Durability Is Only Skin Deep

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INTRODUCTION

Building envelopes are human prostheses that represent the 'third skin' separating indoor environments from the outside world. Like our first skin which is a living, regenerating organ, and unlike our second skin, clothing, which seldom outlives the vagaries of fashion cycles, the skins of buildings are ideally intended to last the life of the whole building, in particular its structure, or skeletal system. In traditional building forms employing loadbearing masonry, this relationship was axiomatic since the structure was also the skin. But as building technology evolved, and the structural and cladding functions became separated, the durability of the skin over the life cycle of the building increasingly challenged the architect. This challenge often focuses on the design of walls, which represent among the highest cost components of the building envelope system, and are also the most visible aspect of the building, its façade.

Interest in sustainable architecture continues to grow within the discipline of architecture. Unfortunately, it is often viewed as an added value feature. The reality of most contemporary projects is that if the "green" features are ancillary, and reside, so to speak, on a separate layer of a CAD drawing, then this layer is simply turned off when budgets become strained. Exterior walls tend to survive budget cuts, but their quality and durability are often compromised by thinking that focuses on first costs, and remains oblivious to life cycle realities.

This paper examines two exterior wall systems commonly employed in commercial and institutional projects in much of Canada and parts of the United States. Both share an identical external skin, brick veneer. However, one relies on steel stud backup (BVSS), while the other is tied to non-loadbearing concrete masonry (BVCM). These are examined within the context of a cold climate, defined as a climate with an outside winter design temperature lower than –7 °C [1]. The scenario posed in this paper is that of the client wishing to substitute a BVSS wall system for a BVCM wall system. It attempts to explain the potential implications of this substitution in terms of performance and durability, and presents the assessment chronologically according to advances in building science knowledge. Larger questions of durability in relation to sustainability are subsequently discussed.

COMPARATIVE ASSESSMENT

The first step in the assessment process is to render the candidate wall designs in section view, and to identify their constituent elements. The two sections appear in Figure 1 and represent conventional Canadian cold climate practices. The thermal resistance and vapor permeance characteristics of the elements are also noted.

The second step is to determine the interior and exterior design conditions to be used in the hygrothermal analysis of the candidate wall sections. The exterior design conditions are based on climate normals for the selected location (Toronto, ON), and the interior conditions are normative across a broad range of commercial and institutional occupancies: interior (23 °C, 40% r.h.); and exterior (-18 °C, 60% r.h.).

