RESEARCH REPORT

Development of High Performance Stucco for Durable Housing Construction - A Pilot Study

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Client Report

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Development of High Performance Stucco for Durable Housing construction – A Pilot Study

for

Canada Mortgage and Housing Corporation
700 Montreal Road
Ottawa, ON
K1A 0P7

29 June 2006

Development of High Performance Stucco for Durable Housing Construction – A Pilot Study

Final Report

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Development of High Performance Stucco for Durable Housing Construction – A Pilot Study

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Acknowledgement

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High-performance Stucco for Housing

INTRODUCTION

Stucco or Portland cement plaster is widely used as an exterior cladding material in Canada. In some regions, particularly those with heavy rainfall, there have been moisture-related problems in wall systems clad with stucco.

Studies show that stucco cladding with low liquid diffusivity and higher water-vapour permeability can positively influence the overall moisture management capacity of wood-frame stucco walls. For this reason, Canada Mortgage and Housing Corporation, in cooperation with the National Research Council's Institute for Research in Construction, conducted research to improve the performance of stucco cladding by modifying existing stucco design mixes and testing new materials.

OBJECTIVES

This research investigated several high-performance stucco materials. For the study, high-performance stucco was defined as stucco that limits water entry on its exterior surface (liquid diffusivity) and, at the same time, allows water vapour (water-vapour permeability) to move through the stucco assembly and escape to the exterior.

The research considered stucco as an isolated material component of the exterior wall system—the project did not investigate system performance of the wall assembly with stucco as a cladding. The effects of imperfections, defects and anomalies typically found in exterior wall systems were beyond the scope of this investigation.

Computer-based simulation demonstrated that the combined wetting and drying potential of wood-frame stucco walls is significantly influenced by liquid diffusivity and the water-vapour permeability of the stucco material.

Liquid diffusivity defines the rate of movement of water within a material, induced by a water concentration gradient. A material that allows liquid-water diffusion through its boundary surface would change its weight with time when it is brought in contact with liquid water. For this study, the water-absorption coefficient was taken as a measurement of liquid diffusivity or rate of movement of water within a material (in accordance with the ISO Standard ISO 15148:2002).

Water-vapour permeability is the rate of water-vapour transmission per unit area per unit of vapour-pressure differential under specified test conditions.

RESEARCH

There were two phases to the experimental work. Phase I established the basic moisture-transport properties, water-vapour permeabilities and water-absorption coefficients of four stucco materials currently used in Canada (the base-case stuccos), including one mix based on the requirements of the National Building Code of Canada (NBCC).

In Phase II, researchers tested four, trial high-performance stucco materials having lower water-absorption coefficients but higher water-vapour permeabilities than the base-case stucco materials tested in Phase I.

Three stucco samples were cast for each type of stucco mix in a 380 mm by 380 mm (14.9 in. x 14.9 in.) (internal dimension) wood frame. The thickness of each stucco sample after curing was approximately 21 mm (0.8 in.) (See Figure 1.). Metal lath was placed within the scratch coat. No sheathing membrane was placed between the metal lath and the bottom plate of the wood frame. The stucco mixes were prepared in conformance with manufacturers' instructions or in conformance with the NBCC stucco mix design.

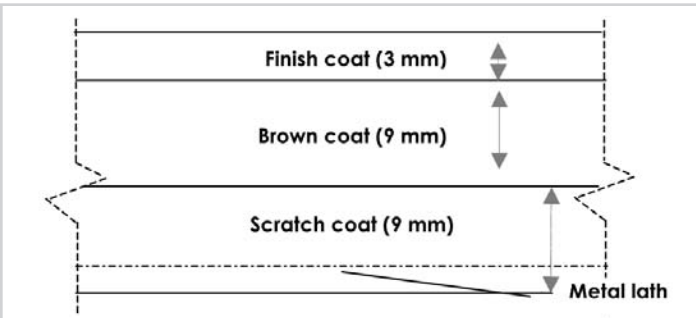

Figure 1 Typical composition of test samples

PHASE I—BASE-CASE STUCCOS

Four base-case stucco mixes were investigated:

1. N1—Commercial stucco I
2. N2—Commercial stucco II
3. N3—Commercial stucco III
4. N4—NBCC stucco

N1, N2 and N3 were representative commercial stucco mixes from different regions of Canada. N4 was a stucco mix meeting the requirements of NBCC Article 9.28.5.

PHASE II—STUCCOS MODIFIED FOR HIGH PERFORMANCE

Four different options were investigated:

1. M1—Using hydrophobic coating on exterior surface
2. M2—Using hydrophobic aggregate
3. M3—Using aggregates coated with hydrophobic chemical
4. M4—Using zinc stearate as an admixture

M1—Hydrophobic coating on exterior surface

Hydrophobic (water repelling) materials have low affinity to liquid water. Trial mix M1 was made by applying the hydrophobic chemical triethoxy-n-octylsilane directly on the exterior face of the base case stucco N4. Two coatings were applied 24 hours apart and the samples were allowed to dry for at least seven days before conducting the water-vapour permeability and water-absorption tests.

M2—Use of hydrophobic aggregate

Hydrophobic aggregates allow free, convective air movement through their pores but repel liquid water coming in contact with them. It was speculated that the presence of such aggregates in a stucco mix would reduce the water-absorption capacity of the stucco material without reducing its ability to transport air and water vapour across it.

M2 was comprised of high PH hydrophobic aggregate obtained from SilCoat Ltd. Five mix designs with different proportions of hydrophobic aggregate were tested, each cast in one coat and having a thickness of approximately 13 mm (0.5 in.).

M3—Use of aggregates coated with hydrophobic chemical

For trial mix M3, the graded, dry, natural sand (the same used for N4—NBCC stucco) was soaked in a hydrophobic liquid, octyltriethoxysilane and then dried before being incorporated into the stucco mix.

M4—Zinc Stearate as hydrophobic admixture

Zinc stearate is a zinc soap that repels water. It has already been demonstrated to decrease liquid water transport and water-vapour sorption capacity in plaster. For mix M4, zinc stearate was used as an admixture to the N4 base-case mix design.

FINDINGS

Figures 2 and 3 summarize the overall experimental results obtained from this project.

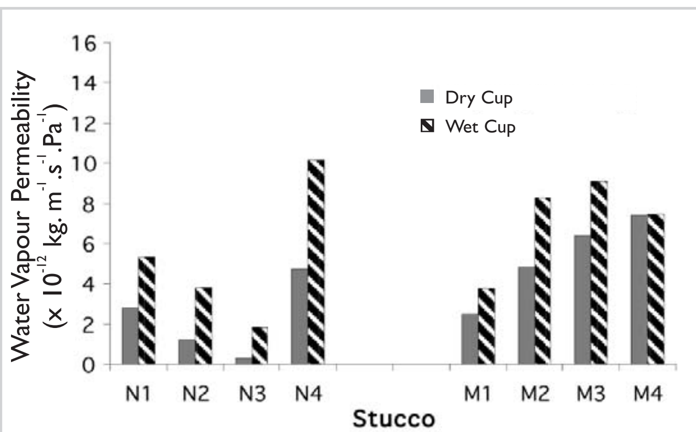

Figure 2 Water-vapour permeability of base case (N1, N2, N3, N4) and modified stucco materials (M1, M2, M3, M4)

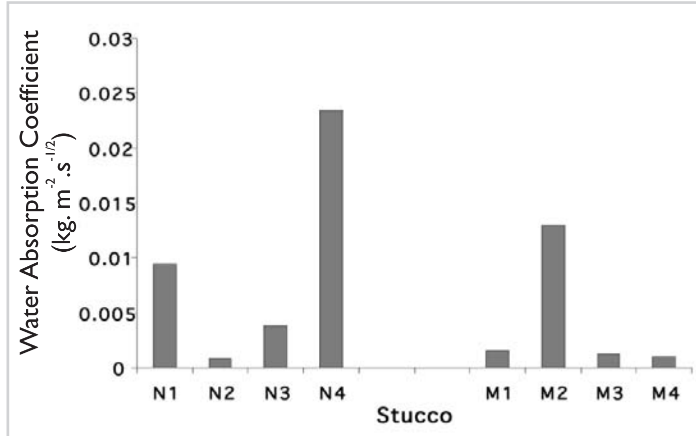

Figure 3 Water absorption cœfficient of base case (N1, N2, N3, N4) and modified stucco materials (M1, M2, M3, M4)

In assessing the results, it is important to remember that high-performance stuccos need to both:

a) limit water entry from the exterior, and

b) allow trapped moisture to escape to the exterior.

