Building Envelope Failure Diagnosis Project: Terrasse du Patro Housing Development

by Eric Turcotte and Adam Neale

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Dr. Dominique Derome
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# TABLE OF CONTENTS

LIST OF FIGURES ................................................................................................................................. II

LIST OF TABLES ....................................................................................................................................... II

1  INTRODUCTION ................................................................................................................................... 1

2  DESCRIPTION OF THE TERRASSE DU PATRO DEVELOPMENT .................................................... 2
   2.1  GENERAL INFORMATION .................................................................................................................. 2
   2.2  DESCRIPTION OF THE PROBLEM .................................................................................................... 3

3  DESCRIPTION OF THE ENVELOPE ..................................................................................................... 4

4  DIAGNOSTIC TOOLS ............................................................................................................................. 8
   4.1  THERMOGRAPHIC IMAGING ............................................................................................................ 8
   4.2  RELATIVE HUMIDITY READINGS .................................................................................................. 11
   4.3  POLYETHYLENE EXPERIMENT .................................................................................................... 12
   4.4  CONDENSE .................................................................................................................................... 14

5  ANALYSIS ........................................................................................................................................... 16
   5.1  THERMAL BRIDGES ...................................................................................................................... 16
   5.2  WATER INFILTRATION .................................................................................................................. 19
   5.3  CONDENSATION ........................................................................................................................... 23

6  SUGGESTIONS .................................................................................................................................... 26
   6.1  RE-BUILDING ................................................................................................................................. 27

APPENDIX A: PLAN OF THE SITE ............................................................................................................. 30

APPENDIX B: CROSS-SECTIONAL DRAWING OF SLAB/WALL JUNCTION ........................................ 31

APPENDIX C: SLAB JUNCTION DETAIL ................................................................................................. 32

APPENDIX D: CONDENSE ANALYSIS .................................................................................................... 33

APPENDIX E: CONDENSE ANALYSIS .................................................................................................... 34

APPENDIX F: CONDENSE ANALYSIS .................................................................................................... 35

APPENDIX G: CONDENSE ANALYSIS .................................................................................................... 36

APPENDIX H: EXISTING WALL DETAIL ................................................................................................. 37

APPENDIX I: PROPOSED MODIFICATIONS ............................................................................................ 38
LIST OF FIGURES

Figure 1. Apartment building studied ................................................................. 2
Figure 2. Spancrete prefabricated slab .............................................................. 2
Figure 3. Example of mold growth in closet ...................................................... 3
Figure 4. AutoCAD drawing of the slab/wall junction ...................................... 4
Figure 5. Cross-section of the wall assembly ..................................................... 5
Figure 6. Perspective of the wall assembly ......................................................... 6
Figure 7. Discontinuity caused by Masonite board placement ....................... 7
Figure 8. Sample infrared image ................................................................. 8
Figure 9. Polyethylene sheet test .................................................................. 13
Figure 10. Indoor (left) and outdoor (right) infrared images of thermal bridge leaks .... 17
Figure 11. (left) Condensation is apparent in the colder .................................. 17
Figure 12. (right) Exterior side of the faulty closet: thermal bridge ............. 17
Figure 13. Window sill images ....................................................................... 18
Figure 14. AutoCAD drawing of window detail ................................................. 19
Figure 15. Two examples of mold patches adjacent to Masonite bearing strips .... 20
Figure 16. Water stains at the base of the wall ............................................... 21
Figure 17. Gap behind the flashing (left) and insufficient overhang (right) ....... 22
Figure 18. Modified wall assembly ............................................................... 27

LIST OF TABLES

Table 1. Thermographic images ................................................................. 9
Table 2. Relative humidity readings ............................................................ 12
Table 3. Summary of Condense analysis results for high indoor RH .......... 15
Table 4. Summary of Condense analysis results for low indoor RH .......... 15
1 INTRODUCTION

In any building, the performance of the building envelope plays an important part in the overall behavior of the construction. The building envelope designates the system composed of the walls, roof, foundation, etc. which is designed to protect the building’s interior from the natural elements: air, water, heat, light, noise, etc. The comfort of the occupants, along with the durability and economical performance of the building, depend directly on the capacity of the building’s envelope to act as a barrier to these elements. In a way, separating the occupants of a building from outside influence is the main reason for having the building in the first place. Thus it is not surprising that the most common cause of dissatisfaction in a building performance is related to the failure of its envelope.