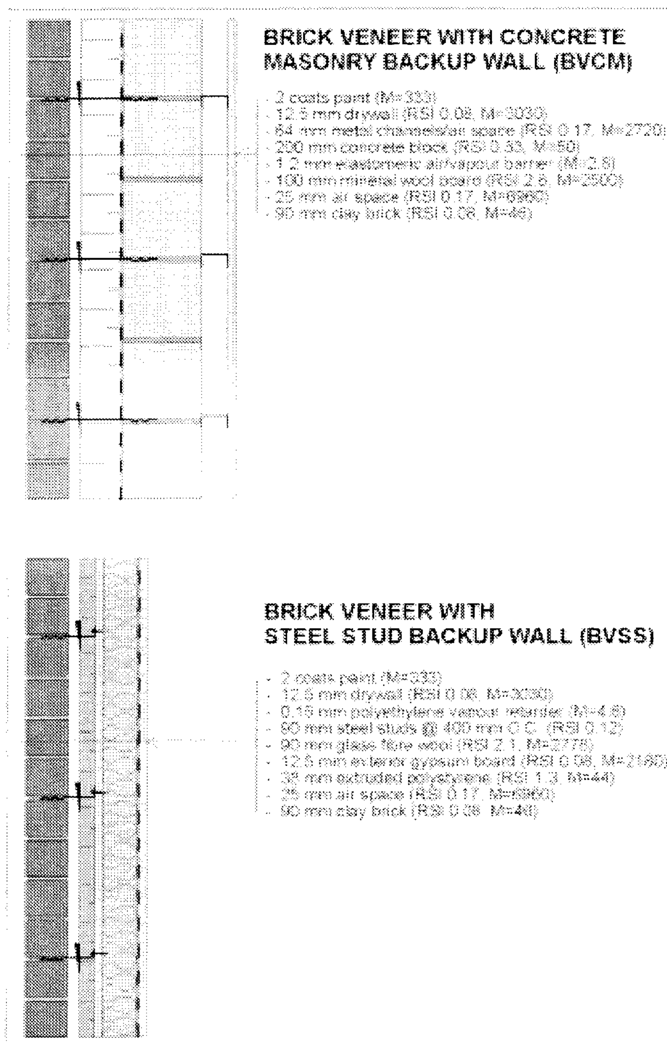

Fig. 1. Typical Sections of the Competing Wall Systems

The third and, to a large extent, most important step is to apply appropriate assumptions to guide the assessment. Based on heuristics derived from the analysis of building envelope defects, the following assumptions guide this assessment:

1. Workmanship and materials are imperfect. Inaccuracy and inconsistency of workmanship and materials result in buildings that only approximately fulfill their design intent.

2. Environmental separator design strategies employing redundancy of critical control functions, as defined in Table 1, are in most cases superior to '*perfect barrier*' strategies. In general, they are less expensive and more forgiving to construct, since permissible variations in the quality of materials and workmanship are greater than those required by a '*perfect barrier*' approach.

3. Separators must adequately control moisture migration, heat transfer, air leakage and solar radiation. In cold climates, experience indicates that when the requirements for the control of moisture migration have been satisfied, the other control requirements are either simultaneously satisfied, or more easily satisfied, than if moisture migration is not addressed at the outset.

Within the context of a cold climate and Canadian construction practices, these assumptions guide users to assume flawed construction that must be compensated with redundant control measures related to moisture management.

CONTROL FUNCTION	PHYSICAL MECHANISM	CONTROL STRATEGY
MOISTURE MIGRATION	*Bulk Water*	Shedding Conveyance Drainage Storage and Drying Pressure Equalization (rain-screen principle) "Perfect" Barrier
	Capillary Water	Capillary Barrier Capillary Break (air gap)
	Water Vapor	Vapor Barrier Thermal Insulation Arrangement
	Air Leakage	Air Barrier Thermal Insulation Arrangement
HEAT TRANSFER	*Conduction, Radiation*	Thermal Insulation
	Convection	Air Barrier
AIR LEAKAGE	*Stack, Wind and Mechanical Effects*	Air Barrier
SOLAR RADIATION	*Heat, Visible Light*	Orientation Fenestration Shading Devices Glazing Characteristics

Table 1. Control Functions and Strategies for Environmental Separation (Adapted from Bomberg and Brown [2].)

Given the data from the first two steps, it is now possible to perform a simple analysis of thermal and vapor pressure gradients across the wall assemblies. In the first instance, the simplified procedures presented in the ASHRAE Handbook of Fundamentals are employed recognizing their inherent limitations [3]. However, it is important to recognize that the qualitative value of information provided by these methods, which were available long before the introduction of the steel stud backup innovation, is often sufficient to inform the architectural design process.

Analysis of Temperature Gradients

Results for the steady-state calculations of temperature gradients across the candidate wall sections are presented in Figure 2.