The M1 trial mix (hydrophobic coating) reduced the water absorption but also resulted in low moisture permeability. M2, the stucco mix containing the hydrophobic aggregate, had the highest water-absorption cœfficient.

M3, the trial stucco using aggregates coated with hydrophobic chemical, and M4, the mix using zinc stearate as an admixture, showed promising results. Both had relatively low water-absorption coefficients combined with high water-vapour permeability compared to the base stucco materials used in Canada.

CONCLUSIONS

This research showed it is possible, through appropriate mix design, to reduce the water-absorption coefficient of the stucco material without reducing water-vapour permeability.

The use of aggregates coated with hydrophobic chemical (trial mix M3) and the use of zinc stearate as an admixture (trial mix M4) gave promising results. They demonstrated the ability to lower liquid-water absorption capacity and have normal or higher water-vapour transmission capacity compared to stucco materials currently used in Canada.

This pilot study using small-scale specimens showed positive results. The next step in improving the performance of stucco will be testing the overall hygrothermal behaviour of the modified stucco materials on full-scale wall systems.

CMHC Project Manager: Silvio Plescia, Senior Researcher, Housing Technology Group

Consultant: Institute for Research in Construction, National Research Council

Research report: *Development of High Performance Stucco for Durable Housing Construction—A Pilot Study*

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Mars 2007 Série technique 07-104

Stucco haute performance pour les habitations

INTRODUCTION

Au Canada, le stucco ou le plâtre de ciment Portland s'emploie couramment comme matériau de parement extérieur. Certaines régions, particulièrement celles qui ont de fortes précipitations de pluie, ont été touchées par des problèmes d'humidité dans les murs revêtus de stucco.

Des études ont montré qu'un parement en stucco présentant une faible diffusivité des liquides et une imperméabilité à la vapeur d'eau élevée peut influer favorablement sur la capacité globale de gestion de l'humidité des murs à ossature de bois dotés d'un parement en stucco. C'est pour cette raison que la Société canadienne d'hypothèques et de logement, en collaboration avec l'Institut de recherche en construction du Conseil national de recherches du Canada, a fait mener des recherches visant à améliorer la performance des parements en stucco en modifiant la formulation des mélanges actuels et en mettant à l'essai de nouveaux matériaux.

OBJECTIFS

L'étude avait pour objectif d'examiner plusieurs matériaux haute performance pour le stucco. Pour les besoins de la recherche, on a défini le stucco haute performance comme un stucco qui limite la pénétration de l'eau sur sa paroi extérieure (diffusivité des liquides) tout en permettant à la vapeur d'eau (perméabilité à la vapeur d'eau) de se déplacer à travers le stucco pour s'échapper à l'extérieur.

Dans le cadre de cette recherche, le stucco a été mis à l'essai à titre de composant indépendant d'un système mural. Les travaux n'ont pas examiné la performance d'un système mural revêtu de stucco. L'analyse des répercussions découlant d'imperfections, de défauts et autres défectuosités que l'on trouve habituellement dans des murs extérieurs n'était pas comprise dans la portée de l'étude.

Des simulations informatisées ont révélé que la capacité de mouillage et d'assèchement des murs à ossature de bois revêtus de stucco variait considérablement selon les caractéristiques de diffusivité des liquides et de perméabilité à la vapeur d'eau du stucco.

La diffusivité des liquides s'entend de la vitesse de déplacement d'un liquide dans un matériau, sous l'effet d'un gradient de teneur en humidité. Un matériau qui permet à l'eau de se diffuser à travers sa paroi extérieure verrait son poids se modifier au fil du temps lorsqu'il est mis en présence d'eau. Pour les besoins de l'étude dont il est question ici, le coefficient d'absorption d'eau a été pris comme une mesure de la diffusivité liquide ou de la vitesse de déplacement de l'eau dans un matériau (aux termes de la norme ISO 15148:2002 de l'ISO).

La perméabilité à la vapeur d'eau est une mesure de la transmission de la vapeur d'eau par unité de surface par unité de différence de température, sous des conditions d'essai normalisées.

RECHERCHE

Les travaux se sont déroulés en deux étapes. Lors de l'étape 1, on a établi les propriétés fondamentales de transport de l'humidité, la perméabilité à la vapeur d'eau et le coefficient d'absorption d'eau de quatre stuccos employés couramment au Canada (les stuccos de référence), y compris un mélange répondant aux exigences du Code national du bâtiment du Canada (CNBC).

Au cours de l'étape 2, les chercheurs ont mis à l'essai quatre stuccos haute performance présentant un coefficient d'absorption d'eau plus faible et une plus grande perméabilité à la vapeur d'eau que les mélanges de stucco de référence mis à l'essai dans l'étape 1.

Trois échantillons par type de stucco ont été préparés et mis en place dans un cadre en bois de 380 sur 380 mm (14,9 sur 14,9 po) (dimensions internes). Les échantillons après mûrissement avaient une épaisseur d'environ 21 mm (0,8 po) (*voir* la figure 1). La couche d'accrochage a été appliquée sur un lattis métallique. Aucune membrane de revêtement n'a été placée entre le lattis métallique et l'élément inférieur du cadre en bois. Les stuccos ont été gâchés en conformité avec les instructions du fabricant ou en conformité avec les indications du CNBC.

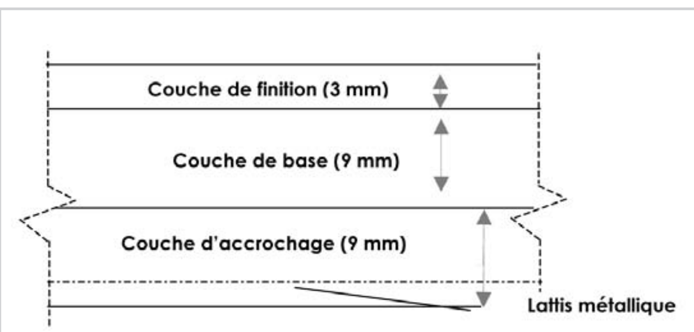

Figure 1 Composition type des échantillons d'essai

ÉTAPE 1 — STUCCOS DE RÉFÉRENCE

Quatre stuccos de référence ont été étudiés :

1. N1 — Stucco commercial I
2. N2 — Stucco commercial II
3. N3 — Stucco commercial III
4. N4 — Stucco conforme au CNBC

Les stuccos N1, N2 et N3 sont représentatifs de mélanges disponibles dans le commerce dans différentes régions du Canada. Le mélange N4 répond aux exigences de l'article 9.28.5. du CNBC.

ÉTAPE II — STUCCOS MODIFIÉS HAUTE PERFORMANCE

Quatre stuccos différents ont fait l'objet d'essais :

1. M1 — Enduit hydrophobe sur la paroi extérieure
2. M2 — Granulats hydrophobes
3. M3 — Granulats enrobés d'une substance chimique hydrophobe
4. M4 — Adjuvant au stéarate de zinc

M1 — Enduit hydrophobe sur la paroi extérieure

Les matériaux hydrophobes (qui repoussent l'eau) affichent une faible affinité pour l'eau. Le stucco d'essai M1 a été produit par l'application d'un enduit de triéthoxy-n-octysilane directement sur la paroi extérieure du stucco de référence N4. Deux couches ont été appliquées à 24 heures d'intervalle, et les échantillons ont été asséchés pendant au moins 7 jours avant d'effectuer les essais de perméabilité à la vapeur d'eau et d'absorption d'eau.

