Abstract

The Dynamic Buffer Zone (DBZ) is not a new concept for retrofitting problem buildings. The implementation of this approach was performed on an existing high humidity facility, with an exterior glass and aluminium curtainwall cladding, to eliminate the problem of icicles which formed on the exterior cladding. The icicles created a safety concern when they fell from the facade. Another case study will also be presented for the retrofit of the DBZ in a historic masonry building to eliminate condensation problems.

Keywords: Building envelope, condensation, air barrier, rain screen, dynamic buffer zone, mechanical pressurization.

1 Introduction

There has been much discussion since the 1950’s regarding how to provide a separation between interior and exterior environments in the cold Canadian climate. Part 5 of the 1985 National Building Code, “Wind, Water and Vapour Protection”, has outlined the minimum requirements for this separation. Section 5.3.1. discusses air barriers and their location in the building envelope. Reducing air leakage by incorporating a continuous air barrier in the building envelope design is fundamental in the successful performance and durability of the building envelope. There are a variety of approaches which have been used to achieve airtightness in the building
envelope, with some being more successful at fulfilling this requirement than others. Part 5 does not restrict approaches to airtightness, but states that “the assembly shall be designed to provide an effective barrier to air exfiltration and infiltration, at a location that will prevent condensation within the assembly……”.

Condensation and moisture build-up within the building envelope may cause the materials which make up the construction to deteriorate prematurely. Such moisture can also promote the growth of molds which can pose a health risk. Dripping water, icicles and staining appearing on or from claddings may be the first visible signs of moisture problems within the wall fabric. Wetting of the cladding and then freezing temperatures may result in spawling problems of claddings.

The physics of condensation within the building envelope is quite complex and quantification of the phenomenon using mathematical computer models is the subject of some research today. The basic factors which affect the process have been known for some time and include but are not restricted to the following: indoor and outdoor temperatures, material properties such as air and vapour permeability, building envelope construction details, indoor relative humidity and indoor/outdoor air pressure differences. Condensation on or within the building envelope occurs when water vapour is transported to a location that is at or below the dewpoint temperature.

Early researchers believed that the primary driving force in this transport was diffusion, a process dependent on vapour concentration differences and materials’ resistance to vapour flow. This idea spawned the use of a ‘vapour barrier’ in the building envelope. Researchers now realize that while vapour diffusion can be a factor in some situations, the major reason for the amount of condensation in the construction of walls during the colder seasons is the outbound mass flow of moisture-laden air through the building envelope due to air leakage.

There are three separate air pressure loads across the building envelope which cause air leakage. Wind, stack or chimney effect and mechanical pressurization have been documented in papers and the Canadian Building Digests produced by the National Research Council of Canada (NRC). William Rose provided an excellent summary of the history of condensation problems and ventilation requirements in attics in a paper presented to Thermal Envelope VI Conference (Rose 1995).

Problems still may occur in some buildings having high relative humidity where even a small amount of air could result in moisture being transported into the building envelope construction. Older buildings where the interior environment is changed to provide humidity may also experience problems they never had. The Dynamic Buffer Zone (DBZ) concept can extend the durability of the building envelope for these types of situations.

First we should look at some of the history behind the problem of condensation and how the use of mechanical pressurization was viewed by the researchers. To do that I will provide excerpts from William Rose’s paper (Rose 1995).

The first explicit statement that air leakage could be a major factor in building envelope condensation problems may have been by Neil Hutcheon of NRC, in 1950, in an unpublished report concerning a condensation problem at a Saskatchewan
hospital. Hutcheon noted frost accumulation 10 times greater than predicted by normal vapour transmission and concluded, “It seems necessary to assume some other mechanism for vapour migration than the usual one of vapour diffusion under vapour pressure differences, to explain the rate of moisture transmission. It is possible that leakage of warm, moist inside air outward and upward, carrying water vapour can account for this.” (Rose 1995). Hutcheon also discussed air leakage as an important mechanism for moisture transport, as distinct from vapour diffusion, in a paper for ASHAE in 1958 (Hutcheon 1958). With regards to pressure differences induced by building mechanical systems, Grant Wilson of NRC stated in 1961, “Buildings are sometimes pressurized by a substantial excess of supply over exhaust air. The purpose of such pressurization is to reduce infiltration, presumably to overcome drafts and prevent the entry of dust.” “(Mechanical) pressurization magnifies condensation problems that result from exfiltration of air and the practice is of doubtful merit in most Canadian climates. Instead, more attention should be given to increasing the air-tightness of the warm side of buildings. In general, humidified buildings should not be pressurized, and provision of a small suction in such buildings might be advantageous if condensation problems are anticipated.” (Wilson 1961). Thus even early on it was evident to researchers that mechanical systems might be used to reduce or eliminate condensation problems due to air leakage.