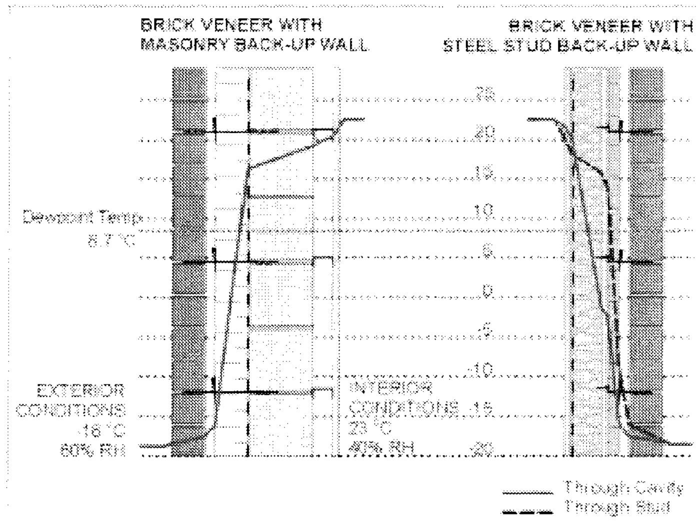

Fig. 2. Temperature Gradients Through Wall Sections

The effective thermal resistance of the masonry backup wall system is calculated as RSI 3.78 (R-21.46), and for the steel stud backup wall system RSI 3.44 (R-19.53). The nominal thermal resistance of the latter wall system is higher, but after accounting for thermal bridging across the steel studs, the assembly exhibits a 9.8% higher rate of heat transfer with respect to the masonry backup wall system. In the case of the masonry backup wall system, the vapor accessible surface temperature of the preferred nucleation site is 15.4 °C, well above the dewpoint temperature of 8.7 °C. The surface temperature of the exterior gypsum board in the cavity of the steel stud backup assembly is –0.8 °C. If indoor air migrates into the stud cavity, condensation will occur.

Analysis of Vapor Pressures

The calculation of vapor pressures across the two wall sections is depicted in Figure 3. Vapour pressure gradients across the two wall sections are similar. Steady-state calculations indicate that the masonry back-up wall system experiences a moisture migration rate of 0.22 grams/m^2.day at the design condition, not accounting for air leakage, whereas the steel stud backup wall system permits the transport of 0.34 grams/m^2.day. Examination of the saturation vapor pressures indicates that in the case of the BVSS wall, the exterior gypsum board is a condensing plane.

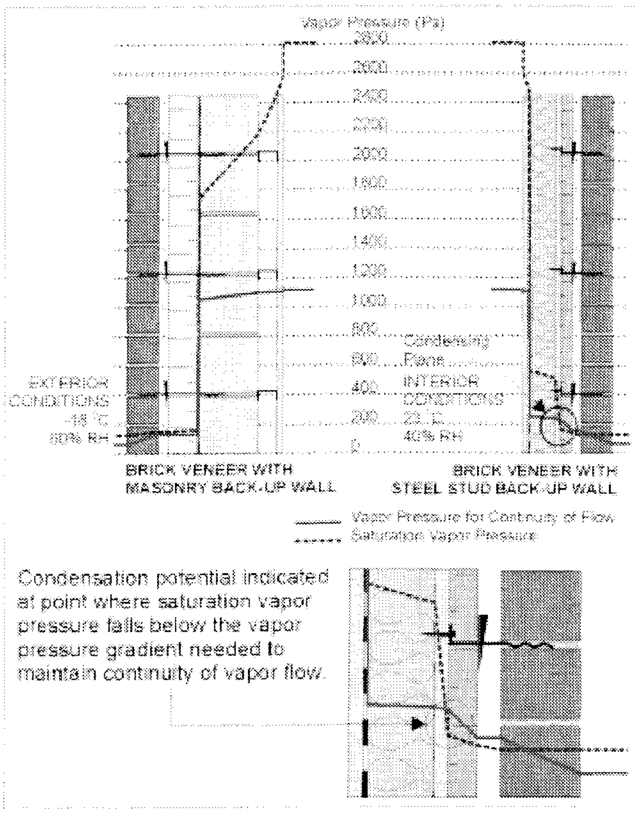

Fig. 3. Vapor Pressure Gradients Across the Two Wall Sections

The saturation moisture content of the exterior gypsum sheathing is approximately 8.4 kg/m^2. Assuming perfect construction with respect to air leakage, the gypsum board in the BVSS system appears fully capable of storing all the diffusing vapor during the heating season, and then releasing it over the remainder of the year (storage and drying strategy). If the preceding analysis represents the state of mainstream envelope design at the time steel stud back up walls were introduced, then it is understandable they may have been deemed acceptable. However, assuming imperfect construction demands that air leakage must also be considered, especially in cold climates.

Assessment of Condensation Potential

To engage in this assessment, the building science clock must be turned ahead by some two decades after the steady-state hygrothermal analysis methods were first introduced. Research into the leakage characteristics of building assemblies, and the introduction of computer simulation tools for modeling moisture migration confirm what may already have been inferred from less sophisticated techniques.

The steel stud backup wall system is highly vulnerable to condensation damage arising from unintentional openings in the envelope that permit the exfiltration of indoor air into the insulated cavity. The EMPTIED (Envelope Moisture Performance Through Infiltration, Exfiltration and Diffusion) computer program was used to simulate the performance of the steel stud backup wall assembly appearing in Figure 1 [4]. The simulation assumed a normalized leakage area of 1 cm^2 per 1 m^2 of interior wall area corresponding to typical values reported in practitioners' literature [5]. A 5-year period was simulated using Toronto weather data, and the results for year 5 are depicted in Figure 4.