In this project we will investigate the role played by a building envelope failure in various problems encountered in a group of buildings that are part of a social housing project located in the town of St-Hyacinthe. The managers of this housing project have noticed recurrent problems affecting the interior of the buildings and its occupants, mainly condensation, mold, and high heating costs.

Using basic building science principles, we will demonstrate and explain the mechanisms by which the envelope of these buildings can be held responsible for the given failures; first we will provide general information about the project and its history. Then we will describe precisely the various problems encountered in the buildings. We will also provide a graphical description of the existing physical envelope as observed on-site and as it appears in the original architects drawings. In the course of our investigation we will use some diagnostic tools such as thermo graphic imaging and relative humidity readings to get additional understanding of the failure mechanisms. Additionally, the theoretical performance of the existing walls will be analyzed with a special software called Condense, and compared to their actual performance.

Then, using all the gathered information, we will analyze the behavior of the envelope and show clearly how it causes the various problems witnessed. Once the specific causes of the problems will have been highlighted, we will present possible corrective solutions for remedying the problems.
2 DESCRIPTION OF THE TERRASSE DU PATRO DEVELOPMENT

The Office Municipal d’Habitation de St-Hyacinthe is responsible for a group of 10 structures located in a development called Terrasse du Patro. Because these buildings all use similar construction techniques, one in particular will be studied for the purposes of evaluating the general building envelope performance of all. The structure in question is shown highlighted in Appendix A (units 812 and 814), and is a three-story apartment complex with a total of 14 living units. In particular, data was obtained from apartment #1 of 814 Terrasse du Patro.

Figure 1. Apartment building studied

2.1 General Information

The buildings of the Terrasse du Patro were constructed in 1970. The structural components consist of concrete block walls and pre-cast concrete slab elements making up the floors and the roof (shown in Figure 2). These slabs, known as hollow core slabs, are pre-tensioned to resist deflection and have hollow cores to save weight. They are eight inches thick, 3’4” wide and span 21 feet. They are manufactured in Wisconsin by a company called Spancrete.

Figure 2. Spancrete prefabricated slab
The original insulation consisted solely of 2” expanded polystyrene on the inner wall surfaces, and the walls were finished with gypsum on the inside and stucco on the outside. The apartments are heated using a radiant water heating system (which has undergone major renovations in 2002). While the modifications to the buildings are not well documented, it is known that before 1980 there were some major modifications to the design of the envelope. It is unknown whether it was due to poor stucco work, insufficient insulation or other reason, but a second layer of stucco was built up on top of the original one with a 2” gap between the layers. The gap between the two rain screens was filled with sprayed foam polyurethane insulation, applied with a variable thickness. Other modifications include the addition of insulation in the closets, radiant heating system repairs and other indoor renovations. Also, some occupants have done personal modifications to the apartments, but these vary too widely from one residence to the next to be properly documented.

2.2 Description of the problem

The manager of the *Terrasse du Patro* development has received numerous complaints from his tenants about mold, and consequently requested an investigation into these problems. Photo documentation indicates that mold and condensation are serious recurring issues in the closets of the bedrooms and in the kitchens of several different buildings (Figure 3 and 11). The radiant heating system found in the apartments is sufficient to warm the air, but at very high cost. Residents also complain of drafts in the winter, and cold spots were apparent in certain locations in the residences. To generalize, the primary issue is heavy condensation and mold growth, with secondary issues of high heating cost and inadequate thermal comfort.

![Figure 3. Example of mold growth in closet](image)
3 DESCRIPTION OF THE ENVELOPE

The exterior walls are made of concrete masonry units (CMU) or concrete blocks. Some of them are load bearing: they are the sole support for the concrete slabs which form the floors and the roof. As can be seen in Figure 4 and on the construction drawing in Appendix B and C, the slabs are supported only at their extremities; along their length they only “float” next to the wall. The walls supporting the slabs are made of 8” blocks, while the other ones are 6” blocks.

Figure 4. AutoCAD drawing of the slab/wall junction
Figure 5 shows the various elements composing the wall: stucco, sprayed polyurethane, old stucco, concrete block, expanded polystyrene, gypsum board. In some area there is likely a small air space between the new stucco and the sprayed polyurethane, because of the variable thickness of the polyurethane. See also Figure 6 for a perspective view of the assembly.