M2 — Granulats hydrophobes

L'utilisation de granulats hydrophobes permet à l'air de se déplacer par convection dans les pores du matériau, tout en repoussant l'eau qui vient en contact avec le stucco. On a posé comme hypothèse que la présence de tels granulats dans un mélange à stucco réduirait la capacité d'absorption d'eau du stucco, sans réduire la possibilité pour l'air et la vapeur d'eau de s'y déplacer.

Le stucco M2 était composé de granulats hydrophobes à pH élevé provenant de SilCoat Ltd. Cinq formulations composées de proportions variées de granulats hydrophobes ont été mises à l'essai, chacune d'elles étant mise en place en une seule couche d'environ 13 mm (1⁄2 po) d'épaisseur.

M3 — Granulats enrobés d'une substance chimique hydrophobe

Dans le cas du mélange d'essai M3, on a fait tremper un sable naturel, sec et calibré (le même que pour le N4 — stucco CNBC) dans un liquide hydrophobe, un composé d'octyltriéthoxysilane, puis on l'a asséché avant de l'incorporer au mélange.

M4 — Adjuvant au stéarate de zinc

Le stéarate de zinc est un savon qui repousse l'eau. Il a déjà fait la preuve dans le cas du plâtre qu'il diminue le transport de l'eau et la capacité d'absorption de vapeur d'eau. Pour le stucco M4, un adjuvant de stéarate de zinc a été ajouté au mélange de référence N4.

CONSTATATIONS

Les figures 2 et 3 présentent les résultats expérimentaux globaux obtenus.

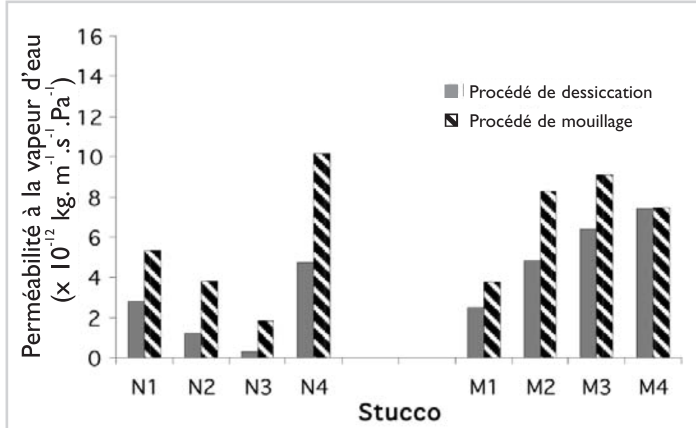

Figure 2 Perméabilité à la vapeur d'eau des stuccos de référence (N1, N2, N3 et N4) et des stuccos modifiés (M1, M2, M3 et M4)

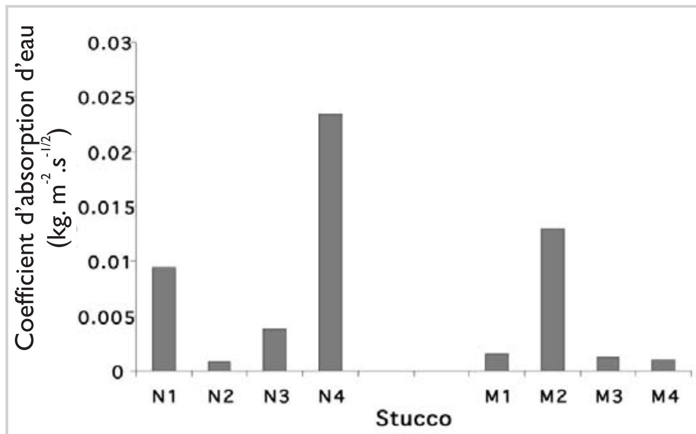

Figure 3 Cœfficient d'absorption d'eau des stuccos de référence (N1, N2, N3 et N4) et des stuccos modifiés (M1, M2, M3 et M4)

Dans le cadre de l'évaluation des résultats, il importe de se rappeler que les stuccos haute performance doivent :

a) limiter la pénétration de l'eau depuis l'extérieur et

b) permettre à l'humidité emprisonnée de s'échapper vers l'extérieur.

Le stucco d'essai M1 (enduit hydrophobe) présentait une absorption d'eau réduite, mais également une faible perméabilité à la vapeur d'eau. Le mélange M2, qui contenait les granulats hydrophobes, a affiché le plus important cœfficient d'absorption d'eau.

Le stucco d'essai M3, formulé à l'aide de granulats enduits d'une substance chimique hydrophobe, et le mélange M4, formulé à l'aide d'un adjuvant de stéarate de zinc, ont donné des résultats prometteurs. Les deux présentent un coefficient d'absorption d'eau relativement faible, jumelé à une valeur élevée de perméabilité à la vapeur d'eau, comparativement aux stuccos de référence employés au Canada.

CONCLUSIONS

Cette recherche révèle qu'il est possible, à l'aide de mélanges appropriés, de réduire le coefficient d'absorption d'eau du stucco, sans pour autant diminuer sa perméabilité à la vapeur d'eau.

L'utilisation de granulats enduits d'une substance chimique hydrophobe (mélange d'essai M3) et le recours à un adjuvant de stéarate de zinc (mélange d'essai M4) ont donné des résultats prometteurs. Ces formulations ont montré qu'il était possible de diminuer le taux d'absorption d'eau tout en affichant un taux de transmission de la vapeur d'eau inchangé ou plus élevé, comparativement aux stuccos employés couramment au Canada.

Cette étude pilote, réalisée à l'aide d'échantillons de faible dimension, a donné des résultats favorables. La prochaine étape visant à améliorer la performance des stuccos consistera à évaluer le comportement hygrothermique global des stuccos modifiés en modèle vraie grandeur.

Directeur de projet à la SCHL : Silvio Plescia, recherchiste principal, Groupe de la technologie du bâtiment

Consultants pour le projet de recherche : Institut de recherche en construction, Conseil national de recherches du Canada

Rapport : *Mise au point d'un stucco haute performance pour habitations durables*

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1.0 Introduction

Moisture management in the building envelope plays an important role determining long-term durability and serviceability of Canadian houses. Improper or inadequate moisture management has caused severe damages in the Canadian houses. In many cases, building materials may not be able to compensate for deficiencies in the wall design and construction. Service life, as a result of these deficiencies, is shortened in the areas of heavy and sustained rainfall. In such a situation, it is important to develop a proper understanding of the mechanisms of moisture transport into and out of the building envelope, address the deficiencies, incorporate design features that will reduce moisture loading on the wall, and consider the modification of the hygrothermal properties of the building materials. In the latter case, such modifications of the hygrothermal properties of the building material can be engineered through innovative manufacturing technique and the material evolved through the process can lead to better moisture management in the building envelope.

2.0 Research Significance

Stucco or portland cement plaster, as exterior cladding material, is widely used in the Canadian Housing Industry. On many occasions (e.g. Vancouver, BC; Calgary, Edmonton, AB) wood frame stucco walls have experienced moisture related problems. This phenomenon is particularly accelerated in locations with heavy and sustained rainfall. This has subsequently led to serious long-term performance problems. The financial implications of this problem on the housing industry are enormous by any standard (*Barrett 1998*). Several researchers and technical experts have tried to assess the causes and thereafter determine the ways to solve or limit the moisture management problem in stucco walls. However, solutions to these types of problems are not always easy to find.

Nevertheless recent computer based simulation studies at the Institute for Research in Construction (IRC) of the National Research Council (NRC) Canada have demonstrated that the combined wetting and drying potential of the wood frame stucco wall is significantly influenced by the water vapour permeability and liquid diffusivity of the stucco material. A lower liquid diffusivity and higher water vapour permeability of the stucco material can positively influence the overall moisture management capacity of the wood frame stucco wall (*Mukhopadhyaya et al. 2003*). Also, another study at the IRC/NRC showed that among all the major components (stucco, sheathing membrane, sheathing board and vapour barrier) stucco has the most significant variation in the material properties that influence the overall moisture response of the ideal (i.e. without deficiency) stucco walls without rain-screen exposed to Western Canada coastal climate (*Mukhopadhyaya et al. 2002a*). This study also indicated that the combination of maximum water vapour permeability and minimum liquid diffusivity would be very desirable characteristics for exterior stucco cladding. Hence, water vapour permeability and liquid diffusivity are the two most important properties for the stucco that need to be considered carefully to obtain optimum moisture management in the wall assembly.