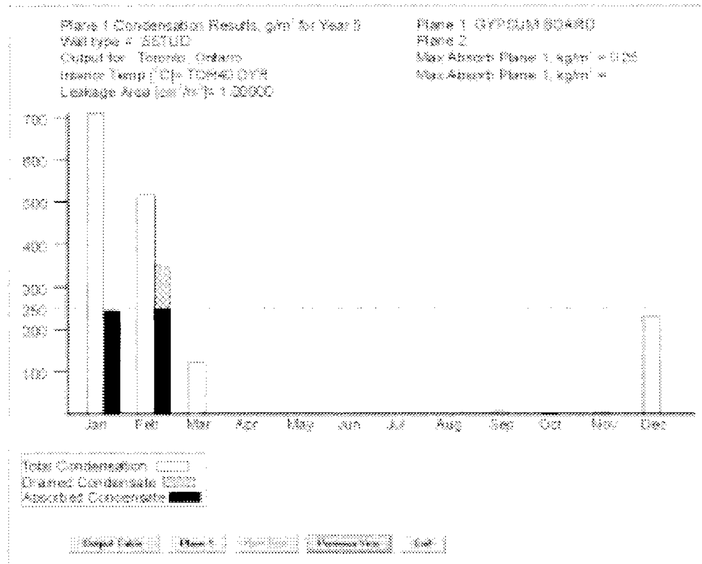

Fig. 4. Condensation Within Steel Stud Cavity Predicted by EMPTIED

Condensation was evidenced in each of the 5 years simulated by the software indicating that this condition is chronic. The EMPTIED model assumes that after a condensing plane is saturated, in this case the exterior gypsum board, the remaining water *must* be drained away to minimize moisture problems. In conventional steel stud backup wall assemblies, deliberate drainage paths are seldom provided, hence the water is stored in the glass fibre insulation until it seasonally dries. This has led to documented cases of corrosion and generated a number of publications aimed at providing remedies [6,7,8]. Since the onset of widespread performance problems in buildings employing this type of wall assembly, better practice guidelines have been developed and made available to practitioners [9].

Simulations for the masonry backup wall assembly under identical conditions indicated no condensation problems as may be inferred from the higher than dewpoint surface temperature at the masonry block and air/vapor barrier membrane interface. It may be concluded that the condensation potential of the originally introduced steel stud backup wall assemblies is very high in cold climate applications. The potential for corrosion of the steel stud backup wall and brick ties should in itself convince designers and owners to abandon this approach. But additional considerations may be required to reinforce the argument.

Forgiveness

Lines on working drawings are straight, and the dimensions are precise, but in the field the building artifact is always an approximation, sometimes too crude an approximation to perform adequately. How does this come about?

Contractors and their trades are highly constrained by time and budget on virtually all construction projects. They are generally not inclined to spend more effort on construction than is profitable. If the successful (usually lowest) bidder on a construction project discovers that an assembly or detail is too expensive to execute properly, then ad hoc modifications (a.k.a. cutting corners) are implemented by workers intent on meeting productivity quotas.

In some cases, the skill levels of the trades are too low for the work they have been awarded. In other cases, the knowledge and experience of those performing quality assurance and supervision are simply not up to par. When none of the above factors come into play, other problems such as substandard materials or bad weather affect the quality of the finished product. Unforeseen site conditions, usually involving soils and groundwater, may compound the situation further, along with human factors such as labor disputes (strikes).

For these reasons, practical considerations in design should not be underestimated. Forgiving building systems that recognize the reality of imperfect materials, workmanship, site conditions and human factors are truly elegant and sustainable design solutions.

The steel stud backup wall assembly depicted in Figure 1 can only achieve acceptable performance if it is constructed flawlessly with respect to the control of air leakage. Building occupants can easily undermine the integrity of even perfectly built envelopes by puncturing the assembly to attach objects, run additional wiring, and perform various alterations. In the masonry backup wall assembly, the interior finish may be punctured and damaged with no effect on the integrity of the air/vapor barrier membrane, which typically enjoys 200 mm (8 inches) of solid protection. Fasteners for lightweight external attachments to the brick veneer are also unlikely to accidentally penetrate the air space and external insulation to disrupt the air barrier.