![Cross-section of the wall assembly](image-url)

*Figure 5. Cross-section of the wall assembly*

*all dimensions in mm unless otherwise indicated*
Figure 6. Perspective of the wall assembly

The construction drawings in the appendix show that originally there was no insulation provided at the extremities of the slabs where they rest on the concrete blocks: the void is filled with masonry. Today the sprayed polyurethane covers this area.

Note also on these drawings that the slabs don’t rest directly on the surface of the concrete blocks: rather they rest on Masonite boards laid on top of the blocks. The Masonite boards have the same 8” width as the blocks. At regular intervals, a reinforcing bar goes through the Masonite board to anchor the slabs to the walls. One can only imagine that these bars
necessitate a discontinuity in the Masonite covering as can be seen in Figure 7 below. This discontinuity creates a possible path for air infiltration.

Figure 7. Discontinuity caused by Masonite board placement

Another observation that can be made from the construction drawings is that the roof is totally uninsulated: the plans called only for expanded polystyrene along the walls. The roof is simply composed of the concrete slabs, probably covered with some waterproof membrane.
4 DIAGNOSTIC TOOLS

Several different diagnostic tools were used to help isolate the problems seen in the building development. These include thermographic imaging, relative humidity readings and polyethylene vapour barrier experiments. They are described in the following sections.

4.1 Thermographic imaging

Thermographic images are the result of taking a picture with an infrared camera. These cameras have the ability to detect the temperature of a surface by recording the energy radiating from that surface. Infrared energy is not visible to the human eye, but at ordinary temperatures all objects emit a certain amount of it. Since thermal cameras sense infrared energy (which varies with the temperature of objects in a scene), the image generated provides a thermal signature of the scene. Thermographic photos are widely used as a tool in building envelope failure diagnostics because of the ease at which they identify irregular temperature zones on a buildings interior and exterior surfaces. Typically the user can set the desired range of temperatures to be displayed in the photo, and the colors in the image will vary from the lowest temperature to the highest. If the image is taken in color, the spectrum will vary from very dark blue (nearly black) to white as the temperature increases.

The camera used for this project was the Agema Thermovision 470. When taking the infrared pictures, the user must enter several parameters that will affect the quality and accuracy of the images. The first is the emissivity of the material, which is a property (between 0 and 1) that determines the amount of radiation emitted from the material being viewed. For building materials this value is typically 0.9. In addition, the user must enter the distance from the camera to the surface, ambient temperature and the range of temperatures that the image will display. Once the parameters are entered correctly into the camera’s built-in computer, the image is then stored for later retrieval and analysis. A sample image is shown in Figure 8 with the corresponding temperature scale for that image.

Figure 8. Sample infrared image
Table 1 describes the various images taken of the apartment in St-Hyacinthe. For the infrared photographs shown, the emissivity of the materials was taken to be 0.9, the ambient temperature was 21.2 °C indoors and 4.4 °C outdoors.

### Table 1. Thermographic images

<table>
<thead>
<tr>
<th>Image #1</th>
<th>Location: Indoors, Master Bedroom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td>This image shows one of the corners of the room where the concrete slab meets with two exterior walls. A visibly darker portion can be seen in the corner, indicating a notably lower temperature along the joint where the slab rests on the wall. The window in the lower left portion of the image is visibly cooler than the average wall temperature.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Image #2</th>
<th>Location: Indoors, Master Bedroom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td>This image is a continuation of the previous one, which displays the joint where the concrete slab rests on one of the exterior walls. Note that the perspective in this image is different than the last, and that this is the wall from the previous image that does not contain the window. The same dark line can be seen here, signifying a lower temperature zone.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Image #3</th>
<th>Location: Indoors, Master Bedroom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td>A view of the window sill and panes. The image indicates lower temperatures on the window sill and around the panes of glass.</td>
</tr>
</tbody>
</table>
**Image #4**  
**Location:** Indoors, Closet in Master Bedroom  
**Description:** This image shows the ceiling in one of the closets where mold typically forms. As was seen earlier, there is a notable decrease in temperature found in the corner, denoted here by the darker color. In the top right corner of the image another similar discrepancy can be seen, and is shown more clearly in the next photo.

