sheathing Papers

It has been proposed that housewraps are more suitable as a sheathing paper than the traditional asphalt coated building paper. If this is true, we would expect to see some difference between problem occurrence on walls equipped with housewrap and those having building paper. Unfortunately we do not have a large sample of buildings using housewrap, so these statistics provide an indication only and have a wide margin of error. The following statistics are drawn from the database:

- 9 of 72, or **13 %** of walls in the database have housewrap sheathing paper.
- 5 of 51, or **10 %** of problem walls have housewrap sheathing paper.
- 16 of 166, or **10 %** of symptoms were reported on housewrap walls.
- The average number of symptoms per housewrap walls is 3.2, compared to an average for building paper walls of 3.3.
- The mean time to problem noticed for housewrap walls is 3.4 years, while for building paper walls, it is 3.1. Due to the small housewrap group size, there is a wide error margin, and the figure for housewrap walls has low significance.
- The mean repair cost/unit of problems reported on housewrap walls is $4,817, while for building paper walls it is $7,314.
- No specific problem categories are over-represented or under-represented.

The sample size of housewrap walls is too small to draw any conclusions. There is some tentative indication that housewrap sheathing paper reduces the number of problems experienced. There is also some indication that the housewrap walls take longer before problems are noticed and cost less to repair than walls using building paper. Further tracking of performance of walls having housewrap would be worthwhile in order to confirm or disprove the above indications.

3.3.4 Orientation of Wall

It is commonly believed that East-facing walls are significantly more exposed to wetting and therefore deteriorate faster. There is substantial data on storms and wind-driven rain frequency to support this hypothesis. We would therefore expect to see some difference between problem occurrence on East-facing walls versus walls that face other directions.

The database contains fields which allow some analysis of the importance of this effect. For each symptom, the evaluator was asked to indicate whether the symptom occurred on each of the four possible facing directions of the wall. The following statistics are drawn from the database to shed some light on the size of this effect:

- In 39 of 166 symptom reports, directionality could not be determined because no information was available about one or more directions. For example, where an investigation looked only at the East face of the building, or the specific detail causing the problem occurs only on the East face, there is no information on whether a problem would have been found on the North face if it was investigated and if the detail occurred on that face.

- 37 of the remaining 127 symptom reports (29 %) having complete information on directionality showed a possible relationship of the problem with the direction orientation of the wall. A possible relationship was defined by at least one direction being a "Yes" for occurrence of the symptom, and at least one other direction being a "No". The directional split of these was:

North:	7 problems on 5 buildings
East:	23 problems on 15 buildings
South:	20 problems on 10 buildings
West:	12 problems on 9 buildings

Note that some problems and buildings are counted more than once above; a symptom may be found on two directions but not on the other two. There are 19 buildings having at least one symptom that is related to direction.

The remaining 90 cases were judged to be "omni-directional", that is, the problem was found on all faces of the building.

- 19 of the 37 reports found to show a relationship with direction actually had a symptom which occurred on only one direction and not on others. Of these, 1 faced North, 7 faced East, 8 faced South, and 3 faced West.

- Looking at the categories of problems represented by the above 37 directional reports, problems related to decks, balconies, and guardrails are over-represented relative to the rest of the database, while problems in the "Other" category, which includes eavestroughs, vents, and cladding/weather barrier/sheathing defects, are under-represented.

In summary, the relationship of problems to the direction the wall faces plays a role in about 30 % of cases; the East and South directions dominate, accounting for almost 70 % of reported directional symptoms. Problems related to decks, balconies, and walkways are over-represented in the directional group, relative to their proportion of all problems. This indicates that wind-driven rain is important in forcing water penetration through any flashing or waterproofing defects on horizontal surfaces.

3.3.5 Insulation

Some practitioners believe that the increase in insulation levels in wood frame walls in recent years has provided less heat to wet exterior materials to promote drying. All the walls in the database which separate living space from exterior are insulated with glass fibre batts; however the 38 x 140 walls have an extra 50 mm of insulation and may show an increase in problem occurrence as a result. The thicker walls tend to be located at lower floors of buildings for structural reasons, and may be subjected to more water from runoff and less-effective overhangs. On the other hand, depending on the specific building features and geometry, the wind driven rain may be more severe near the top of walls.

Thirty-two of 41 (78 %) of walls of 38 x 89 construction have problems, while 13 of 22 (59 %) of walls of 38 x 140 construction have problems. We conclude that extra insulation, or at least a thicker wall, appears to improve the situation rather than make it worse. This may be due to the greater volume of air and absorptive material, allowing the wet materials on the exterior to dispose of more moisture in wetting materials in the thicker wall cavity, and thus dry out sooner.

3.3.6 Drying of Wall Assemblies

Moisture problems result from a sequence of events which occur when water is brought into contact with a wall. First, the water must penetrate the cladding and possibly the sheathing paper; the current study has documented a number of ways that this has been found to occur on buildings in the Lower Mainland. Secondly, the water must remain in contact with the water-sensitive components of the wall (sheathing, framing, insulation, subfloor, interior finishes) long enough to weaken them, either by chemically dissolving materials or by initiating rot. Over time, and given conducive conditions, liquid water will evaporate and leave the wall cavity or drain out at the bottom. The balance between the rate at which water enters the wall from the outside and leaves via drainage and evaporation determines whether the wall provides durable performance or not.

The investigation of problems in this study provides ample evidence as to how water enters walls on buildings in the Lower Mainland. There is much less information available on how water leaves walls, and the importance of this part of the overall moisture management balance.

There are essentially three ways that water can leave wall assemblies; drainage, via mass movement of humid air, and via diffusion. Drainage occurs in two modes; bulk water runs down large passages under the influence of gravity or air pressure, or water moves along very small passages in porous materials via capillary action and evaporates at the surface of the porous material. Bulk air movement can only occur if there are significant air passages through the wall, and some force moves air through those passages. Diffusion relies on movement of water vapour molecules through materials.