Rain penetration through brick veneer is now a well understood phenomenon [10]. If external moisture reaches the insulated cavity of the steel stud backup wall assembly, the extruded polystyrene and polyethylene effectively sandwich the moisture in wetted cavity insulation. The masonry back-up wall assembly enjoys the storage and drying benefits of the concrete masonry units in the event of external moisture penetration.

In consideration of these factors, it is reasonable to conclude that the masonry backup wall assembly is more forgiving, both during construction and after occupancy.

Additional Considerations

Durability and forgiveness aside, additional considerations which may apply include fire resistance rating, sound transmission rating and susceptibility to mold growth. The fire and sound integrity of assemblies constructed with concrete masonry backup walls generally exceeds framed backup wall systems when the same types of insulation materials are employed. A far more important consideration today is the susceptibility to mold growth associated with the BVSS systems. Research conducted into the protection of exterior gypsum board from moisture accumulation in BVSS systems indicated that in many cases, mold growth was evidenced in the assembly [11]. Given the highly litigious nature of mold-related indoor air quality problems reported in the media, this consideration alone may prove sufficient to avoid the substitution of the BVCM with the BVSS wall system.

An interesting perspective on cladding systems which are attached to the structural system is their interdependence with respect to durability. When cladding and structural systems are integral, as in the case of traditional loadbearing masonry buildings, this relationship was obvious. But when the two functions were separated, the effect of cladding durability on structural durability was not explicitly addressed. In Canada, the rotting of wood-frame structures enclosing hundreds of condominium projects in British Columbia serves as a sobering lesson in building systems integration. In the BVCM wall system, the interior finish is simply that, and may be damaged, altered and even completely removed with no effect on the performance of the real skin (from concrete masonry units out to brick veneer). In BVSS, the interior finish is also a component of the skin which unfortunately is unable to regenerate itself after exposure to normal occupancy and especially, interior renovations. This suggests that when building envelope and structural functions are separated, it then becomes prudent to separate control functions and assign them to individual components. If this is not possible, it must be recognized that they are not, in fact, separated. Occupant tolerant building envelopes cannot depend on knowledgeable occupants for their durability. The BVCM wall system is an appropriate response to modern commercial and institutional buildings because it avoids functional ambiguity.

SYNOPSIS

Brick veneer with steel stud back wall systems have evolved since their introduction to North American construction. Newly advocated approaches no longer insulate the stud cavities and all of the insulation is placed on the exterior over an air/vapor barrier system, adhered to gypsum sheathing securely attached to the studs. Figure 5 depicts a typical contemporary example.

In this evolutionary process, most of the advantages enjoyed by masonry backup wall systems have been gained, and much of the economic advantage has been lost. But important questions remain to be answered. Was the high cost associated with the development of steel stud backup wall systems justified? And why did architects originally select these systems when reasons for questioning their performance was evidenced from simple analytical procedures readily available at the time?

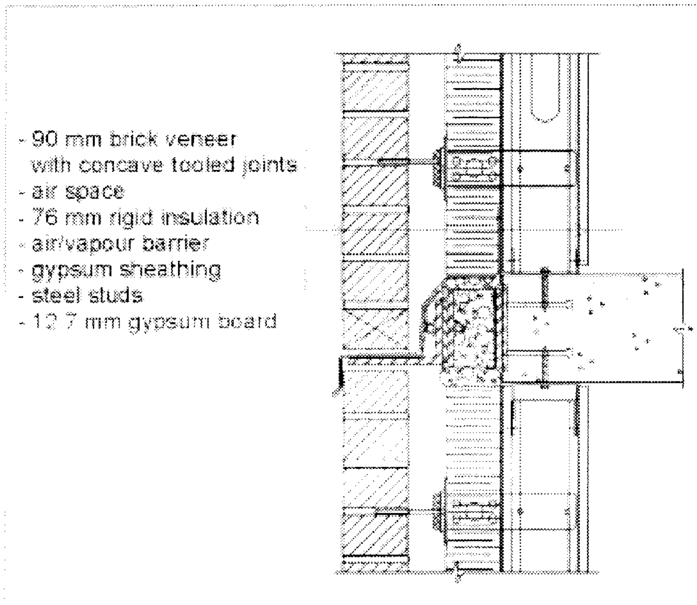

Fig. 5. Contemporary BVSS Wall System (Source: Brick Veneer Steel Stud: Best Practice Guide, *CMHC)*