**Image #5**  
**Location:** Indoors, Bedroom  
**Description:** This is a photo of the opening to the closet in the master bedroom. Consistent with earlier images, this one shows a decrease in temperature where an interior partition meets the exterior wall and concrete slab. The closet doors can be seen at the bottom of the image.

**Image #6**  
**Location:** Outdoors, apartment complex  
**Description:** This image shows the lower two apartments of a typical building in the *Terasse du Patro* development. At the base of the building there is a notable increase in temperature, as well as bright yellow areas in the regions surrounding the balconies, which also indicates higher temperatures.

**Image #7**  
**Location:** Outdoors, apartment complex  
**Description:** Similar to the image above, this one shows the second and third floor apartments of the same building. The areas immediately surrounding the patio doors, as well as the balconies themselves, indicate warmer than ambient temperatures. The bright yellow spots to the right of the patio doors are present even though there are no visible heat sources at those locations on the stucco walls.
Image #8
Location: Outdoors, first floor balcony
Description: The balcony in this image is located above the apartment where the indoor photos were taken. The wall seen at the lower-center of this photo is seen from indoors at the left of Image #4. The yellow area clearly shows an higher temperature zone where the balcony meets the exterior walls of the apartment.

Image #9
Location: Outdoors, balconies for 2nd and 3rd floors
Description: This photo is similar to Image #8 in that it shows a marked temperature increase where the balcony meets the exterior walls of the apartment.

Image #10
Location: Indoors, spare bedroom
Description: This image of an exterior wall in the spare bedroom contains temperature drops at several locations on its surface, denoted by darker patches. The line of brighter pink seen at the bottom illustrates a baseboard heater, and there is a line of cold temperatures seen at the left of the image where the two exterior walls meet.

4.2 Relative humidity readings
Relative humidity is an expression signifying the proportion of the vapor pressure of the air with respect to the saturated vapour pressure for a given temperature. In simpler terms, it gives the percentage of the moisture that the air is holding relative to the maximum amount it can hold. The relative humidity is temperature dependant, so if the temperature decreases significantly and the moisture content of the air does not, the relative humidity will increase. This will continue until the air can no longer hold any more moisture, or in other words, the vapour
pressure has reached the saturation pressure and the temperature has reached the dew point. Once this occurs, the water in the air will condense.

For building envelope analysis, this process is important for explaining the presence of condensation. Generally speaking, when warm air comes into contact with a cold surface, if the temperature reaches the dew point temperature, water will condense on the surface. If left unchecked, a frequent condensation problem combined with sustained high relative humidity in the air may lead to mold and/or material degradation. Water can have adverse effects on many materials, such as the rotting of wood studs, expansion of gypsum board and paint delamination. It is important to note that while condensation might occur infrequently given extreme circumstances (i.e. prolonged steam generation from a very hot shower, running hot water for an extended period of time in the kitchen, etc), it only becomes an issue if it is a regular occurrence.

The occupants of an apartment are generally the determining factor in whether there will be condensation or not. As human beings produce water vapour through breathing and their daily activities (showers, dish washing, etc.), the relative humidity of the apartment may rise to a point where a small enough temperature difference will produce condensation.

The values for ambient temperature and relative humidity may be easily read using a digital psychrometer. This device is designed to read both quantities with minimal time required for stabilization. The following results were read using a digital psychrometer at various locations in or around the apartment:

<table>
<thead>
<tr>
<th>Location</th>
<th>Ambient Temperature (°C)</th>
<th>Relative Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master bedroom</td>
<td>21.8</td>
<td>41.8</td>
</tr>
<tr>
<td>Closet in master bedroom</td>
<td>21.2</td>
<td>36.3</td>
</tr>
<tr>
<td>Outdoors</td>
<td>4.4</td>
<td>56.1</td>
</tr>
</tbody>
</table>

### 4.3 Polyethylene experiment

Polyethylene is a material used typically as a vapor barrier in building envelopes because of its low permeability. That is to say, it is a material that allows only a negligible amount of water to permeate through it. For this reason, it is a suitable material to use for a test to determine the amount of moisture seeping through the ground slab of the apartment building.