In terms of the volume of water that can be removed per unit time, gravity drainage through large passages is by far the highest-capacity. Next is capillarity, if the evaporating surface is not already wet. Bulk air movement has about the same capacity if the air is not already close to saturated. Vapour diffusion is typically a much slower process through the building materials commonly used in walls.

In considering a typical Lower Mainland wall clad in stucco, it is evident that if water penetrates through or behind the cladding, its main way of drying out is via capillary action and evaporation at the outer surface of the stucco. The combination of sheathing paper, membrane and metal flashings, if they are continuous, will restrict drying inwards, and since there are no air passages between the stucco and the sheathing paper drying due to air movement will be minimal. The lack of a cavity will also significantly restrict gravity flow of water between the stucco and the sheathing paper. Furthermore, if there are discontinuities at the sheathing paper then water will flow past the sheathing paper into the sheathing and other wood components.

In the Lower Mainland climate, the outer cladding surface will be wet a substantial part of the time during the winter due to the quantity of rainfall, high air humidity and resulting poor air drying potential. In addition, low permeance coatings placed on the exterior of the stucco will further retard its drying potential. The stucco remains wet, and is in contact with the sheathing paper. If the sheathing paper is building paper, it relies on impregnated chemicals for water repellency. These chemicals are slowly dissolved and expose the paper, an organic material susceptible to loss of structure and rot. Once the paper disintegrates, the outer surface of the sheathing is exposed. Now the stucco can dry fairly easily by transferring its moisture to the sheathing, but as the sheathing is exposed to constant high moisture levels, it begins to swell and rot.

Long term monitoring of drying characteristics for these types of walls in the Lower Mainland climate has not been undertaken to date. However, simplified modeling of these wall systems using computer simulations such as MOIST provide some indication of the sensitivity to drying mechanisms in stucco walls. For example, a MOIST simulation of the OSB in a stucco wall constructed without an acrylic finish coat indicates that the OSB is likely to dry at a low rate for approximately 10 weeks after a single wetting event during the winter months. This time frame could be extended to 15 to 20 weeks with the addition of a low permeance coating. It is clear that very few wetting cycles are required to maintain the wood components of the wall in a wet environment throughout the winter months. It is worth noting that these simulations indicate that the rate of drying for the sheathing in all wall types included in this survey are incapable of accommodating the anticipated wetting events of our climate. This emphasizes the need for prevention of moisture ingress into these wall systems and/or the need to develop assemblies with better drying characteristics.

Typical vinyl cladding (placed directly over sheathing paper without furring strips), is formed to resemble wood siding, and therefore contains an air channel which varies in size (up to 12 mm) between the cladding and the building paper. Thus water that penetrates behind the cladding for whatever reason, has two modes by which it can leave the wall - via gravity drainage down relatively large channels, and via evaporation into the air filling the channels. Thus it takes a much larger volume of water entering the vinyl-clad wall to overwhelm its drying capability.

Wood siding lies somewhere between stucco and vinyl siding in terms of providing opportunity for drying. The air channels are less regular and smaller than with vinyl siding, and the porous nature of wood means that only large amounts of bulk water can drain via gravity, after the wood is soaked.

The above discussion of differences in drying performance between the common cladding assemblies appears to be supported by the problem statistics described in this study.

What can we expect in terms of drying performance from the use of housewrap as the sheathing paper? Most housewraps have much lower vapour diffusion resistance than building paper - 10 to 20 times less. However, vapour diffusion is a slow drying process, so this does not make a lot of difference to the overall drying capacity. Housewrap's main advantage is that it is not organic - it does not rot, lose structure or water repellency with continuous exposure to water. Its disadvantage is that it is a good air barrier and therefore restricts air flow through the wall to a greater extent than building paper; once water gets past the housewrap and into the sheathing and framing cavities, it is even more difficult to dry out. The data on buildings using housewrap, although sparse, does not show substantial performance differences from those using building paper.

How might we expect choice of sheathing to affect drying performance of walls in the Lower Mainland? There is little difference between plywood and OSB in terms of vapour transmission and water absorption. Structurally, they are both affected by long-term water exposure; both will swell and rot, although plywood will generally be less affected than OSB. The data on buildings using plywood sheathing does not show substantial performance differences from those using OSB.

In summary, the data collected in this study, although not explicitly directed at the drying characteristics of walls in the Lower Mainland, reflect what we would expect to find if drying performance is a key variable in determining why some walls perform well while others do not. The study data indicates that the defects that allow water to penetrate into walls are widespread and appear on many wall systems, both performing and non-performing. It is therefore the quantity of wetting at these defects combined with the drying characteristics of the wall assembly that determine whether a wall can accommodate the presence of moisture and thus provide acceptable performance.

3.4 Differences between "Control" and "Problem" Buildings

Many of the obvious differences between the "control" building group and the "problem" building group have already been presented in the preceding discussion. The following summarizes those differences:

- The wind exposure of the "control" buildings is on average lower than that of the "problem" buildings. This indicates that the local environment around many new buildings has some correlation with the problems experienced.

- Roof overhangs are significantly larger on the control buildings than on the problem buildings. Also, the control buildings have many fewer flat roofs with parapets over the exterior walls than the problem buildings.

- In general, there are fewer architectural features and details on the control building walls, and a greater percentage of the details are flashed on the control walls. In comparing Table 3.4 to Table 3.5, the most striking difference is the near-complete lack of exterior walkways on the control buildings and the much smaller percentages of saddle details and exposed columns. Although the frequency of penetrations in the two groups are similar, they are flashed in a much higher percentage of the cases on the control walls.

- The materials making up the wall sections of control walls are less-likely to be the most commonly-used materials of stucco, building paper, and OSB. Stucco cladding is found in 65% of the problem walls and 48% of the control walls. Building paper is used as the weather barrier in 86% of the problem walls and 81% of the control walls. OSB is used for sheathing in 73% of the problem walls and 52% of the control walls.