Clearly, building science knowledge was able to identify potential performance problems when BVSS systems were introduced. Had a fraction of the cost associated with BVSS defects and failures been invested in an industry-wide program of research and development, most, if not all, of the problems could have been avoided. Given the sophistication of currently available hygrothermal modeling tools [12], today there are few excuses for not troubleshooting building envelope performance at the design stage. But it remains to be seen if these advances in building science will be used to enhance the durability of innovative assemblies, or to whittle away the factors of safety against moisture protection in order to reduce first costs?

SUSTAINABILITY AND DURABILITY

Currently accepted measures of sustainability attempt to reconcile factors such as embodied and operating energy, exergy (absolute energy efficiency) ecological footprint, greenhouse gas emissions and externalities within a life cycle analysis that spans the useful life of buildings. Such measures attempt to quantify resource depletion and/or environmental degradation, and may also be expressed as the amount of environmental impact per year of building service. Interesting relationships have emerged from assessments performed according to various measures. For example, the sustainability of high embodied energy building components with a relatively long service life may be better than lower embodied energy alternatives with a shorter service life, especially if the former provide superior thermal performance [13]. Embodied energy and thermal performance being equal, the relationship between durability and sustainability is linear – the more durable, the more sustainable.

But what is the reasonably expected durability of building envelopes? In Canada, guidelines for building durability have attempted to define acceptable ranges of durability for buildings and their components according to the following parameters:

> *"The loads on components and the building that result from the operation of the systems and services should be considered along with environmental and structural loads."[14]*

Design for durability implies the need to contextualize the forces and factors impacting the building, and suggests that a building envelope in New York should be different from one in Miami for the same occupancy, and that in the same climatic zone, different occupancies may result in different envelopes. Advocates of bioclimatic design go one further and suggest that envelope design should also vary according to solar and wind orientation [15].

If structural designs vary according to occupancy, snow, wind and seismic loads, how was it that a single envelope design, such as BVSS, could have been advocated across a broad range of climatic zones? North America's building science community is now coming to realize the need for limit states design of building envelopes according to the parameters outlined above, in response to the various climatic zones [16]. This in turn will lead to durability which is as predictable as the integrity of building structures. Only then will measures of sustainability truly reflect the environmental impacts of buildings by reliably assessing the useful service provided by all of the components, including walls. Until such time as the durability of building envelopes can be designed and predicted as accurately as that for structures, measures of sustainability remain highly questionable at the design stage.

Sustainability concepts may also be applied to investment values. The increasingly common condition assessment of buildings prior to purchase is making even the most short-sighted developers recognize that future returns on buildings with prematurely failing façades or mold problems are put at risk. Durability sustains investment values as much as it sustains our limited resources, and this economic relationship should be recognized as entirely symbiotic.

DURABILITY IS ONLY SKIN DEEP

The structures of modern buildings are engineered to perform adequately for a long time, typically several hundred years as confirmed by numerous precedents which remain serviceable to this day. Mechanical and electrical systems are routinely upgraded or replaced in the life cycle of commercial and institutional buildings, along with the periodic renovation of interior finishes and furnishings. It is normally expected that the structure will remain serviceable for the useful life of the building, and that services, finishes and furnishings may come and go. This leaves architects and owners to ponder the relationship of the skin to the rest of the building.

Many important questions remain unanswered regarding envelope durability and its relationship to whole building sustainability. Where does the skin of a building begin and end? Are 'pure' unambiguous skins preferred to composite envelope assemblies with interdependent components? What degree of redundancy with respect to critical control functions is necessary for acceptable long-term performance? How is durability defined at the design stage and subsequently confirmed during mock-up testing and construction review? What are the appropriate means of transferring the answers to these questions, assuming we obtain them, to students and practitioners of architecture? These pivotal questions surrounding the quest for envelope firmness have been largely obscured by deference to commercial commodity and fiscal delight.