In 1965 in a paper entitled ‘Moisture Accumulations in Roof Spaces Under Extreme Winter Conditions’, presented to the RILEM/CI Symposium on Moisture Problems in Buildings, Dickens and Hutcheon identify air leakage as a mechanism of moisture accumulation. They go on to describe some of the mechanical ventilation of roof spaces to avoid condensation problems. “The building had experienced severe condensation problems prior to the installation of fans which were used initially to dry out the wet roof structure. The fans were also kept running the following winter to counteract air leakage into the roof space from the heated area by slightly pressurizing the space…. Ideally the pressure should be sufficient to prevent air flow into the roof space from below without causing significant reverse flow of cold air into the building.” (Dickens and Hutcheon 1965).

In another paper presented at the same 1965 symposium, Trygve Isaksen from the Norwegian Building Research Institute identified air leakage as a cause of condensation within roof spaces and offered three possible solutions to the problem in a flat wooden roof. He states: “A cheaper solution is to use a small medium pressure fan to blow in cold air above the insulation in the existing roof, creating a super pressure in the air space to prevent air leakage from beneath.” (Isaksen 1965).

Both papers pointed out that one method of preventing humid interior air from leaking into an air space within the building envelope was to pressurize the space with outside air by mechanical means.

Kerby Garden wrote in 1966, in a Canadian Building Digest concerning swimming pools: “The best enclosure design may be one in which the exterior enclosure elements are not exposed to the severe environment of the swimming pool
space. This can be accomplished by incorporating a heated space between the interior surfaces and the main enclosing elements and ventilating it with low humidity air. In this case the inner layers of materials will be required to resist the passage of air and vapour, but will not be subjected to a temperature gradient. Any moisture that might leak into the space will not raise the humidity appreciably because it will be removed by the ventilation process. This space can be as little as is required for proper air movement or it can be wide enough to perform as a corridor.” (Garden 1966).

Here the concept of a buffer zone between the humid interior and the exterior envelope is introduced. The buffer zone is ventilated with low humidity warm air which flushes away any moisture that might leak into it. The idea of pressurizing this space to prevent air leakage was not discussed. The use of a buffer zone to prevent condensation in high humidity buildings had actually been used in practice before this time. For example, Ernest Cormier an architect working in eastern Canada in the 1950’s and 60’s, had used heated air between single lites of glass in a Government Printing Office to prevent condensation (Handegord 1998).

When the idea of a conditioned buffer zone was combined with the idea of mechanical pressurization to prevent air leakage the result is what is now termed the Dynamic Buffer Zone (DBZ).

The first description of the DBZ may be in the book ‘Building Science for a Cold Climate’ (Hutcheon and Handegord 1983). “When the insulation is located between two impermeable layers it becomes possible, in principle at least, to control air and vapour flow in walls and roofs by pressurizing this intermediate space mechanically using dry air. The impermeable layers may have to have a high degree of airtightness to avoid loss of energy by leakage. This approach is attractive in extreme situations such as high-humidity textile mills and swimming pool buildings where heated, ventilated air under pressure is needed and can be supplied by way of the intermediate space.” The fact that the authors say, “at least in principle,” suggests that few built examples were available at that time.

2 Dynamic Buffer Zone -- (DBZ)

While the code requires air tightness in building envelope assemblies subjected to a temperature differential, a differential in water vapour pressure and a differential in air pressure, the high degree of airtightness required to eliminate or at least control condensation problems in some humidified buildings may not be possible. This is true in existing building retrofits, the repair of building envelope failures, and even in some cases of new construction.

The Dynamic Buffer Zone concept introduces, between the inner and outer surfaces of the building envelope, heated cold outside air containing little moisture. The DBZ concept attempts to eliminate air leakage into the building envelope by pressurizing this area. It is not intended to ventilate this space to dry it out. Heating
of the outside air is only necessary to a degree where inner surfaces will not become excessively cold, and where infiltration through imperfections in the inner surface will not result in condensation. Such infiltration of cold air could result in condensation on cooled surfaces, freezing of pipes and comfort problems. The DBZ air temperature is much closer to that of the interior. This can in turn reduce stack effect in the cavity and reduce air infiltration through the wall at lower elevations.