3.0 Objective

This research project focuses on the possibility of engineering a portland cement stucco material that will limit liquid water entry on its exterior surface and at the same time allow water vapour to dry out of it. This research considers stucco as an isolated material component of the exterior wall system. This project does not investigate system performance of the wall assembly with stucco as a cladding. The effects of imperfections, defects and anomalies typically found in exterior wall systems are beyond the scope of this investigation.

Hence, the primary objective of this project is to engineer a stucco mix design that has the effect of lowering the liquid diffusivity and increasing the water vapour permeability characteristics of the stucco material. The performance of the engineered stucco material will be compared with the commonly used stucco materials in Canada.

4.0 Background Fundamentals

For this project it is very important to understand the basics of water vapour permeability and liquid diffusivity. These two moisture transport properties are described in the following paragraphs.

4.1 Water vapour permeability

The water vapour permeability of any building material can be defined as the rate of water vapour transmission per unit area per unit of vapour pressure differential under specified test conditions. The vapour diffusion equation is directly used to determine the water vapour permeability of building materials (*Joy and Wilson, 1963*). The measurements are usually done under isothermal conditions. A test specimen of known area and thickness separates two environments that differ in relative humidity (RH) and vapour pressure (Figure 1). The rate of vapour flow across the specimen, under steady-state conditions (known RH's as constant boundary conditions), is then gravimetrically determined. From these data the water vapour permeability of the material is calculated as:

$$\delta_p = J_v \cdot l/(A \cdot \Delta p) \qquad (1)$$

Where,

J_v = Water vapour flow rate across an area A

l = Thickness of the specimen

Δp = Difference in water vapour pressure across the specimen surfaces

Often, especially for membranes and composite materials, one calculates the water vapour permeance, δ_l , of a product at a given thickness from the above measurements as:

$$\delta_l = J_v/(A \cdot \Delta p) \qquad (2)$$

ASTM Standard E96, Test Methods for Water Vapour Transmission of Materials, prescribes two specific cases of this procedure- a dry cup method that gives the permeance or permeability at a mean RH of 25 % and a wet cup method that gives the permeance or permeability at a mean RH of 75 %. For many hygroscopic materials, such as wood and wood products, the water vapour permeability/permeance is a function of the local relative humidity and increases with RH.

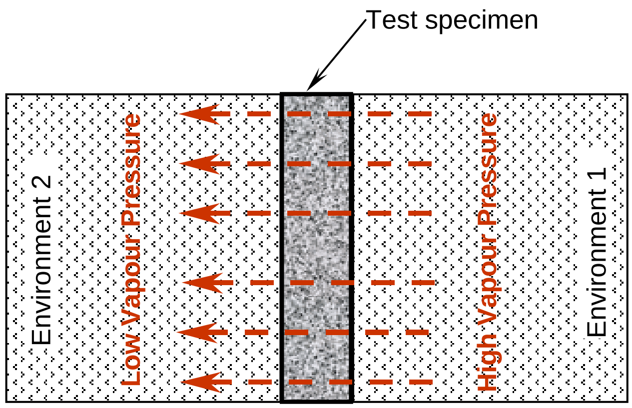

Figure 1 – Schematic of water vapour transmission across a specimen

4.2 Liquid diffusivity

Liquid diffusivity defines the rate of movement of water within a material, induced by a water concentration gradient. A material that allows liquid water diffusion through its boundary surface would change its weight with time when it is brought in contact with liquid water (Figure 2). A schematic plot (*Kumaran 1999*) of the increase in weight of the test specimen versus the square root of the time indicates that the specimen weight increases linearly (Figure 3) before it comes close to the saturation limit. The slope of this linear variation is called the water absorption coefficient (A_w) and can be mathematically written as:

$$A_w = \left(\frac{M_t - M_i}{A\sqrt{t}} \right) \quad (3)$$

where

M_t = weight of the specimen after time 't'

M_i = initial mass of the specimen

A = liquid contact area of the specimen

t = time.

In this study, water absorption coefficient is taken as a measurement of liquid diffusivity or rate of movement of water within a material (*Mukhopadhyaya et al. 2002b*) in accordance with the ISO Standard ISO 15148:2002 (E).

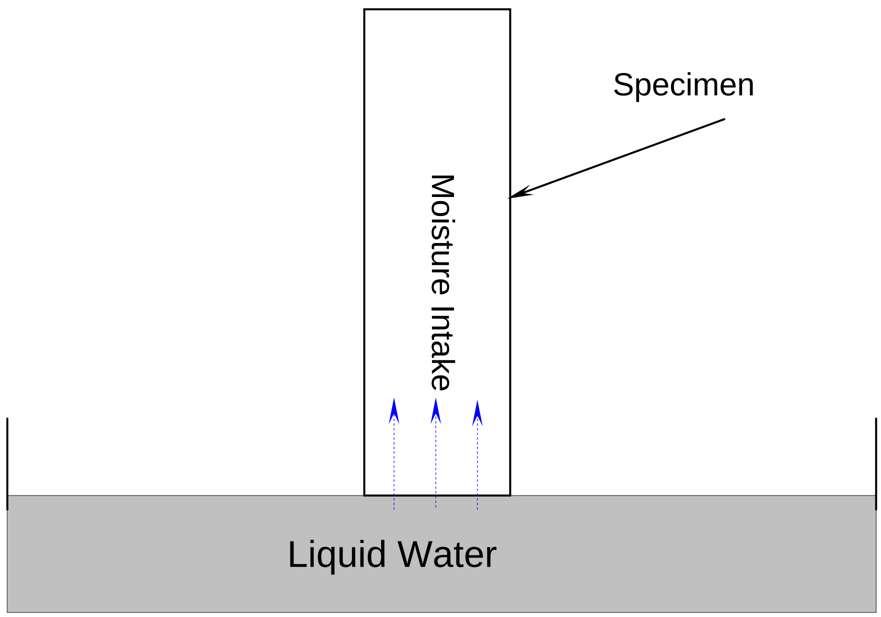

Figure 2 - Moisture movement into a material from surface contact with liquid water

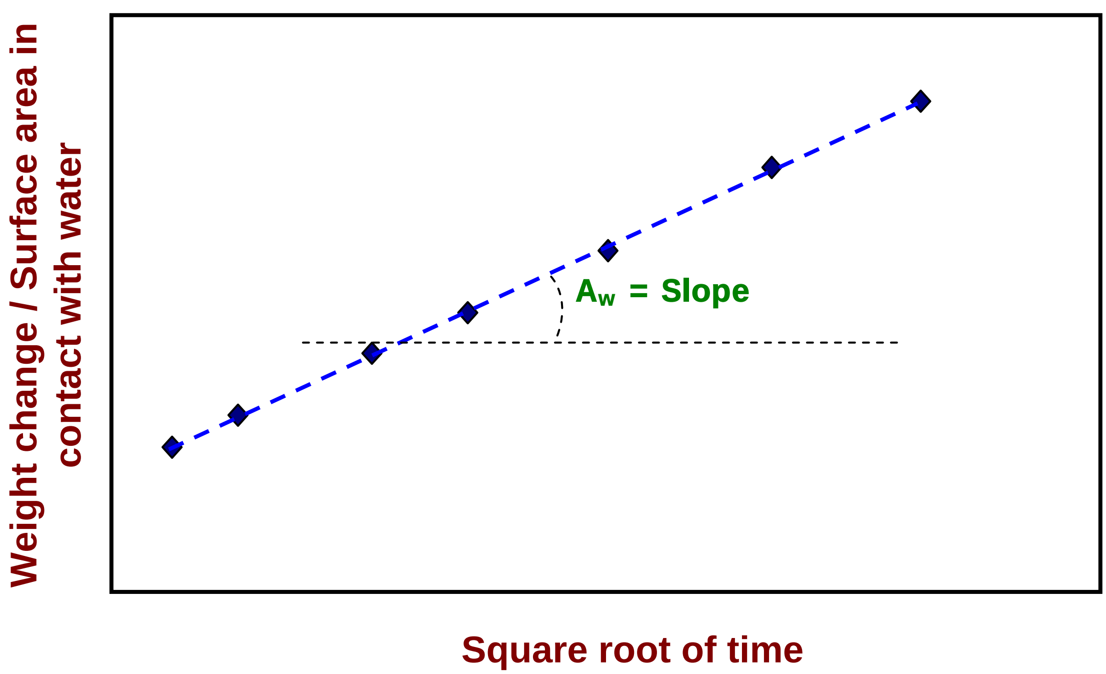

Figure 3 - Results from water absorption test

5.0 Experimental Work

The experimental work was undertaken in two phases: **Phase I** – Preparation and testing of *base case* stucco, and **Phase II** – Preparation and testing of *modified* stucco for high performance.