The experiment involves placing a square polyethylene sheet on a relatively clean surface and securing it on all sides with standard duct tape. The sheet should be roughly 450 mm square,
and should be sealed on all edges with the tape. While the experiment is crude in design, it is sufficient to determine whether any moisture is seeping through the surface below, and consequently raising the relative humidity of the room.

![Figure 9. Polyethylene sheet test](image)

Five sheets of polyethylene were placed in the apartment building’s ground floor in various locations of interest, including the master bedroom closet, the master bedroom, and the mechanical room holding the boilers for the apartment heating system. The sheets were left undisturbed for a minimum of three weeks, and in no case was there any presence of moisture seen under the polyethylene. A sample polyethylene sheet test is shown in Figure 9.
4.4 Condense

Condense is a software that was designed to help analyze wall assemblies in terms of their resistance to heat and water vapor flows. Its main use is to be able to predict where condensation might occur in a given wall. The user can vary the materials that the wall is built with, along with any conditions of outdoor or indoor temperatures and relative humidity (RH). For typical outputs, see Appendix D to G.

The software functions as follows: first it calculates the total resistance of the wall to heat flow (by adding up the individual resistances of the elements composing the wall). Resistance of an element is the inverse of its conductance, and conductance is obtained by dividing the conductivity of the element (which is listed in material properties tables) by the thickness of the element. For example, we see from Appendix D that the total resistance of the wall investigated here is about 3 RSI (International System units) or R18 (English units).

Then the software uses Fourier’s Law of Heat Flow to determine the total heat flow through the wall, and from there, knowing the individual resistances of the elements, it can find the temperatures at the interfaces of each element. This gives the temperature profile seen in the Condense output in red.

In blue we see the profile of the saturated vapor pressures across the assembly as a function of local temperatures at the interfaces: this line gives, for each location, the vapor pressure at which vapor will condense.

Finally, using a procedure very similar to the one used previously for heat flow along with the permeability of each element, the software establishes the actual vapor pressure profile at the interfaces of each element (green line in output). Now if at any location in the assembly the vapor pressure line crosses the saturated vapor pressure line, it means that the vapor will condense at this location because the material at that point is too cold to sustain the water vapor in its gaseous state.

For this project Condense was used to analyze the behavior of the typical exterior wall already described above. We inputted all the existing elements as they are shown in Figure 5: stucco, insulation, concrete, etc. The list of these materials appears in the output of the program (Appendix D). We ran the program for a variety of atmospheric conditions. Here is a list of the conditions that were found to cause some meaningful condensation in the assembly:
From these results the following observations can be made:

- Even for low indoor RH, condensation is likely to occur at least in the old stucco zone with outdoor temperatures of $-10 \, ^\circ C$.
- At a higher indoor RH, condensation starts occurring in the old stucco with outdoor temperatures of $0 \, ^\circ C$, and almost occurs at $5 \, ^\circ C$.
- At the higher RH, condensation will occur in the concrete blocks starting at $-10 \, ^\circ C$.
- Note from the output in Appendix D that at $0 \, ^\circ C$, the vapor pressure line is dangerously close to the saturated vapor pressure line, suggesting that condensation could easily occur in the concrete blocks if they were just slightly colder, or if hot moist air would manage to exfiltrate through cracks directly to the concrete.
5 ANALYSIS

The problems mentioned earlier were noted to be recurring mold and condensation, inadequate thermal comfort and high heating cost. While it may occur that a single defect may cause several problems in a building, often it is a system of deficiencies that contribute to the overall failure of a design. The common deficiencies in building envelopes are thermal bridges, water infiltration and condensation in the wall. It is believed that each of these factors has a role in the Terrasse du Patro building deficiencies.

5.1 Thermal Bridges

Much like water will flow in the path of least resistance, heat will similarly travel through the path with the lowest thermal resistance. If such a path exists from the interior of a building to the exterior, it is said to be a thermal bridge. This process is often seen in concrete slabs, wood studs and metal window frames: all materials with thermal resistances lower than standard insulation. The effect of a thermal bridge is to allow heat to escape from the indoor environment, which is characterized by cooler surface temperatures indoors, and warmer surface temperatures outdoors.

The first design flaw noticed in the building plans was the way the slabs are joined to the concrete block walls. Before the polyurethane was added to the exterior wall there was no insulation between the slabs and the outdoor environment. This created a concrete thermal bridge through the building envelope to the indoor space, resulting in wide scale heat loss. The problem was partly remedied with the polyurethane renovations, except in the case of the balconies.

