Designing for High Humidity Environments – Further Thoughts

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Last year I presented a session to the Canadian Prairies Chapter of IIBEC, which explored the challenge of envelope design for high humidity occupancies with an emphasis on roofing. Humidity as a challenge for designers and builders in Canada is not a new topic. In fact, it is so fundamental to Canadian construction that Neil Hutcheon chose the topic for the first Canadian Building Digest, published by the Division of Building Research (DBR) at the National Research Council. In CBD-1 *Humidity in Canadian Buildings* (1960) Hutcheon noted:

"Humidity is one of the most important of the topics that are of special concern in Canadian building design and operation. Low outdoor temperatures in winter give rise to condensation on and in walls and windows and tend to produce low relative humidities indoors. When even moderate humidities must be carried within buildings serious difficulties can be expected unless the designer appreciates fully what humidity is and how it relates to building performance."

Regrettably, (or rather reassuringly), nothing has really changed in the ensuing 60 years since that writing. Our analysis tools have improved, more on that later, and new materials have emerged onto our market, but the underlying physics remain. Of greater concern, we as an industry have evolved very little. Last year I wrote:

"[Envelope] design has a long founded basis in both science and practical application – in essence we know how to make [envelopes] that work. But much of the design tools and practical case examples are founded on or rely upon fairly typical conditions. Interior conditions within most residential or commercial occupancies are fairly well understood and controlled with typical HVAC equipment. But what happens or can happen when those conditions are altered or uncontrolled? Hotter and humidified – either directly or indirectly, interior occupancies sometimes with aggressive chemicals in the air can pose special challenges in roofing and envelope design and may preclude the use of typical materials and assemblies."

In essence, we rely on our experience as an analog to predict future performance which while emotionally comforting may be intellectually disingenuous. In a world where the rate of change appears to be accelerating, relying on the past seems an increasingly risk fraught proposition. What if the typical analogs aren't representative of the conditions we are actually dealing with?

So where do these special buildings exist? How about in every Canadian community – the recreation Centre. Hockey rinks, curling sheets, community pools, even hot yoga studios, and even the odd industrial or commercial facility such as composting facilities and commercial laundries. All of these occupancies and more can present challenges to envelope design and construction.

Slightly more insidious are recent design changes in response to social enlightenment, sustainable construction objectives and new codes and regulations. The recent emergence of "white", "cool", "high albedo" and other euphemisms for non-traditional roofing systems has revealed vulnerabilities. In an industry steeped in traditions, I consider materials with less than a 40 year track record to be "new" or "non-traditional". Any system or material with less than two full life cycles under its belt is "new" to me.

More recently the implementation of NECB 2011 (then 2015 and 2017 in very short order) has seen typical commercial roof insulation levels jump from R-10 (2") or R-20 (4") for a good roof to a *minimum* of R-40 (8"). What are some of the unintended effects of such radical change? Time, and possibly the computer, will tell. Recent emphasis on sustainability has increased our desire to design more efficient new structures. This has led to the development of more energy efficient envelope and roofing assemblies, and the use of non-traditional and sometimes even novel assemblies – many of which do not have a substantial case history to commend them. This, combined with non-typical interior conditions, can be a recipe for disaster!

Let's set some general parameters for what would constitute a high humidity or special environment. These are my guidelines, generally supported by ASHRAE and other standards/design guidelines.

- Interior operating temperature exceeds 25°C for prolonged periods (i.e. more than 8 hrs) on a repeating basis.
- Interior operating humidity exceeds 40% regularly (several times per week or seasonally).
- Aggressive chemicals in interior air.

So what does this all mean? Let's look at vapour pressure – the pressure exerted by imbalances in moisture vapour within two separated bodies of air. In the case of a typical Canadian community pool condition:

- Wintertime exterior conditions: -20°C, 30% Rh Vapour pressure 38Pa
- Interior operating conditions: 25°C, 45% Rh Vapour pressure 1425 Pa

The net vapour pressure acting outwards on the roof and envelope assemblies is 1.4 KiloPascals! To put that in perspective – the Calgary ground snow load from the Alberta Building Code is only 1.1 kPa and the basic 1/50year wind load is a measly 0.48 kPa. So the pressure exerted on the envelope by invisible water molecules in the air is <u>greater</u> than the snow load and the wind load – why are we not designing for it? Well we should be.