The objective of the *Phase I* was to establish the basic moisture transport properties, water vapour permeability and water absorption coefficient, of commonly used stucco materials (referred to as *base case* stucco in this report) currently available in Canada. Four stucco mixes were used in this phase, including one that was strictly based on the basic minimum requirement of the National Building Code (NBC) of Canada.

The objective of *Phase II* was to develop a *modified* stucco material that has lower water absorption coefficient but higher water vapour permeability in comparison with the *base case* stucco materials tested in the Phase I.

5.1 Preparation of test specimens

Three stucco samples were cast for each type of stucco mixes in a custom-built pine wood frame (Figure 4) with internal dimension 380 mm×380 mm.

The total thickness of each stucco sample after curing was approximately 21 mm (Figure 5). The respective thicknesses of scratch and brown coat were approximately 9 mm. The thickness of the finish coat was a minimum of 3 mm.

Metallic mesh conforming to the requirement of the NBC Canada (Article 9.28.4) was used as stucco lath embedded inside the scratch coat stucco and nailed with the bottom plate of the wood-frame (Figure 4). There was no sheathing membrane placed between the metal lath and the bottom plate of the wood-frame.

The stucco mixes were prepared in conformance with manufacturers' written instructions or in conformance with mix designs outlined in the NBC Canada (Article 9.28.5.3).

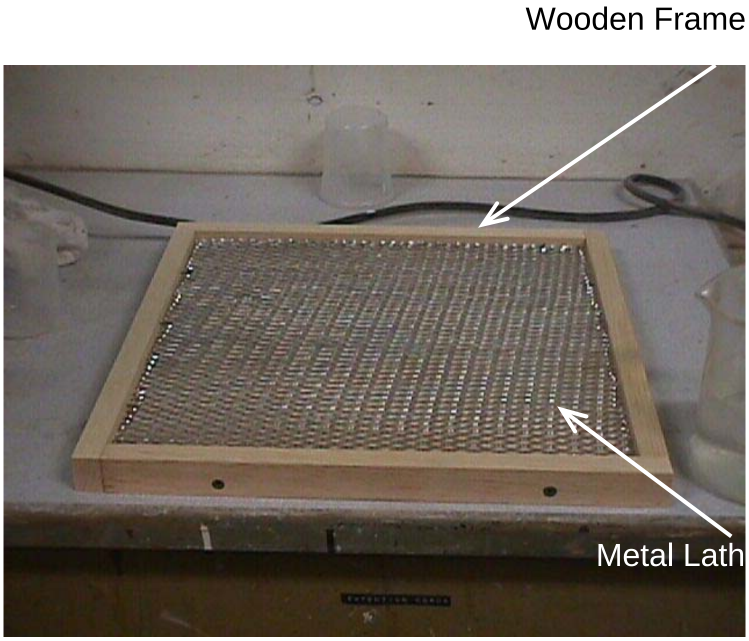

Figure 4 - Custom-built pine wood-frame with metal lath

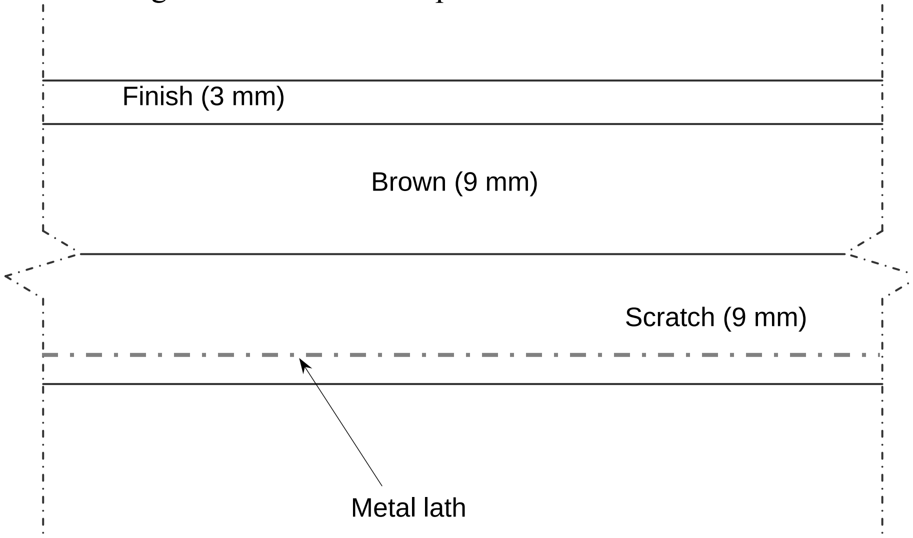

Figure 5 - Schematic three-coat stucco

5.2 Phase I - base case stucco

Four stucco mixes, identified as N1, N2, N3 and N4, investigated in Phase I of this study were:

(1) Commercial Stucco I – N1
(2) Commercial Stucco II – N2
(3) Commercial Stucco III – N3
(4) NBC Stucco – N4

N1, N2 and N3 are commercial representative stucco mixes from different regions of the country (Canada). The stucco mixes used were delivered in the laboratory in bags with instructions on the mixing and curing process. These instructions provided the guidelines for the preparation of the specimens. In general, commercial stucco mixes consisted of hydraulic cement, lime, aggregate and additional admixtures to improve workability and physical properties of the stucco mixes. The mix composition of the finish coat, distinctively different from the scratch coat and brown coat, included colour pigment and a water resistive ingredient.

The mix design for the NBC stucco (N4) was in accordance with Part 9 (Article 9.28.5) of the National Building Code (NBC) of Canada. The mix design used for this purpose is shown in Table 1. Potable water was added to this mix to achieve required workability. Unlike the commercial stuccos N1, N2 and N3, the NBC stucco N4 had a stone dash finish. The stone chips were partially embedded in the brown coat before the brown coat started to harden.

Table 1 - Mix design for NBC stucco – N4 (by volume)

Portland Cement	Masonry Cement	Aggregate*
1	1	7

**: graded natural sand*

5.3 Phase II – Modified Stucco for High Performance

The primary objective of this research project lies with the development of *modified* stucco that will limit liquid water entry on its external surface and at the same time allow water vapour to dry out of it.

Four different options investigated were:

1. Use of hydrophobic coating on exterior surface – M1.
2. Use of hydrophobic aggregate – M2.
3. Use of aggregates coated with hydrophobic chemical– M3.
4. Use of Zinc Stearate as admixture– M4.

Following paragraphs outline the mix-design and construction details for the aforementioned four stucco materials.

5.3.1 Hydrophobic Coating on Exterior Surface – M1

Hydrophobic (i.e. water repelling) materials are those that have low affinity towards liquid water. In fact, when liquid water comes in contact with a surface coated with hydrophobic material, it tends to form discrete droplets on the material surfaces. Low surface tension and lack of active chemical groups on their surface to form "hydrogen-bonds" with water are the reasons behind the water repelling characteristic of hydrophobic materials.