- The team's evaluations of quality of design, construction, and materials indicates that there are certain details that are often poorly-designed on the control buildings as well as the problem buildings. For example, the majority of saddle details were rated poor design on both groups of buildings; the main reason is that no detail was provided for saddle joints in the plans, so that this troublesome detail was left up to the designer, contractor and their trades people to resolve on-site. The same situation was found with penetrations through the walls; there are typically no details or instructions in the construction documents describing how these are to be flashed, and terminated. The difference between a performing detail and one which causes problems, is often the individual trades person's knowledge and experience of what might work in each situation, the contractor or designer's diligence in requesting and providing clarification during construction, and the sensitivity of the assembly performance to a particular detail.

4. DISCUSSION AND CONCLUSIONS

4.1 General

It should be emphasized that conclusions drawn from this study are not necessarily representative of the general population of buildings constructed in the Lower Mainland over the past ten years. The buildings chosen for the study represent a sample of buildings which experienced envelope performance problems and which had been investigated previously by the study team members. Extrapolating the results to reach similar conclusions regarding the overall population of buildings is not statistically valid. For example, it is not possible to address issues related to what extent water problems exist in the general population based on the results of this study.

Ideally an examination of a moisture related problem for the purposes of this study would include the examination of many issues throughout the design, construction, operation and maintenance phases of a projects life. However, due to the nature of the investigative process, very little information is available to the team to establish why the design evolved the way it did, why the as-constructed details were as they were found during the investigation, or what the maintenance and operations history was. The investigation necessarily focused on symptoms of a problem for which the technical cause could be determined along with the development of an appropriate remedial work strategy. Thus, it is beyond the scope of the current study to examine the question of why the design, construction, operations and maintenance activities were undertaken as they were. This study only links specific aspects of the results of these activities (as-designed or as-constructed assemblies) with the problems observed.

The sample size (193) for problems investigated as part of this study is large enough to reach many well supported conclusions. However, when this sample size is broken down to facilitate comparison of discrete variables, the actual sample size in some cases becomes too small to permit significant conclusions to be drawn. This lack of adequate sample size and its impact on the data analysis is noted in the conclusions where appropriate.

There are some solid well founded conclusions which clearly follow from the analysis of the data. Additional conclusions can be reached which are based on further interpretation or which are inferred from the data. Some of these additional conclusions would benefit from further research, or additional data would be of value in supporting conclusions with greater certainty. We have therefore attempted to differentiate between the conclusions specifically supported by the data, and those conclusions which are inferred by the authors based both on additional interpretation and analysis of the data and the collective expertise of the study team.

Finally, although the current study provides the construction industry with focal points for the development of solutions to envelope performance problems, the study included performance problems on walls of a wide variety of cladding types, wall assemblies, and details. In establishing these focal points it should be acknowledged that all cladding types and wall systems, as well as most of the stakeholders in the construction industry, have opportunities for improvement.

4.2 Specific Conclusions

Several specific themes emerge from the analysis of the data. These conclusions are necessarily interrelated, however, independently they represent opportunities for improvement in performance:

1. Exterior water is the moisture source for by far the majority of the performance problems. Neither construction moisture nor interior moisture sources were found to be significant.

2. The vast majority of the problems (90%) are related to interface details between wall components or at penetrations. Very few problems (10%) can be directly related to the basic assembly of the wall materials in the field areas of the walls. In other words, water enters the wall assembly at details and stays in the wall assembly long enough to initiate rot of wood components. However, while the basic wall assembly in the field of the wall does not appear to be a significant source of moisture ingress, it does contribute to the problem if it restricts drying or drainage characteristics of the wall assembly.

3. Exterior moisture penetration through or around windows is a significant contributor to moisture problems. Water penetrates through the window frame joints and through the

interface details between the windows and adjacent wall assemblies. The current reliance by the industry on the CSA A440 standard as a method of control of installed window quality is not adequate since it does not deal with window perimeter interface details.

4. Exterior moisture penetration at perimeters of decks, balconies and walkways are significant contributors to moisture problems.

5. Exterior moisture penetration at saddle flashings is a significant contributor to moisture problems.

6. The lack of details shown on drawings, and to a lesser extent poor details shown on drawings combine to represent a significant contributor to the poor performance of the as-constructed details.

7. The poor construction of details whether shown on the drawings or not, is a significant contributor to the poor performance of the as-constructed details.

8. All cladding types experienced performance problems although the number of problems reported on stucco walls is substantially more than on other walls and the cost of repairing damage to stucco walls is significantly higher on average.

9. Buildings with roofs overhanging walls perform significantly better.

10. There is insufficient evidence to establish differences in the prevalence of moisture problems in wall assemblies constructed with OSB or plywood.

11. There is insufficient data to establish differences in the prevalence of moisture problems in wall assemblies constructed with housewrap or building paper.

12. In general, buildings with simple details or those which contain fewer of the details which are associated with problems (exterior walkways, saddle connections) performed better.

Our focus on these themes in establishing opportunities for improvement should not be construed to dismiss other potential causal factors as insignificant. Each factor must be considered at some level in the design, construction, operations or maintenance of the building.

4.3 Related Issues and Conclusions

While the study focused on moisture sources and paths, the performance of many of the components, details and assemblies is clearly also very sensitive to the drainage and the drying potential of the wall assemblies. The ability of a wall to perform effectively is a balance of water management principles associated with the control of moisture ingress, drying potential, and drainage. Although not a specific focus of the study, the drainage and drying aspects of this balance warrant further discussion in this report as well as being the subject of additional research effort.

The impact of the Lower Mainland's unique climate needs to be reviewed in the context of these three water management principles. The seasonal winter rainfall is almost 500% higher, and sunshine hours almost 300% lower, than most inland communities in Canada. The Lower Mainland's wind driven rain index is almost 400% higher. These climatic factors combined with the mild temperatures and the reduced time frame for drying of envelope assemblies, place the Lower Mainland in the highest probability area in Canada for wood decay. It is clear that thc ability of wall assemblies to perform must take into account these climatic conditions in establishing effective water management strategies.