Where is all this water vapour coming from? Let's revisit the community pool. A typical small recreation pool can be considered as follows:

- Pool Hall building (Natatorium): Volume 2500 m3
- 25m standard pool length with 8 lanes (standard activity): Area 300 m2
- Water temperature 29°C

- Typical outdoor conditions: Winter -4°C, Summer 28°C

When the pool is occupied, using an activity factor of 1 gives 60L/hr of evaporation and during un-occupied hours (activity factor 0.1) yields 17L/hr of moisture given off to the air. Wave pools, hot tubs and waterslides all have activity factors > 1.0 and increase the evaporation rate – have you even seen any community pools without these features lately?

Now certainly it can't be as bad in ice rinks right? Not so fast – we still have a giant puddle of water in our building it just happens to be frozen. The saturation vapour pressure over calm water and ice are virtually identical down to -5°C which is about the limit of most ice making plants. Also the wintertime condensation potential within roof and envelope assemblies is higher (about 2 times) for ice rinks because of the generally colder temperatures throughout the roof/envelope assemblies.

So what can we do about this? Certainly mechanical ventilation and, if possible, dehumidification are important but be aware that the mechanical designer is concerned with the comfort of occupants and the quality of the indoor air. Design standards for indoor air quality in pools and ice rinks focus the ventilation at the level of the people and not up near our roof assemblies. Ice rinks, pools with waterslides and diving towers tend to be quite high roofed and the mechanical designer is compelled to direct the ventilation where the people are – at the pool level/ice surface or bleachers; so there is no real ventilation at the roof or upper walls.

Going back to our typical small pool the minimum ventilation rate necessary to control that condensation is about 5 ACH with ASHRAE recommending rates between 6 to 8 ACH.

Our mechanical design colleagues aren't insensitive to our plight with the ASHRAE Applications Handbook (Chapter 4, 1999) noting:

"Humans are very sensitive to relative humidity. Fluctuations in relative humidity outside the 40% to 60% range can increase levels of bacteria, viruses, fungi and other factors that reduce air quality. For swimmers, 50% to 60% relative humidity is most comfortable. High relative humidity levels are destructive to building components. Mould and mildew can attack wall, floor, and ceiling coverings (as well as your E&O insurance policy …I added that, not ASHRAE); *and condensation can degrade many building materials. In the worst case, the roof could collapse due to water condensing on the structure."*

Well that is a cheery outlook! Sorry to be a bit dour but the worst case has happened, more than once. The suspended acoustic ceiling, some lights and other equipment suspended from the roof of a BC Lower mainland community pool crashed into the pool while it was full of little swimmers. While traumatic, luckily there were no serious injuries.

How do we deal with these problems? The first step is understanding what you are up against. There are a number of analysis methods which will help you understand the challenge and pick materials and assemblies that will give you a fighting chance.

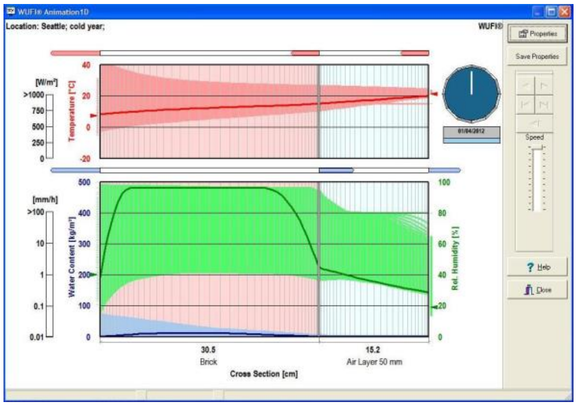
Old school methods include the Glasser method which is a simple steady state analysis using a psychrometric chart that you can get from the internet or any decent HVAC supply outfit. The problem with the Glasser method is it is steady state and the world…just isn't. Weather fluctuates, occupancy loads change and materials degrade over time.

Other options include ASTM C755 (2015) Standard Practice for Selection of Water Vapour Retarders and ASTM E241 Standard Guide for Limiting Water Induced Damage to Buildings.