Obviously a certain degree of air tightness is necessary in both the inner and outer surfaces of the wall to maintain positive pressure within the air space between them without presenting other problems of noise and excessive cost.

In tests on buildings in Ottawa, it was found that the exterior mass masonry and interior finish lath and plaster were sufficiently air tight to achieve the pressures required (Quirouette 1977). By contrast the retrofit of a hospital aluminium and glass curtainwall to be described further in this paper required extensive sealing of the exterior and some interior sealing to achieve the required air tightness.

The fans which operate the DBZ should be fully automated to see economies in the design and to control the system performance during changes in weather conditions. One control strategy is to initiate the operation of the system based on outside air temperature while another is to activate the system when the moisture content of the air in the buffer zone increases to above outside levels. The writer prefers the temperature approach because temperature is easier to monitor.

In 1986, based on discussions with Kerby Garden, Alberta Public Works eliminated severe condensation problems within the terra cotta dome of the Alberta Legislature Building by pressurizing the air space below the terra cotta with heated dry exterior air. This was a direct application of the DBZ concept (Ogle et. al 1995).

In 1996 and 1997 building envelope consultants Michel Perreault and Rick Quirouette implemented the DBZ in several heritage masonry buildings that were being renovated, including new operating conditions with high interior humidities which potentially place the masonry in peril. Pressure, temperature and humidity data were obtained from test sections of the walls and control strategies for the mechanical system were devised (McGrath and Perreault 1996) and (Quirouette 1997).

3 Case studies

3.1 Case study No. 1 Alberta Legislature Building (1986)

In the early 1980’s it was noted that the terra cotta tile dome of the Alberta Legislature had, in one of the 8 segments, bulged from its original curved plane. One of the concerns addressed in the subsequent structural and building envelope studies was the severe condensation that was occurring on the inner surfaces of steel and terra cotta book tiles.

The dome is approximately 55 feet in diameter and is composed of an outer terra cotta decorative or finish tile and an inner book tile supported on a steel frame.
From the same steel frame, an inner dome is suspended, creating a large attic space. Leakage of humid interior air through a stairwell access and through the construction was resolved by limited air sealing of the known air leakage problem locations and implementation of the DBZ concept (Figure 1).

A 500 cfm fan, was used to extract cold exterior air from the cupola at the top of the dome. The air was ducted into the attic space and around the attic space. A glycol heat pump was used to heat the air being introduced. Two heaters with a 40 kW total output were installed in addition to augment the air temperature when necessary. The fan pressurized the attic space to about 30 Pa, during cold conditions, while the heaters maintained the space at a minimum of 5°C.

The DBZ eliminated the condensation problem without affecting the aesthetics of the stabilized terra cotta dome. Actual measurements of typical conditions within the attic during a winter day before and after implementation of the DBZ are noted in Figure 1.
3.2 Case study No. 2: Aluminium and glass curtainwall Alberta (1997 - 98)

The interior environment of this problem building was operated at a positive pressure relative to the exterior, of about 40 Pa and a relative humidity at approximately 35% during the winter. Operational requirements dictated that these operating conditions could not be changed.

The construction of the building envelope consisted of a finished inner wall of drywall, metal furring, cast-in-place concrete (CIP) or concrete block. Openings within the CIP concrete portions of wall were created for the installation of double glazed sealed units in aluminium frames. Adhered to the exterior of the CIP concrete and concrete block was a peel and stick membrane. The intent of this design was for the membrane and backup wall to provide a continuous air barrier system. Rigid insulation was mechanically fastened tight to the membrane. The exterior curtainwall cladding consisted of a single lite of vision glass or single lite of opaque glass flush glazed, in a so-called “open rainscreen” aluminium frame. The cladding was designed to provide aesthetic feature horizontal covercaps, and a uniform reflective appearance from the exterior. It was only designed to shed and drain rainwater, not to provide any air tightness.

In the first winter of operation condensation appeared on the inner surface of the exterior vision lites of glazing and icicles formed on the exterior of the covercaps and glass. During periods of warm weather or when the sun created enough heat to reduce the adhesion of the ice on the metal and glass of the exterior, large pieces would depart the facade and ricochet off lower horizontal covercaps away from the building facade. This created a significant safety hazard to pedestrians within a zone of 9’-0” (2.74 m) from the building perimeter.