Hence, it is quite logical to use hydrophobic coating on the exterior face of the stucco to reduce liquid water entry (i.e. low water absorption coefficient). However, it is also to be noted that there remains a possibility that application of hydrophobic coating on the stucco surface may also reduce the ability of the stucco to breath (i.e. lower water vapour transmission capacity).

The chemical name of the hydrophobic coating used on the exterior surface is Triethoxy-N-Octylsilane. This coating was applied directly on the exterior face of the NBC stucco – N4. The exterior surface of the stucco was cleaned and made free from any residue or loose stone dash finish before applying two flood coats of hydrophobic coating with a paintbrush. The coated surface was dried for twenty-four hours before application of the second coat. The stucco samples were cured for at least seven days before conducting water vapour permeability and water absorption tests.

5.3.2 Use of Hydrophobic Aggregate – M2

Hydrophobic aggregates are those that allow free convective air movement through its pores but repel liquid water coming in contact with it. In other words, it is envisaged that the presence of such aggregates in the stucco mix will help to reduce the water absorption capacity of the stucco material without reducing its ability to transport air and water vapour across it.

The hydrophobic aggregates used for this purpose had been obtained from an overseas source (SilCoat Ltd., Israel). The particular type used for this purpose is identified as 'high PH hydrophobic aggregates' (Figure 6). In order to determine the effectiveness and proportion of hydrophobic aggregate, five mix designs (Table 2) were tested and water absorption characteristics were determined. The stucco samples were cast in one coat and had a thickness of approximately 13 mm.

Table 2 - Various mix designs with hydrophobic aggregate (by volume)

Mix Design	Portland Cement	Masonry Cement	Aggregate	Hydrophobic Aggregate
1 (NBC Stucco – N4**)	1.0	1.0	7.0	-
2 (NBC stucco with hydrophobic aggregate)	1.0	1.0	7.0	0.3
3 (NBC stucco with hydrophobic aggregate)	1.0	1.0	7.0	0.6
4 (NBC stucco with hydrophobic aggregate)	1.0	1.0	7.0	1.2
5 (NBC stucco with hydrophobic aggregate)	1.0	1.0	7.0	1.8

*** Same as described in section 5.2.*

Based on the water absorption characteristics (see section 6.0 for more details) of five aforementioned mix designs (Figure 7), mix design 5 (PC[1]:MC[1]:AG[1]:HA[1] – 1.0:1.0:7.0:1.8) was considered in this study for further investigation. These specimens had scratch coat, brown coat and stone dash finish (similar to the NBC Stucco – N4).

Figure 6 - Hydrophobic aggregate

[1] PC – Portland Cement; MC – Masonry Cement; AG – Aggregate; HA – Hydrophobic Aggregate

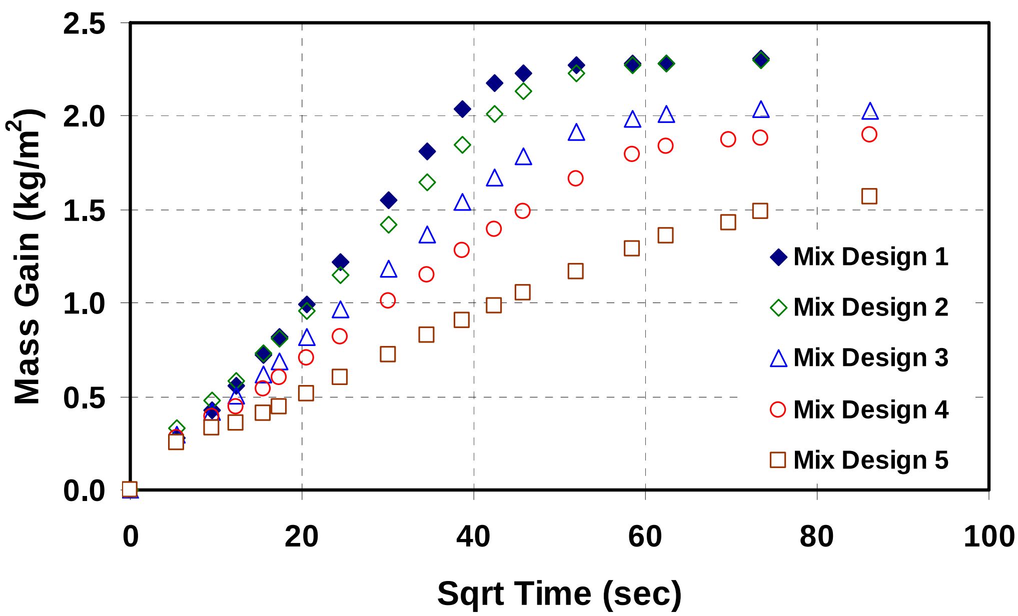

Figure 7 – Water absorption characteristics of various mixes with hydrophobic aggregate

5.3.3 Use of Aggregates Coated with Hydrophobic Chemical – M3

In this attempt to develop 'high performance stucco' the graded dry natural sand (the same one used for NBC Stucco – N4) was completely soaked into a hydrophobic liquid 'Octyltriethoxysilane' and then dried in ambient condition (22° C, 50% relative humidity) of the laboratory. The hydrophobic liquid 'Octyltriethoxysilane' has the same generic chemical composition as that of the hydrophobic coating (Triethoxy-N-Octylsilane) used in section 5.3.1. This treated sand was then used as hydrophobic aggregate for the stucco mix design. The mix design used for this purpose was PC:MC:AG:HA – 1.0:1.0:7.0:1.8 (same as mix design 5 in section 5.3.2).

5.3.4 Zinc Stearate as Hydrophobic Admixture – M4

Zinc Stearate is a zinc soap that repels water. It has been already demonstrated that the use of Zinc Stearate, as an admixture with lime-pozzolana plaster, can lead to a significant decrease of liquid water transport properties and water vapour sorption capacity of lime-pozzolana plaster (*Černý et al, 2004*). However, presence of Zinc Stearate, as an admixture, can significantly decrease or slightly increase the water vapour permeability of the lime-pozzolana plaster, depending on the nature of the pozzolanic admixture used in the lime plaster (*Černý et al, 2004*).

In this study, Zinc Stearate (fine, soft white powder, insoluble in water) was used as an admixture to the NBC Stucco – N4 mix design. The mix design ratios are shown in Table 3.

Table 3 - Stucco mix design with Zinc Stearate admixture (by volume)

Portland Cement	Masonry Cement	Aggregate	Zinc Stearate
1	1	7	0.25

6.0 Results

A total of eight types of stucco mixes were considered in this study. Four of them, *base case* stucco in Phase I, were tested to establish the water vapour permeability and water absorption characteristics of stucco materials commonly used in Canada. The remaining four stucco mixes, in Phase II, were the stucco materials that were *modified* with the intent of developing a *high performance* stucco material that would have lower water absorption coefficient and higher water vapour permeability in comparison with the *base case* stucco materials tested in Phase I. The experimental results obtained from the Phase I and Phase II of the study are presented in the following paragraphs.

6.1 Base case stucco

The water vapour permeability and water absorption coefficients of the four *base case* stucco materials are shown in Tables 4 and 5.

Water vapour permeability of the *base case* stucco materials at 75 percent mean RH (i.e. wet cup method) were found to be always higher than the values measured at 25 percent RH (i.e. dry cup method). NBC Stucco – N4 was the most water vapour permeable and Commercial Stucco III – N3 was the least water vapour permeable stucco among the four *base case* stucco materials considered in this study. These values of water vapour permeability compare very well (Figure 8 and Table 6) with the values obtained from the contemporary literatures (*Kumaran et al. 2000; Kumaran 2002; Kumaran et al. 2002*) for the stucco materials. The water absorption coefficient values of four *base case* stucco materials (Table 5) show that NBC Stucco – N4 was the most and Commercial Stucco II – N2 was the least liquid water absorbent material. The comparisons between the water absorption coefficient values obtained from this study and the values obtained from recent literatures (*Kumaran et al. 2000; Kumaran 2002; Kumaran et al. 2002*) are shown in Figure 9 and Table 7.