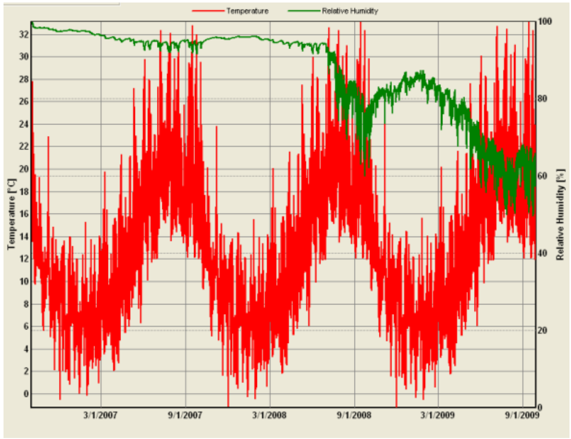
Understanding the complex interactions between heat, air and moisture movement within assemblies of new high performance buildings or buildings with special occupancies is key to ensuring longevity and durability. These coupled interactions are dynamic, multi-dimensional phenomena and are not adequately modeled using one dimensional or static analysis.

Known commonly as hygrothermal or HAM (heat air and moisture) simulation, modern numerical methods based on the finite element/finite volume principle are employed to predict the transient thermal and hygric behaviour of multi-layer building assemblies exposed to natural weather and user defined interior conditions. The use of hygrothermal computer simulation programs is supported by various standards including ASTM E-241 (2000), WTA Guideline 6-2-01 and ASHRAE/ANSI 160 (2007). For the purposes of this brief, the focus will remain on programs with support in North America.

WUFI®Pro (Wärme und Feuchte instationär) is a one-dimensional heat and moisture transfer model that is used to assess the hygrothermal behavior of multi-layer building envelope assemblies. Created at the Fraunhofer Institute for Building Physics in Germany, a partnership with the Oakridge National Laboratory (ORNL) resulted in the development of a North American version. Currently, WUFI is in use in both Canada and the United States.



WUFI uses measured weather data, including driving rain and solar radiation, allowing realistic simulations of the behaviour of assemblies under exposure to weather. Its calculations are based on detailed data regarding vapour diffusion and liquid transport in building materials and have been validated by measurements obtained in the laboratory and outdoor testing. One of the latest upgrades allows for the accounting of imperfections within the components and assemblies by introducing moisture sources and adding vented areas. WUFI can be used to test potential solutions as well as assess deterioration mechanisms within building envelope assemblies. It can assist with estimating the drying times of materials having trapped or concealed construction moisture, investigating the danger of interstitial condensation, or studying the influence of driving rain on exterior building components. The program can also help to select repair and retrofit strategies with respect to the hygrothermal response of a particular assembly subjected to various climates. This allows the comparison of different designs with respect to total hygrothermal performance.



In essence, WUFI is designed to model only porous materials. Metals, glass and other effectively impermeable materials are cumbersome to model and require a certain manipulation of program settings. WUFI is only able to model one-dimensional systems. The interactions between bridged materials, such as insulation and framing, cannot be accounted for. Because of the limitations noted above, unless one is an expert in verification of input data, the model is limited to the value of "warning – change your design to one that is more safe". This is sufficient and appropriate for most design assignments.

HygIRC is a Canadian program developed for research purposes by the Institute for Research in Construction (IRC) of the National Research Council (NRC) of Canada. The program was part of MEWS (Moisture Management for Exterior Wall Systems) Research Program as a way to analyze the building physics in low-rise, wood-frame construction. Initially designed for research purposes, HygIRC is slowly being introduced into the commercial sector. A major benefit of HygIRC is the ability to not only identify the area of greatest moisture build-up, but also the wetting period duration (Mukhopadhyaya et al 2003). HygIRC not only pinpoints a potential problem, it also aids in determining the magnitude and severity of that problem.

The newness of this software means that its accuracy and reliability are still uncertain and can only be confirmed by long-term, controlled experiments. As such, the program is constantly undergoing adjustments to its algorithm and set-up. Another drawback is the RHT scale that is unique to this program. The RHT scale applies a linear weight to relative humidity and temperature; this assumption may not always be the case. Only through long-term, controlled experiments will the validity of the RHT assumptions be confirmed. Also, the RHT scale is not immediately intuitive. Unlike HygIRC's contemporaries, which can give numbers and results that can be easily interpreted; the RHT scale requires a certain amount of background knowledge and understanding of how that scale was derived.