A review of the as-designed and as-constructed wall assemblies and details for the buildings in this study suggests that designers and contractors are confused with respect to the basic water management strategies employed in maintaining an effective building enclosure. Wall assemblies in this study, as well as more generally, can be considered to have utilized one of three general strategies to manage water; face seal, concealed barrier (an enhanced face seal), or a rainscreen strategy.

As its name implies, a face seal strategy attempts to eliminate entry paths for exterior moisture at the face of the cladding. In addition, air tightness and drainage is provided at the face of the cladding and therefore drying requirements for the assembly are minimal since it is not intended that moisture be in contact with wood components located behind the cladding. In these systems, the presence of a sheathing paper provides a capillary break to reduce wetting of the sheathing during construction, but it is not intended to provide a drainage plane behind the cladding. Typically flashings have not been incorporated into these systems.

A concealed barrier system attempts to maintain a face seal but also provides a weather barrier (a combination of sheathing paper, membrane and metal flashings) behind the cladding to resist the migration of moisture further into the wall assembly and to direct water to the exterior if and when it does penetrate past the cladding. Drainage provisions are therefore provided through a combination of water shedding at the face of the wall and a minimal amount of drainage at the sheathing paper. There is no intentional cavity between the cladding and the sheathing paper. Without a cavity the beneficial effects of pressure equalization in reducing moisture ingress past the cladding cannot be realized. However, in this assembly the drying requirements are intended to be minimal since the bulk of the water is still intended to be kept out of the assembly at the face of the cladding. The small amount of water which does penetrate the cladding is not intended to penetrate past the sheathing paper. Rather it is intended that this small amount of water drains out of the system or diffuses to the exterior or the interior without causing damage to the wall assembly. The intended air tightness plane in this assembly may be at several locations, the face of the cladding, the combinations of materials which form the weather barrier, or on the interior of the wall assembly utilizing a combination of interior gypsum board, poly and sealants.

A rainscreen assembly utilizes the cladding to keep the majority of the exterior moisture outside of the assembly but does make significantly improved provisions for drying and drainage. The key difference between a rainscreen assembly and a concealed barrier assembly is the presence of a cavity. This cavity provides for free drainage of a larger volume of water. Inherent in these assemblies is greater potential for drying since the presence of a cavity allows for the beneficial effects of air movement into and out of the cavity rather than simply relying on vapour diffusion. Pressure equalization is possible but will depend on the degree and location of compartmentalization, the size of the cavities and the size of the openings to the exterior, and the relative stiffness of the cladding and stud wall assemblies. These characteristics combined with cladding surface drainage features such as flashings control how much water actually penetrates the cladding. Air tightness in this assembly is located at the weather barrier plane, or at the interior of the wall assembly.

The problem walls in this study failed to utilize these strategies effectively. Our review of the design documentation and the as-constructed details indicates that there were inconsistencies in the application of the strategies. For example, in some instances it was not clear whether a face seal or concealed barrier strategy was intended. Flashing would be provided at the base of a wall, but various other aspects of a continuous weather barrier for an effective concealed barrier assembly were not provided. There is therefore a need to clearly establish and communicate a water management strategy throughout the design and construction process.

Regardless of whether a face seal or concealed barrier assembly was intended, the results of the study clearly indicate that sealing of the surface of the cladding was not achieved effectively. In addition, the potential for damage due to excessive collection of moisture within the assemblies was emphasized by the unique climatic conditions in Lower Mainland environment which tend to encourage wetting and limit the drying potential of the assemblies.

None of the walls in the study intentionally utilized a rainscreen wall assembly. Although some cavity is inherent in the vinyl siding, this cavity was formed as a result of trying to simulate the appearance of wood siding. Other aspects of rainscreen wall concepts were not typically included in the problem vinyl wall assemblies, most notably a continuous air tightness plane at the weather barrier or appropriate flashings.

In general therefore, it can be concluded that the face seal systems evaluated in this study are very sensitive to design and construction variables which lead to ingress of water through the cladding, and that in the environment of the Lower Mainland it may not be possible to achieve acceptable performance with face sealed systems. Concealed barrier systems are also very sensitive to water ingress through the exterior cladding and weather barrier. In order for these systems to perform adequately, significant improvement is required in the design and construction of interface details.

Rainscreen systems theoretically provide the best opportunity to achieve acceptable performance due to the more forgiving nature of the assemblies in the application and balance of basic water management principles.

5. RECOMMENDATIONS

The results of this study clearly indicate that there are opportunities in many aspects of the design and construction process which will impact positively on the performance of envelope assemblies. Materials, as well as operations and maintenance activities have not been identified as a focal point for improvement. The recommendations which are discussed below reflect these conclusions. The recommendations range from fairly philosophical in nature, encompassing all aspects of the design and construction process, to those which are quite prescriptive and focus on one facet of the process.

1. Clarity in design strategies utilized in wood frame wall construction must be established. Since there is confusion within the design documents with respect to basic water management principles, the first component of establishing this clarity is for further education of the design community with respect to these principles. The creation of a Best Practices Guide and the continuing education program of the AIBC are important vehicles in this educational process.

2. Details are clearly the focal point of the water ingress sources. Both the design and construction of the details have room for improvement. Once again, the poor quality of these details reflects general confusion with respect to water management principles. Therefore it is likely that once the strategy is clearer, the development and construction of the details will similarly be clearer. However, there are some specific aspects of the design documentation that could be improved to assist in describing the critical details. First, the critical details need to be shown on the drawings, and in some cases three dimensional or isometric drawings will be required to describe the intent. In addition, details should be drawn at a large enough scale to clearly describe the arrangement of materials. Details at 1:2 scale may be necessary in some instances.

3. Guidance to designers in the form of good details needs to be developed for at least the three key problem areas identified in this study; windows, saddle flashings and the perimeter of decks, balconies and walkways. The inclusion of this information in the Best Practice Guide currently being developed by CMHC is an appropriate starting point.