The values of measured moisture transport properties (i.e. water vapour permeability and water absorption coefficient) clearly indicate that the *base case* stucco materials/mixes chosen for this study are very much representative of the contemporary stucco materials used in Canada.

It is also to be noted from Tables 4 and 5 that the *base case* stucco with very low water absorption coefficient does not have a very high water vapour permeability. Thus based on the results presented in Tables 4 and 5, the *high performance stucco* is the one that has the dry cup water vapour permeability around 4.7×10^{-12} $kg.m^{-1}.s^{-1}.Pa^{-1}$ or higher, wet cup water vapour permeability around 10.1×10^{-12} $kg.m^{-1}.s^{-1}.Pa^{-1}$ or higher, and water absorption coefficient around 0.0008 $kg.m^{-2}.s^{-½}$ or lower.

Table 4 - Water vapour permeability of *base case* stucco

Specimen ID	Water Vapour Permeability ($kg.m^{-1}.s^{-1}.Pa^{-1}$)	
	Dry Cup (25% mean RH)	Wet Cup (75% mean RH)
Commercial Stucco I – N1	2.807×10^{-12}	5.325×10^{-12}
Commercial Stucco II – N2	1.223×10^{-12}	3.818×10^{-12}
Commercial Stucco III – N3	0.282×10^{-12}	1.826×10^{-12}
NBC Stucco – N4	4.738×10^{-12}	10.14×10^{-12}

Table 5 - Water absorption coefficient of *base case* stucco

Specimen ID	Water Absorption Coefficient ($kg. m^{-2} .s^{-½}$)
Commercial Stucco I – N1	0.0095
Commercial Stucco II – N2	0.0008
Commercial Stucco III – N3	0.0039
NBC Stucco – N4	0.0235

Table 6 - Water vapour permeability of various stucco materials from literatures

Specimen ID	Mean		Lower Limit		Upper Limit	
	Water Vapour Permeability ($kg.m^{-1}.s^{-1}.Pa^{-1}$) × 10^{-12}					
	Dry Cup	Wet Cup	Dry Cup	Wet Cup	Dry Cup	Wet Cup
VAN I to VAN III* (8 Stucco Specimens)	2.45	6.05	1.59	3.93	3.31	8.17
ASHRAE**	1.06	2.53	-	-	-	-
MEWS – I***	1.68	5.03				
MEWS - II***	1.04	2.57				
MEWS - III***	2.64	3.62				

** Kumaran et al. 2000; ** Kumaran 2002; Kumaran et al. 2002*

Table 7 - Water absorption coefficient of various stucco materials from literatures

Specimen ID	Water absorption Coefficient ($kg. m^{-2}. s^{-1/2}$)
VAN I*	0.0072
VAN II*	0.011
VAN III*	0.00058
VAN IV*	0.03
VAN V*	0.033
VAN VI*	0.039
VAN VII*	0.011
VAN VIII*	0.016
ASHRAE**	0.012
MEWS - I***	0.0050
MEWS - II***	0.0123
MEWS - III***	0.0074

** Kumaran et al. 2000; ** Kumaran 2002; Kumaran et al. 2002*

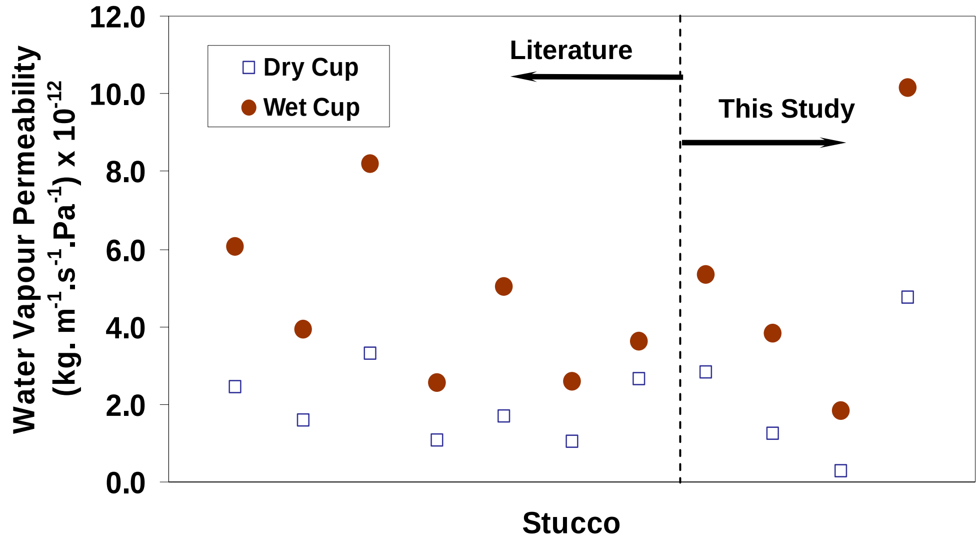

Figure 8 - Water vapour permeability of *base case* and various stucco materials from literatures

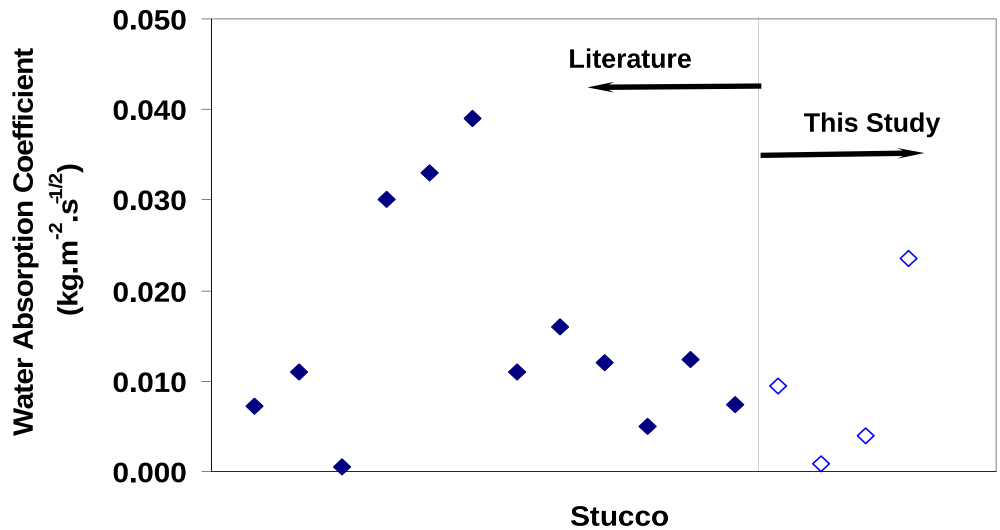

Figure 9 - Water absorption coefficient of *base case* and various stucco materials from literatures

6.2 Modified stucco for high performance

A desirable "high performance stucco" is the one that has high water vapour permeability and low water absorption coefficient. Four *modified* stucco mixes were tested for this purpose and the results are shown in Tables 8 and 9.

Table 8 - Water absorption coefficient of *modified* stucco mixes

Specimen ID	Water Absorption Coefficient ($kg.\ m^{-2}\ .s^{-½}$)
Hydrophobic coating on exterior surface – M1	0.0016
Hydrophobic aggregate – M2	0.0130
Aggregates coated with hydrophobic chemical – M3	0.0013
Zinc Stearate as admixture – M4	0.0010

Table 9 - Water vapour permeability of *modified* stucco mixes

Specimen ID	Water Vapour Permeability ($kg.m^{-1}.s^{-1}.Pa^{-1}$)	
	Dry Cup (25% mean RH)	Wet Cup (75% mean RH)
Hydrophobic coating on exterior surface – M1	2.513×10^{-12}	3.752×10^{-12}
Hydrophobic aggregate – M2	4.850×10^{-12}	8.283×10^{-12}
Aggregates coated with hydrophobic chemical – M3	6.405×10^{-12}	9.094×10^{-12}
Zinc Stearate as admixture – M4	7.420×10^{-12}	7.472×10^{-12}

These experimental results show that the stucco mix M2, with hydrophobic aggregate, has the highest water absorption coefficient and the stucco mix M4, with Zinc Stearate admixture, has the lowest water absorption coefficient. However, the stucco mix M1 (hydrophobic coating on exterior surface) and M3 (aggregates coated with hydrophobic chemical) have relatively low water absorption coefficients close to the value of stucco mix M4. Moreover, the water absorption coefficients of all these three stucco mixes (M1, M3 and M4) are closer to the lowest value of water absorption coefficient observed in the case of *base case* stucco (Table 5).