Computer simulation programs give other design professionals the ability to model designs that would be difficult to calculate otherwise. Simulations quickly verify a design's expected performance, highlight problem areas for revision, or predict potential long-term problems in novel, un-tried assemblies. While not a substitute for good judgment, judicious use of simulation programs can highlight potential deleterious side effects and pin-point potential improvements to proposed assemblies, increasing efficiency and reducing costs.

General guidelines for the design of roofing systems and the use of computer programs for predicting such problems were presented by Andre Desjarlais and Nan Byars in their paper *Predicting Moisture Problems in Low-Slop Roofing* (Thermal Envelopes VII). They presented four tenets, which are equally valid for the envelope as a whole:

1. *The average yearly moisture content of an [envelope] must not increase with time*
2. *No condensation can occur under the roof membrane* (…behind the air barrier?)
3. *If a leak occurs in the roofing system, no condensation can occur on the deck* (if insulation is compromised, the structure should still be condensation free)
4. *If a leak occurs in the [envelope] the drying time will be as short as possible.*

OK you say, thanks for trying to scare and intimidate us – but we have been doing this for years and yes a few problems do pop up, but these are related to sloppy construction or bad building operations. I concede the point that a poorly constructed envelope or a badly operated building are disasters waiting to happen. David Scott and Mark Lawton present some obvious cases in *Envelope Durability Problems in High-Humidity Buildings.* They concluded the following based on lessons learned from a series of case studies involving high humidity occupancy buildings:

"Some people would argue that the construction industry has improved its knowledge and methods. Indeed, the concept that high interior humidity, air leakage points, and ex-filtrating pressures result in moisture and durability problems is hardly surprising. However, the authors would note that in practice we see very similar design details employed in current designs. The key difference in the example buildings presented here and in many buildings being constructed today is simply the time it takes for the problems to appear. The industry has yet to find ways of addressing the concern in a consistent manner.

Some general conclusions to be drawn from these examples include:

- *Mechanical pressurization of building envelopes that are required to maintain high relative humidity must be kept at an absolute minimum….*
- *The lack of intentional pressurization did not negate the need for air barrier continuity….*
- *Operating buildings at higher negative pressures is contrary to the design thinking of most designers, and they will need convincing that it is a valid design approach. Negative-pressure operation still requires attention to airtightness to avoid cold drafts and perimeter-zone heating problems and may require special measures such as vestibules at entrances.*

- *A common factor in the examples was the lack of continuity of the air barriers at the interface between different assemblies and materials and, to a lesser extent, the joints between similar materials….*
- *The specific problems discussed related primarily to design, detailing, and material selection rather than poor construction….*

New and emerging materials can present hidden and often unexplored problems. In *Condensation Problems in Cool Roofs,* Kunzel, Bludau and Zirkelbach all writing for the German Institute of Building Physics (IBP), explored a problem with condensation in "cool" roofs – a sustainable design strategy intended to reduce building energy consumption and control urban heat islands. The change or course was away from traditional roofing systems, which were darker in colour. What they found was roofs designed to meet the tenets of Desjarlis and Byars had the capacity to dry to the interior (i.e. a weak interior air/vapour barrier on purpose) and tended to accumulate moisture by vapour diffusion. But that dark surfaced roofs generated enough heat to drive off the accumulated moisture while their "white" or "cool" counterparts did not. The disparity was worse the "colder" the location explored and for cold areas (i.e. Calgary) the problem becomes unstable and the roof accumulates moisture over time to failure.

What about those aggressive chemicals you mentioned in the opening? Pools, in particular, and those that use some form of chlorine can be particularly dangerous. A by-product of the chlorine disinfectant process is a chemical known as Chloramine – a derivative of chlorine, which is highly corrosive to a wide range of metals including most stainless steels. But I thought stainless steel was good? I'm not saying it isn't – it just doesn't belong anywhere near a chlorine disinfected pool.