4. The details shown on the architectural drawings usually reflect generic components. Once the project has been tendered and the actual materials and components to be used have been established, the generic details need to be evolved into shop drawings or further working drawings specific to the materials and components to be used on the project. This is particularly relevant to windows and their integration into the wall assembly. The shop drawings must show the actual window extrusions and their interfaces with the adjacent wall assembly for that specific project. This is contrary to the current practice of some window suppliers who are reluctant to get involved in establishing window interface details.

5. The development of systems and details must reflect logical sequencing of trades and materials. Failure to consider these variables or to package and sequence trade responsibilities adequately has resulted in compromises on many of the key problem details during construction.

6. The communication of the design intent to the construction forces is primarily done through the design documents. Certainly through the implementation of the steps outlined above, the contractors' understanding of the intent will improve and thus so will his ability to build effective envelopes. However, there is still a need to utilize other techniques to better communicate the design intent. Full scale on site mock-ups and in some cases testing of the key systems and details will assist in developing an understanding of how these wall systems are intended to function. In addition, sequencing issues can be worked out and quality standards can be established for the remainder of the project. The mock-ups do not need to be costly nor do they need to be done independent of the actual building construction. The systems and details can be built into the building and tested in place in many instances. If acceptable they then become part of the finished building.

7. The quality management process is currently not well defined for envelope construction. What are the roles and responsibilities of the designer, general contractor and the trades contractor in quality assurance? What procedures and records are used to help ensure the successful construction of the envelope? The development of a quality assurance protocol is essential to improving these aspects of the process.

8. There remains a problem at the trade contractor level in the training of personnel. Some of the workers who appear on site are not familiar with the materials and systems they are

working with or the design intent. Various trade associations are attempting to address this issue but a continued emphasis on training must be maintained.

In addition to the above recommendations there are several aspects of the envelope performance problems studied in this project which warrant further investigative work or development, and are independent of the design and construction process. They include the following:

1. The quantity of buildings which are experiencing performance problems is acknowledged to be high. This necessarily means that there is a great deal of envelope restoration and remedial work activity being undertaken. It is evident that in some cases, these remedial work efforts are superficial and do not adequately address the source of the problems on a long term basis. The most striking example of this within the current study is the use of sealants and coatings to attempt to eliminate water penetration. In many instances the application of these products can be shown to either not address the problems at all or in some cases to even make the problems worse by further retarding the drainage or drying potential. There is clearly a need for further research and guidance on effective remedial work strategies to address the envelope performance problems discussed within this study.

2. Reference was made in the previous chapter to the risks associated with face seal and concealed barrier wall systems. If the industry is to move towards an increased use of rainscreen systems utilizing claddings and other materials that traditionally have not been used in this manner, then some supportive development work must be undertaken. This is particularly true with the use of rainscreen stucco walls where the mandated use of these walls systems may create as many problems as it solves.

3. Drying of wall assemblies was identified as a significant factor in this study. However, there is little documentation available on the drying characteristics of these wall assemblies in our unique climate. Further research to better establish the relationship between our climate, various wall assemblies, drying potential and performance would be of value.

4. The A440 window standard is currently utilized to help manufacturers establish some benchmarks for performance of these manufactured components. It does not deal with the installed window unit, and in particular with the window as an integrated component

of the overall wall assembly. Some enhancement of the standard in this regard or the development of some guidance on extending its use for the installed window assembly would be of value.

5. Although maintenance of exterior wall systems was not identified as a key contributing factor to poor wall performance in this study, it is acknowledged that maintenance can have a profound effect on the performance of wall systems (particularly face seal systems) over the long term. The development of some guidance for building owners would be useful in reducing premature envelope failure of envelope systems. Ultimately the inclusion of this guidance as part of the construction documentation handed over to the owner is seen as a reasonable goal.

MORRISON HERSHFIELD

PROFESSIONAL ENGINEER, PROVINCE OF BRITISH COLUMBIA, D. R. RICKETTS

David R. Ricketts, P.Eng.

PROFESSIONAL ENGINEER, PROVINCE OF BRITISH COLUMBIA, J. E. LOVATT

John E. Lovatt, P.Eng.

APPENDIX A

Data Input Form and Guide

GENERAL BUILDING INFORMATION

Building Identification Number ________________

General Information: This information applies to the entire building and is not unique to one wall assembly or performance problem. Fill in blanks or circle appropriate answer from list of choices.

Collecting Agency ____

Evaluating Individual ___________________________ **Date** ________________________

Source of Data: Specific Investigation for this study Historical Info from files

Type of Building: Strata Title Rental Co-op / Social

Date Building Constructed _______________ (Substantial Completion, IAD for Co-ops)

Number of Storeys______________________ **Number of Units** __________________

Cost of: Problem Investigation ________________ **Remedial Repairs** _______________
(All problems) (All problems)

Shielding: Check the appropriate box for each elevation

Elevation	N	E	S	W	Guideline:
Minimal					No obstructions or local shielding (waterfront)
Low					Few small or lower obstructions within 2 bldg. hts.
Moderate					Many large obstructions within 2 bldg. hts.
High					Large buildings immediately adjacent

Original Windows:

Frame Type: Wood
Vinyl
Thermally broken aluminum
Non thermally broken aluminum
Not Known

Frame Joints: Sealed, Good Condition
Sealed, Seal Failure
Unsealed
Not Known

Sealant at Perimeter: (to adjacent cladding) Yes
No
Not Known

Design: Face Sealed
Drained
Rainscreen
Not Known

Placement: Flush
Rebate

Survey of Building Envelope Failures in the Coastal Climate of B.C.