The measured water vapour permeability values of the four *modified stucco* materials show that the stucco mix M1 has the lowest dry and wet cup water vapour permeability. Hence, it can be said that the application of a hydrophobic coating on the exterior surface of the stucco (i.e. stucco mix M1) cannot reduce the water absorption phenomenon without reducing the water vapour permeability.

Stucco mix M4 shows the highest dry cup water vapour permeability and it is higher than the highest observed in the *base case* stucco mixes (N4 in Table 4). However, the wet cup water vapour permeability of this stucco is almost same like the dry cup value (i.e. water vapour permeability does not increase with the increase of relative humidity). In fact, the dry cup water vapour permeability of stucco mix M2, M3 and M4 are all higher than the highest value observed in the case of *base case* stucco. On the other hand stucco mix M3 (aggregates coated with hydrophobic chemical) has the highest wet cup water vapour permeability value and this value is very close to the maximum wet cup value observed in the *base case* stucco mixes (N4 in Table 4).

7.0 Discussion

The overall experimental results obtained from this project are summarized in Figures 10 and 11. These figures clearly indicate that in the *base case* stucco mixes (N1, N2, N3 and N4), the highest water vapour permeability and the water absorption coefficient values lie with the same stucco mix. However, that is not the case with the trial *modified* stucco mixes. In particular, stucco mixes M3 (aggregates coated with hydrophobic chemical) and M4 (zinc stearate as admixture) show very promising results with relatively low water absorption coefficient combined with high water vapour permeability. However, these are all trial mixes and there exists scope of further refinement and optimisation of these stucco mix designs. It is also to be noted here though water vapour permeability and water absorption coefficient are the two most important moisture transport properties that govern the overall moisture response and management capability of the wall systems with stucco claddings, but there are other hygrothermal properties (e.g. sorption isotherm, air permeability etc.) also that may have some secondary influence on the overall moisture response of the wood-frame stucco wall systems. Apart from these, the effect of the desirable hygrothermal properties of the *modified* stucco on the moisture response of wall systems with stucco claddings also needs to be investigated. Further investigation on all aforementioned issues will be carried out in a separate project at the IRC/NRC in the coming days and will be reported in due course.

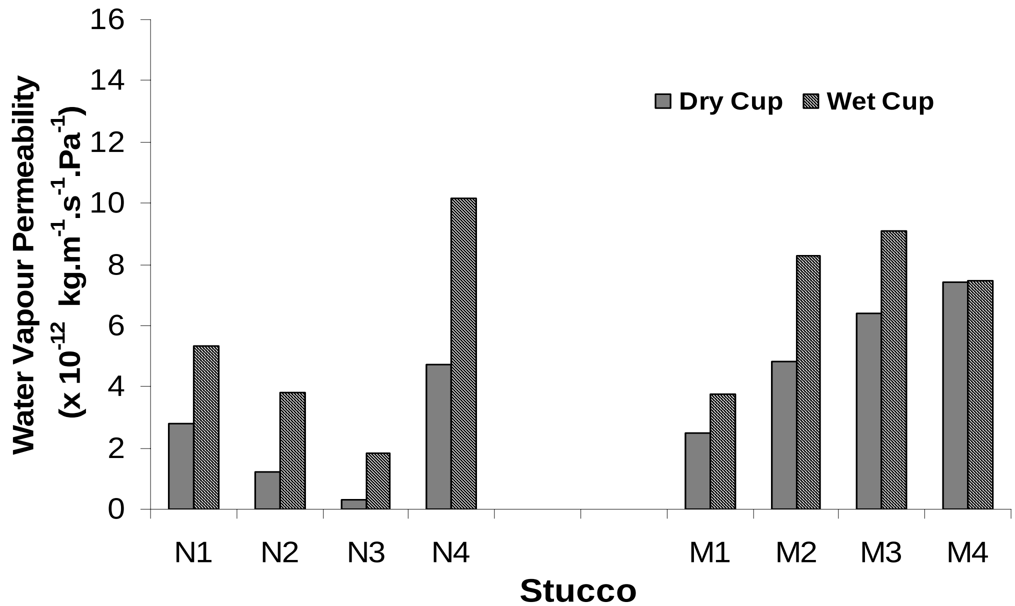

Figure 10 - Water vapour permeability of *base case* (N1, N2, N3 & N4) and *modified* stucco materials (M1, M2, M3 & M4)

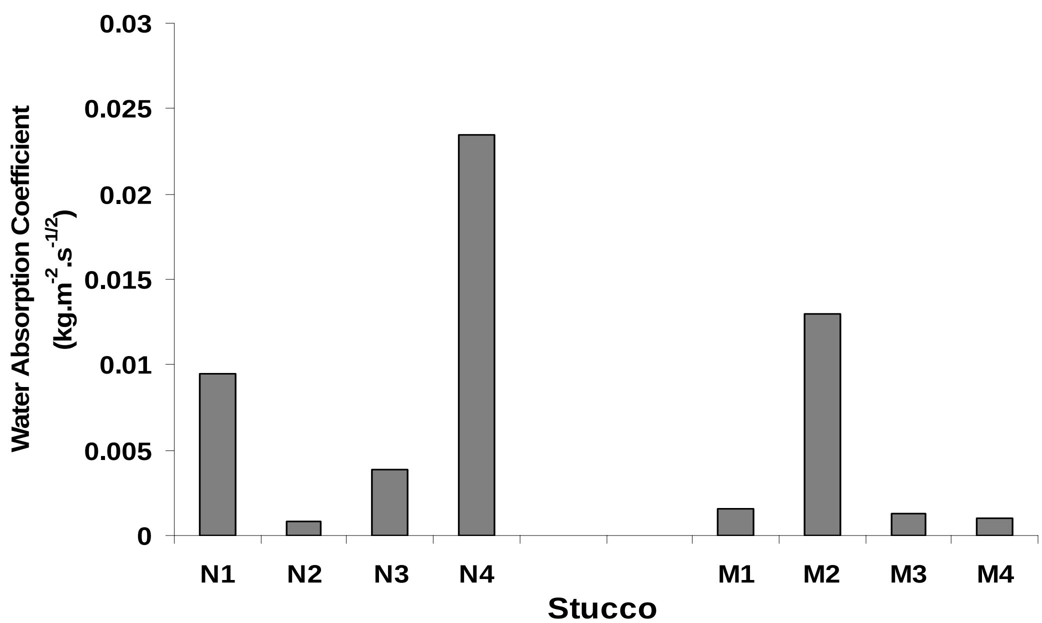

Figure 11 - Water vapour absorption coefficient of *base case* (N1, N2, N3 & N4) and *modified* stucco materials (M1, M2, M3 & M4)

8.0 Conclusions

1. The results from this experimental study show that it is possible to reduce the water absorption coefficient of the stucco material without reducing water vapour permeability through appropriate mix design.

2. Hydrophobic coating used in this study on the exterior face of the stucco appears to reduce the water absorption coefficient and water vapour permeability simultaneously. The effects of other hydrophobic coatings may or may not be the same.

3. Use of aggregates coated with hydrophobic chemical and use of zinc stearate as admixture in the stucco mix seem to be two very promising options to develop high performance stucco material that has relatively lower liquid water absorption capacity but normal or higher water vapour transmission capacity compared to the commonly used stucco materials used in Canada.

9.0 Scope of Further Research

It is to be mentioned that this is only a pilot study that investigated the possibility to develop high performance stucco material that has lower water absorption capacity and higher water vapour permeability at the same time. This preliminary study on small-scale specimens shows positive results. However, further experiments and analyses on the overall hygrothermal behaviour of the material and wall systems are required to progress further from the findings of this study.

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