The cause of the condensation was determined during the installation of the DBZ, to be flaws in the membrane system between the cast-in-place concrete and the window frame (Figure 2). This allowed highly humidified air to escape into the cold cavity space between the membrane and the exterior glass and aluminium curtainwall where it condensed. During warming periods water would drain to the exterior through weeping provisions provide in the aluminium curtainwall framing. Under cold conditions the water would form icicles on the cold exterior surfaces.
During the winter of 1997-98 a 6000 sq. ft. full scale test section of the wall was selected to be converted to a DBZ to determine if this concept could alleviate the safety issue. Two masonry clad stairwells isolated the test area from the other areas of glass and aluminium cladding.

The test section of wall was scaffolded on the exterior to facilitate the sealing of the exterior glass and aluminium curtainwall framing and for the cladding to be air sealed back to the original air barrier system of the building. Construction took place from November to January. The scaffold was tarped and the work platforms heated. The various details necessary to provide this air tightness were complicated by the existing aluminium framing system configuration and provided the design team and the retrofit contractor with several challenging issues. Removal of the opaque spandrel glazing was necessary to modify the vertical aluminium tubes and flashings of the original system. The vertical tubes were used as air ducts. Holes cut into the tube walls of these allowed for horizontal air distribution. The gaps between aluminium sections were bridged with galvanized sheet metal to provide support for the installation of a high temperature peel and stick membrane that provided the seal. The design only required that sufficient air tightness be achieved in the exterior cladding so that an air pressure could be created in the cavity.

The existing configuration of the physical plant central air system of the allowed the design team to install a new small duct prior to the humidification section of the unit. This provided filtered preheated air for the DBZ system with a low moisture content. A VAV box and an additional heating coil were installed in the ductwork to control the flow rate in the DBZ and provide additional heating of the air if it was necessary (to date no additional heating has been required). The insulated
ducting was installed from inside the penthouse, across the roof, to a new horizontal parapet duct that was designed to distribute the air at the top of the test section of wall (Figure 3).

Since the central air system produces a high static pressure (in the range of 1500 Pa to 2500 Pa), a pressure reducing damper (blast gate) was installed between the central air system and the VAV box. This damper was adjusted to reduce the supply air stream static pressure to a maximum of around 70 Pa. A safety sensor was installed near the top of the wall cavity. If a static pressure above 120 Pa occurs the controls automatically shut off flow at the VAV box and an alarm is sent to the building operator.

The new DBZ ventilation control devices were tied into the existing Direct Digital Control (DDC) building automation system to ensure accurate control. The VAV box flow rate modulates according to a DDC control loop that references to a static sensor located in the wall cavity near the bottom of the DBZ wall. The sensor measures the differential pressure of the cavity with respect to the adjacent interior building space. The box flow rate modulates to maintain a pressure at a minimum differential pressure setpoint of +20 Pa.

This was a pilot project and the first installation to the design teams knowledge, of the DBZ concept for a curtainwall cladding. To foster a successful outcome additional stand-alone monitoring stations were installed within the vertical height of the wall, plus one on the exterior. The exterior monitor senses the outdoor conditions. The three wall monitoring stations sense temperature and humidity, and measure the differential pressure between the wall cavity and the interior space. One
of the stations also monitors the differential pressure between the outdoor air and interior of the building.

Monitoring is performed by portable ACR brand dataloggers configured to take samples four times per hour, for a maximum of around 90 days of continuous data. Datalogger information is downloaded onto a portable laptop PC without interfering with the data acquisition process underway. Data can then be graphed and analyzed to review the system’s performance and fine tune its operation.

Data from the monitoring system clearly shows that the approach implemented does work (Figure 4). The visible (more real) proof is that condensation is not appearing in the vision areas of the wall and no icicles are forming. Monitoring of the wall is continuing. The cost of operating the system is estimated at less than $300 CAN per year.

4 Summary

While the approach of creating air tight building envelopes has advanced, the ability to achieve high enough levels of airtightness in high humidity buildings may not always be possible, particularly in retrofit situations. Condensation within the building envelope can be detrimental to the wall components’ durability. Health and safety issues are significant and cannot be ignored any longer.
To date the idea of altering interstitial wall pressures by mechanical means to control exfiltration has largely been overlooked. Some early researchers did suggest mechanically induced pressure or ventilation of air spaces within the envelope as a means of solving condensation problems. However, it is only fairly recently that the pressurization of wall cavities using dry exterior tempered air has been used. The Dynamic Buffer Zone technique has now been implemented successfully on several buildings.

The two case studies presented of existing buildings with building envelope problems have shown that durability and performance of the building envelope can be enhanced by implementation of the DBZ.

5 References


Hutcheon, N.B., (1958) Vapour problems in thermal insulation. Symposium on Thermal Insulation, ASHAE, Minneapolis, Minn.