WALL ASSEMBLY DESCRIPTION

Building Identification Number ________________

Wall Assemblies: List wall assembly components starting with 1 at exterior surface
Use one page for each wall type. Use NK for not known, NA for not applicable.
Complete all information. Use Poor, Acceptable, or NK for Quality information
Where "Poor" is chosen, attach short description

Wall Type _______________

Component	Layer	Thickness, mm	Material Quality	Installation Quality
Low permeance paint or stain		NA		
High permeance paint or stain		NA		
Horizontal wood siding				
Vertical wood siding				
Wood sheet				
Vinyl siding				
Horizontal metal siding				
Metal panel		NA		
2 coat Cement stucco and lath				
3 coat Cement stucco and lath				
Acrylic stucco and lath				
Unit Masonry				
Air space				
Perf. polyethylene housewrap		NA		
Polyolefin housewrap		NA		
Asphalt impregnated paper				
Self Adhesive Mod. Bit. Membrane		NA		
Plywood (untreated)				
Plywood (treated)				
Waferboard / OSB				
Exterior grade gypsum board				
Fibre-reinforced gypsum board (Dens - Glas)				
Semi rigid fibreglass sheathing				
Foam sheathing				
89 mm wood frame with fibreglass insul.		89		
89 mm frame without fibreglass insul.		89		
140 mm wood frame with fibreglass insul.		140		
140 mm frame without fibreglass insul.		140		
Polyethylene sheet		NA		
Foil back interior gypsum				
Interior Gypsum				
Other (specify)________________				

Percentage of total wall surface? _____________

Layer which is most air tight (air barrier)? ______ (choose number from list above)

Level of wall air tightness ? ________ (Scale of 1 to 5, see Guide)

Layer farthest in to which water penetration should be acceptable by design? ________
(exterior moisture barrier, choose number from list above)

WALL DETAILS

Building Identification Number ____________________ **Wall Type** ____________________

Detail Description	**Detail Existence**	**Flashing Existence**	**Design Quality**	**Material Quality**	**Installation Quality**
	(Yes, No, NK)		(Poor, Acceptable, NK)		
Flat Roof parapet					
Inverted soffit					
Roof / Wall Junctions					
Saddle (Guardrail, etc.)					
Decks					
Balconies					
Patios					
Exterior Walkways					
Exposed Columns					
Material Transitions					
Horizontal Movement Joints					
Door Sills					
Door Heads					
Window Sills					
Window Heads					

Penetrations	**Existence**	**Seal Existence**	**Design Quality**	**Material Quality**	**Installation Quality**
	(Yes, No, NK)		(Poor, Acceptable, NK)		
Dryer Vents					
Other Vents and Air Inlets					
Guardrail Attachment					
Electrical Fixtures					
Scupper					
Water, Power, Gas Lines					
Other					

	Existence	**Design Quality**	**Material Quality**	**Installation Quality**
		(Poor, Acceptable, NK)		
Eavestroughs and downspouts:				

Roof Overhang: Width? (mm) ____________________

Roof Overhang: Height above top of wall ? (mm) ____________________

Roof Overhang: Height of wall ? (mm) ____________________

Water drainage down wall ?
(Circle all that apply)

None | Sloped Eaves w/o Eavestrough
Downspouts | Roof Scuppers
Balcony Scuppers | Deck/Walkway Scuppers

Survey of Building Envelope Failures in the Coastal Climate of B.C.

SYMPTOM DESCRIPTION

Building Identification Number________________

Performance Problem Information: Use one sheet for each significant performance problem

Performance Problem No. ________________ (new number for each significant, unique problem)

Which wall type? (enter number from types defined)
% of wall type area this problem adversely affects?

Predominant orientation of problem area(s):
(Enter Yes, No, NK, or NA)

N	E	S	W

Predominant Height of problem area(s):
(Enter Yes, No, NK, or NA)

Floor Level	1	2	3	4	Parapet
Rim Joist/Floor Slab					
Wall Section					

Material Deterioration Found

Layer[1]										
Side of Layer Where Damage is Visible[2]										
Symptoms[3]										
Severity[4]										

1. Choose from layer previously defined for this wall type

2. A - Inside
   B - Outside
   C - Both

3. Choose from:
   A Stains, water marks
   B Water saturated (but no rot)
   C Surface mould or mildew
   D Decay or rot
   E Dimensional change
   F Cracking
   G Other ________________

4. A Minor
   B Moderate
   C Severe

Anecdotal Description of Problem
Include general description of cause-effect scenario and append photograph of problem if possible.

____
____
____
____
____
____
____

History of Problem:
How many years after completion did problem start? ____________
How many years after completion was problem first noticed? ____________

Remedial Work:

Status	No Work	Partially Done	Completed	Not Known
Success	Successful	Unsuccessful (Attach note)		Not Known

Percentage of Total Remedial Cost Related to this Problem: ____________

FAILURE MECHANISMS

Building Identification Number_______________ Performance Problem No. __________

EXTERIOR

Source of Exterior Moisture	% Contrib.	Confidence
Direct rain penetration		
Run-off		
Splash back		
Ponding Water		
Snow Melt		
Indirect (through window)		
Other__________		

Path Through Cladding	% Contrib.	Confidence
Failed material:		
Sealant / Caulking		
Cladding		
Other__________		
At penetration:		
Vent hood (Dryer, etc.)		
Guardrail attachment		
Electrical Fixtures		
Scupper		
Water, Power, Gas Lines		
Other__________		
Poor flashing details:		
Flat roof parapet		
Roof / wall connection		
Saddle (Guardrail, etc)		
Deck exterior edge		
Deck-Balcony Base Flashing		
Material Transition		
Window/Door sill		
Window/Door head		
Inherent pores or joints		
Other__________		

Path Thru Ext. Water Barrier	% Contrib.	Confidence
No exterior water barrier		
Discontinuities		
Material degradation		
No or reversed lap		
At flashing		
At penetration		
Other__________		

INTERIOR

Source of Interior Moisture	% Contrib.	Confidence
None identified		
Wet Basement		
Open sump		
Interior clothes drying		
Abnormal occupancy uses		
Vents leaking into wall		
Other__________		

Wall Condensing Surface	Layer No.
Primary	
Secondary	

Window Condensation	Y or N
Glass	
Frames	

CONSTRUCTION

Source of Construction Moisture	% Contrib.	Confidence
Wet materials used		
Exposure to weather		
Installation uses water		
Other__________		

CAUSE OF MOISTURE PROBLEM

	Practise	Contributed to Problem	
Design	Acceptable Poor Not Designed	Yes	No
Construction	Acceptable Poor	Yes	No
Maintenance	Acceptable Poor Not Maintainable	Yes	No
Operation	Acceptable Poor	Yes	No

Background

The survey will collect information on building envelope failures in wood-frame residential buildings in the coastal climate of B.C. ("problem" buildings). It will also collect information on buildings in which we are currently unaware of any problems ("successful" buildings).