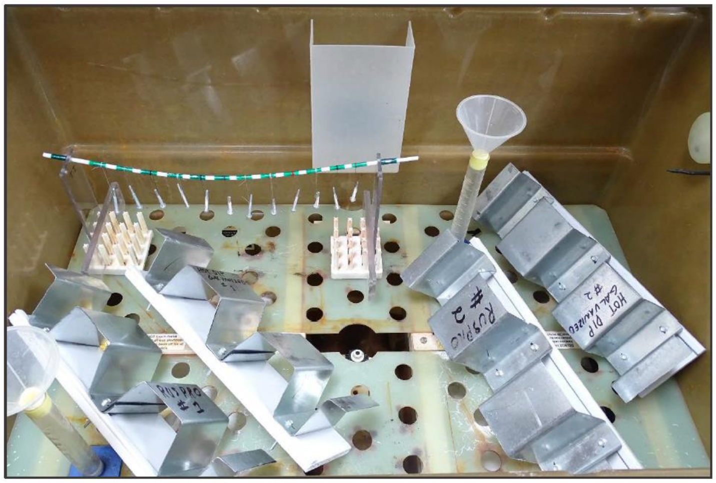
The photo below is of a stainless steel bolt supporting the waterslide in a major community recreation pool after only a few years in service. The irony was that the pool was supposed to be Ozone disinfected but was changed to chlorine for cost savings.

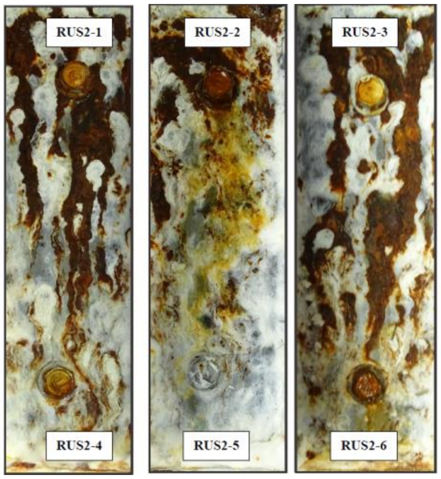
Metal deck fairs little better and often the corrosion origin is at fastener penetrations. The interaction between the hot work steel of case hardened self-tapping screws and the cold worked deck steel as well as the galvanizing is a corrosion cocktail once acids (like chloramine) or salts are introduced.

But we use corrosion protected screws to fasten down our gypsum sheathing and insulation boards – surely those will be ok! Right? The manufacturers give us test data that say they are good for 3000 hours? Well yes … and no. Let's look at the way they get tested and how we use them.

For one of Calgary's new recreation centres, RJC, the Architects, and the Builders, all participated in a study to see just how this all works in the real world. The two photos above right show a pristine (left) corrosion protected screw taken directly from the packaging and another screw that was driven into metal decking and then removed prior to testing (right). Both were exposed to 750 hours of salt fog exposure. Note that the manufacturer's published data is based on testing pristine screws.

We also wanted to see how the screws, decking and structural steel all interacted. The photo below shows our experimental test set-up with screws and deck samples.





Metal decking was also affected which correlated with observations we had made in the field on older pool buildings.

Then what are the effective design strategies to overcome these challenges? The first is have a very robust, continuous and effective air and vapour barrier. Pools and ice rinks should be controlled to slightly negative pressure but you can't rely on the mechanical system not being monkeyed with by a well-meaning building operator or maintenance contractor.

What do I mean by robust? Well I think no vapour barrier is out and we can scratch off loose laid polyethylene and kraft or asphalt building paper – we need to be focused on adhered bituminous products or something of that ilk.

Review the details carefully and challenge the architects/envelope/roofing designer to be explicit on penetration details and interfaces. Don't accept that these interfaces may be another trades responsibility or problem – the courts won't see it that way! Understand the building use up front – if there are special environments be open that these are special and take the necessary steps to ensure they function for the life of the facility.

Look towards adhered systems including the gypsum and insulation. All those fasteners are potential air and water vapour leaks and the dissimilar mental corrosion is a problem that you cannot avoid. Eschew long cantilevers, tall parapets and unvented soffits. These are difficult areas to keep airtight and the projected cooling surface is simply too great to avoid condensation.

Commissioning is your friend! Use mock-ups, pre-construction conferences, testing, check sheets and a documented and auditable quality control program. Use the tables and procedures in CSA S-478 *Guideline on Durability in Buildings* to document the environment, aggressive conditions, anticipated durability and the consequence of failures when they inevitably occur.