Buildings remain architectural artifacts that are largely perceived by their façades. When the skin of the building is less durable than the structure, it implies a high life cycle cost for the building because it will be repaired, restored or retrofit several times. If the facelifts become as frequent as the interior renovations, it is likely the building will lose market value in the case of commercial buildings, or become a severe burden to institutional owners who cannot afford retrofit or replacement. Clearly, this is not sustainable.

Within the context of modern buildings, minimum standards for structural safety implicitly prescribe structural durability. The durability of interiors has long been surrendered to fashion and technological innovation. All that remains to be negotiated is the durability of the building envelope. In these negotiations, there are many good reasons to restore the quality of the modern building envelope to its traditional status as the cornerstone of sustainability. It will require a reconciliation of passive and active systems in our buildings. We will also need to harmonize the apparent incompatibility between the useful service lives of structure, envelope, interior finishes and services. And we must accept that our failing building envelopes reflect a much deeper failure to deal with the whole building system as a cultural and technological artifact supporting social sustainability. But to come to this realization within the context of building envelopes, we must first recognize that durability is only skin deep.

REFERENCES

[1]Hutcheon, N.B. and Handegord, G.O. (1983), *Building Science for a Cold Climate.* National Research Council of Canada, Ottawa, ON.

[2]Bomberg, M.T. and , W.C. (1993) "Building Envelope and Environmental Control: Part 1- Heat, Air and Moisture Interactions," *Construction Canada*, 35(1), pp. 15-18.

[3]ASHRAE Fundamentals (1997), *Chapter 22, Thermal and Moisture Control in Insulated Assemblies.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

[4]*EMPTIED Computer Program* (1998), Canada Mortgage and Housing Corporation, Ottawa, ON.

[5]ASHRAE Fundamentals (1997), *Chapter 24, Thermal and Water Vapor Transmission Data, Table 3.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

[6]Keller, H., Trestain, T.W.J. and Maurenbrecher, A.H.P. (1992) *The Durability of Steel Components in Brick Veneer/Steel Stud Wall Systems.* Proceedings of the 6th Conference on Building Science and Technology, Toronto, ON.

[7]Burnett, E., Building Engineering Group, University of Waterloo (1995, 1996), *Renovation Strategies for Brick Veneer/Steel Stud Construction.* Canada Mortgage and Housing Corporation, Ottawa, ON.

[8]Trestain, T.W.J. (1997). *Assessment Repair Strategy for Existing Buildings Constructed with Masonry Veneer Steel Stud Walls.* Technical Series 97-102, Canada Mortgage and Housing Corporation, Ottawa, ON.

[9]Posey, James B., (1996), *Brick Veneer Steel Stud: Best Practice Guide.* Canada Mortgage and Housing Corporation, Ottawa, ON.

[10]Slevarajah, S. and Johnston, A.J. (1995), "Water Penetration Through Cracked Single Skin Masonry," *Building and Environment*, Vol. 30, No. 1, pp. 19-28.

[11]Pressnail, K.D., Vollering, B., Handegord, G.O., Kelk, G.H. (May 1997), *Protecting Gypsum Sheathing in Insulated Steel-Stud Walls.* Canada Mortgage and Housing Corporation, Ottawa, ON.

[12]Karagiozis, A., Hartwig, K., and Andreas, H. (2001) "WUFI-ORNL/IBP Hygrothermal Model", *Proceedings, 8th Conference on Building Science and Technology*, February 22 & 23, Toronto, ON, pp.158-183.

[13]Cole, R.J. and Kernan, P.C. (1996), "Life-Cycle Energy Use in Office Buildings," *Building and Environment*, Vol. 31, No. 4, pp. 307-317.

[14]*CSA S478-95 Guideline on Durability in Buildings*, CSA International, Rexdale, ON.

[15]Sala, Marco (1998), "Advanced Bioclimatic Architecture for Buildings," *Renewable Energy*, Vol. 15, pp. 271-276.

[16]Lstiburek, J. (2001), *Hygrothermal Climate Regions, Interior Climate Classes and Durability.* Proceedings, 8th Conference on Building Science and Technology, February 22 & 23, Toronto, ON, pp. 319-329.