Buildings meeting the following criteria are eligible for the study:

- Completed after 1984
- Wood frame residential occupancy
- Non-EIFS cladding
- Located within 30 km. of the coast in the Lower Mainland and Vancouver Island.
- For "problem" buildings, must have suffered one or more moisture-related problems affecting exterior walls, exposed balconies, walkways, decks.
- For "successful" buildings, completed before 1991.
- A "Wish List" of combinations of cladding, sheathing, and moisture barrier materials has been established. The three types of cladding are stucco, wood siding, and vinyl siding. The two types of sheathing are OSB and plywood, and the two types of moisture barrier are building paper and housewrap. The study calls for five times as many stucco-clad "problem" buildings as each of the other siding types, and one example of a "successful" building for each combination of cladding, sheathing and moisture barrier.

Information to be Collected

The information to be collected on these buildings can be categorized into four general areas: General Building Information, Wall Construction Details, Symptom Description, and Failure Mechanisms.

For "successful" buildings, only the "General Building Information" and the "Wall Construction Details" are necessary.

In general, the survey form can be completed by filling in the blanks or circling the appropriate choice from a menu of choices. NK stands for "Not Known" and is recognized as a valid answer in most of the "fill-in-the-blank" questions. On our first pass through the input form, where information cannot be found in existing files or by a quick telephone call, use the NK designation. We will then review the status of the data collected and decide on where further information needs to be collected and how to do it. NA stands for Not Applicable and is a valid answer for some questions, as noted on the form and/or in the Guide. In the "Symptom Description" worksheet, space is provided for a brief written description of the problem and its causes; photographs showing the problem are requested if at all possible. In the Wall Construction Details worksheets, an evaluation of the quality of the construction is called for. Where a material or detail is entered as "poor" quality, a short description of the nature of the defect is to be attached to the sheet. On the final worksheet "Failure Mechanisms", the "Cause of Moisture Problem" box classifies the design, construction, maintenance, and operation of the building and whether they contributed to the problem noted. Where any of these are classified as "poor", a short note detailing the reasons for that classification shall be attached.

"General Building Information" is entered on the first worksheet. There will be only one of these worksheets for each building. The building identification number consists of two letters and two digits. It is entered at the top of all the worksheets of the form. The two letters are the first two letters of the collecting agency, as follows:

- Constructive Building Solutions - CB
- Morrison Hershfield - MH
- New Home Warranty Program NH
- Sheltair Scientific SS

The two digits can be assigned by the collecting agency as long as they are unique for each building. Once they are assigned, all wall types and all performance problems relating to that building will contain the building identification number.

We have not asked for information relating to the identification of the building, such as its name, address, title, or property manager in the survey form. This information will be collected by Morrison Hershfield directly from each agency and stored separately in order to protect confidentiality. Where available, the exact date of substantial completion, first occupancy, or Interest Adjustment Date (IAD) should be given; this provides some idea of the season during which wall construction took place.

The overall cost of the problem(s) experienced in a building is expected to be a key factor in judging the importance of problem classes. In "successful" buildings, this cost should be low, less than $10,000. Where a building has suffered a number of problcms, perhaps at different times, the overall cost of investigating and repairing all of them should be included here. In many cases, the repairs will not have been completed, and the overall cost of repairs will require estimation. We would like to be $\pm$100% on these cost figures; if your confidence is less than that, enter NK here.

Wind Shielding information: Select the elevations of the building closest to the compass points. Observe the surrounding landscape in that direction. Check the box which most closely describes the landscape for that compass point. Check one box for each of the four compass points.

In general the same type of windows is used on the entire building. Information on windows is entered by circling the appropriate choice. Information should relate to the original windows only. The following definitions are provided:

- Frame Joints: many investigators feel that window systems which allow water into exterior walls through mitered frame joints which are unsealed are a common contributor to problems. Where frame joints are sealed, the seal can often be damaged or lose adhesion and allow leakage after a short time - this is indicated by the "Sealed, seal failure" choice.
- Design: Most residential windows rely on the exterior seal to prevent water penetration, and do not provide a means for water getting behind the seal to drain back out. These are "face seal". Windows which provide drain slots beneath the glass and an exterior drainage track, but do not have an interior air seal, are "drained" design. Windows which provide exterior drainage for the glazing cavity, and an interior air seal, are "Rainscreen" design.
- Sealant at Perimeter: Are the exterior edges of the frame connected to the cladding by a sealant joint ? Sometimes stucco is brought up to the edge of the window frame with no flexible connection - this counts as a "No".
- Placement: Windows where the exterior plane of the glass is within 25 mm of the plane of the cladding count as "Flush"; those with glass further into the wall count as "Rebate"

WALL ASSEMBLY DESCRIPTION Worksheet

The next worksheet is titled Wall Assembly Description and Wall Details. Most buildings will have one wall section, but some may have more than one, varying in exterior cladding, thickness of framing, or other significant details. Where significant wall area of completely exposed wall occurs, such as walkway exterior walls and patio/deck separator walls, they should be included as a separate wall type. It is useful to list the different wall types that occur on a complex building before starting this worksheet. This worksheet should be completed for each wall type on the building. Wall type numbers are assigned as the building ID number followed by two digits assigned in numerical order.

Looking at a section of the wall assembly, number the layers of the wall starting with 1 at the exterior. Looking down the column of layer descriptions, find the description that matches each layer in the section, and place the layer number in the layer column. If applicable, input the thickness of that layer in millimetres. Based on the investigation undertaken, judge the material quality and the installation quality as Poor, Acceptable (ACC), or NK. For example building paper installed without proper laps would be Poor installation quality. Knotty wood siding would be Poor material quality. Wherever quality is judged "Poor", a note describing the specific faults found should be attached in numerical order. In some wall systems, unusual layers will be found which aren't in the list, they should be described under the "Other" space.

Note that in the layers described, "3-coat cement stucco and lath" includes systems where the third (finish) coat is a proprietary coloured or acrylic-enhanced material. Acrylic stucco and lath is a premixed system containing acrylic.

If the grade of building paper is known, it can be entered as "Conv" or "Heavy" in the Thickness column.

The percentage of total wall surface is the wall area of this wall type divided by the total wall area of the building (including windows and doors).

The layer which is most airtight is the one which has the smallest area of leaks in it, not necessarily what is marked as the air barrier in the plans. This will generally be a judgement call based on the investigation; massive rips and tears in polyethylene vapour barriers often mean that the sheathing or the interior drywall is actually the air barrier. Similarily the level of wall airtightness is a judgement; the higher the number the more airtight the air barrier layer is. In general a standard non-stucco building where the interior drywall was the air barrier would be rated a 2, while a standard stucco building would be rated a 4. A building where the housewrap has been very carefully installed and taped might rate a 5.

The layer farthest in to which water penetration should be acceptable by design is the building paper or housewrap in typical wall sections. Some systems are face-seal, and the design exterior moisture barrier is the outside layer for these.

WALL DETAILS Worksheet

The Wall Details worksheet goes with the Wall Assembly Description. In this sheet we are looking for information on details of the exterior facades. The columns of the table ask whether this wall type has any of the details described, whether they are flashed or sealed, and a judgement of what the quality of the details are in terms of design, material, and installation. We need this information to determine how often these details result in problems and what aspects of their construction are responsible. The following definitions are provided for the details:

Details

Flat Roof Parapet: where the wall or some part of it is located below a flat roof, the parapet flashing is intended to prevent water from entering the top of the wall.

Inverted Soffit: Most soffits (the area on the underside of a roof, deck, or livingspace overhang) are horizontal or slope away from the top of the adjacent wall. On some buildings, the soffit slopes towards the top of the adjacent wall, and water in or on the soffit drains to the top of the wall - this is an inverted soffit.

Roof/Wall Junctions: Where part of the wall is located above a flat or sloped roof below, the roof/wall flashing is intended to keep water on the roof and to deflect water within the wall out onto the roof.

Saddle: Where a solid guardrail or a roof parapet connects to a wall, the saddle flashing prevents water from entering the wall.

Decks: private or semi-private outside areas over occupied living space. The surface must provide watertightness and stand up to moderate traffic. The base flashing protects the bottom of the wall above from water ponding on the deck; the edge flashing (if it exists, in lieu of built-in drains or scuppers) directs water draining off the deck away from the wall surface below.

Balconies: private outside areas which are not over living space, but connect to living space on the same level. They also need base flashings and some system for directing rainfall away from the walls.

Patios are essentially ground-floor balconies.

Exterior Walkways: These are exposed areas of the building used to provide access to the suites. They may or may not be over living space, but are bounded by living space on one side. They are generally covered, but are open to the elements along one side.

Exposed Columns: Columns supporting exterior framing for balconies or walkways, or canopies over entrances. All sides of the column are exposed to outside.

Material Transitions: Where some element of the wall system changes, for example cladding changes from brick to stucco, or at the foundation wall/cladding joint, a flashing directs water out from behind the upper material to the exterior of the lower material.

Horizontal Movement Joints: This includes control joints and expansion joints. Control joints in stucco are often made from V-shaped sheet metal channels; they are often thought to be cracks and are caulked. Expansion joints allow independent movement of the two sides of the joint through a flexible seal.

Penetrations

The main questions we want to address with penetrations are "Does the design, material, or installation of the penetration itself contribute to water leakage into the wall or better drying of the wall ?" and "Does the seal between the penetration and the cladding allow water to penetrate or air to circulate within the wall ?"

Dryer Vents: These are in a separate class because of their tendency to plug up with lint, resulting in warm moist air leaking into the wall cavity.

Other Vents and Air Inlets: Includes kitchen, bathroom, fireplace, and crawlspace vents and inlets for combustion supply.

Guardrail attachment: Where guardrails are anchored into structural members at deck or wall level.

Electrical fixtures: Lamps and exterior outlet boxes let into the cladding.

Scupper: Drainage for a flat roof, deck, or balcony is led through a pipe or opening which penetrates the wall and empties to the outside of the wall surface.

Water, Power, Gas Lines: This would include the named services, plus telephone, cable, aerial leads, etc.

The next five items are concerned with exposure of the wall to driving rain and runoff from roofs above.

Eavestroughs and Downspouts: Here we find out if the roof drainage is controlled and directed safely away from the wall, or cascades off the edges of the eaves or through scuppers. The condition of the eavestroughs and downspouts is also important as they are high-maintenance items.

Roof Overhang Width: how far the roof extends outside of the plane of the wall, in mm. Many people believe that minimal overhang contributes to high wall exposure to rain during periods of low wind; some zoning bylaws provide incentive for developers to minimize overhangs.

Roof Overhang Height above top of wall: In most cases the wall we are describing extends to the roof line, and the overhang height above the wall top is zero. Where a wall type does not extend to the roofline, this height will not be zero.

Roof Overhang Height of Wall: The effect of a roof overhang in protecting a wall from driving rain decreases the farther away from the overhang. The lower part of a wall 10 m. high is unprotected by most overhangs of the roof above.

Water Drainage Down Wall: Select all the sources of water draining on or near the plane of the wall.

SYMPTOM DESCRIPTION Worksheet

In this worksheet, we describe what the symptoms of the moisture problem are. This sheet combines with the FAILURE MECHANISMS worksheet to describe one specific performance problem, and the chain of events causing it, encountered on the building. There may be more than one performance problem encountered on the building or even on one wall type, in which case we complete one worksheet to describe each performance problem. The Performance Problem Number is made up of the Building ID Number followed by two letters (user selected) to identify each unique problem. If similar performance problems occur on more than one wall type on a given building, they must