It was previously mentioned that the closets are the focal area for the more serious problems of the apartment buildings, and it is by no coincidence that they are adjacent to the balconies of the apartments. The ceiling slab for the apartment meets the balcony slab (for the apartment above) at the top of the back wall in the closet. This slab junction can be seen in Figures 4 and 12 and Appendix C. This joint was not designed with any insulation separating the exposed balcony slab from the indoor floor slab and suggests a thermal bridge issue is present. As was suggested earlier, a telltale sign of heat loss due to thermal bridges are indoor and outdoor surface discrepancies. The use of infrared cameras was introduced in Section 4.1, and the results from the photos support the theory that the balconies are a conduit for heat loss. The indoor and outdoor views of the closet back wall can be seen in Figure 10. As expected, the slab above of the closet exhibits a lower temperature than normal, while the balcony/wall joint exhibits a higher
temperature. It is expected that this situation becomes significantly more apparent as the indoor/outdoor temperature difference increases.

Figure 10. Indoor (left) and outdoor (right) infrared images of thermal bridge leaks

Figure 11. (left) Condensation is apparent in the colder areas of the slab
Figure 12. (right) Exterior side of the faulty closet: thermal bridge caused by balcony slab

Other signs of thermal bridges are apparent in the windows as well. It is common envelope practice to align the windows with the layer of insulation in a wall section. The reason for this is to prevent the heat from circumventing the windows thermal barriers by conduction
through the frame. Generally window frames are built with internal thermal breaks, so that there is no single continuous path of a conductive material from inside to outside. However, if the window is placed in such a way that the material that it is built on offers a similar continuous path around the window frame, then the thermal protection that the window has to offer is wasted.

In the case of the apartment buildings in the *Terrasse du Patro*, the windows are centered upon concrete blocks (shown in Figure 14). The window frame is not as wide as the concrete, and consequently there is a horizontal portion of the sill on both sides of the frame with no insulation whatsoever. There is nothing impeding heat loss through the sill, into the concrete blocks, and on to the outside. The infrared photo in Figure 13 shows a visibly colder window frame and sill, implying a loss of heat, and the corresponding normal photo shows the consequences of condensation on cold surfaces: mold growth and wood decay around the window frame.
5.2 Water infiltration

Water infiltration is defined as the penetration of liquid water through the building envelope. This phenomenon can have very adverse consequences on the lifetime of a building because of the destructive nature of the liquid. Many materials will degrade in the presence of water, which is the primary reason that water control is as heavily emphasized in an envelope as thermal resistance. The first rule in building envelope design is to avoid horizontal surfaces,

Figure 14. AutoCAD drawing of window detail
because water accumulation can have such detrimental effects. Also of importance is the proper use and installation of flashings around windows.

The balconies of the apartments were designed to be horizontal to be consistent with the concrete slabs of the building. This was required due to the nature of the joints between the balcony element and the indoor slab element. However, the flat surface of concrete provides a perfect surface for water to collect. It would be very difficult to create a perfect seal at the base of the wall where it meets the balcony, and water infiltration is likely at these locations.

It was mentioned that the concrete slabs rest on an 8” bearing strip made of a material called Masonite, a rigid bearing product made of compressed wood fibers. Spancrete calls for tempered Masonite to be used for supporting the concrete slab elements, yet regular Masonite was specified in the building plans. In addition, Masonite was involved in a class-action lawsuit regarding wood fiber panels that were deteriorating due to water exposure. This indicates that the product has a predisposition for a weakness to water, which would be amplified when placed in a horizontal position where water can collect. The Masonite acts as a storage place for water as well as organic sustenance for mold which, significantly, is always seen to grow directly adjacent to these bearing strips (Figure 15).

![Figure 15. Two examples of mold patches adjacent to Masonite bearing strips](image)

Another cause of water infiltration is improper rain screen, which includes the flashing around the windows in addition to the expansion joints in the stucco. In the building studied, there are effectively two rain screen systems: the two separate layers of stucco. However, for the purposes of this report, it will be assumed that the first layer (constructed directly on the concrete walls) is flawed in some way and can no longer be relied upon to fulfill this purpose. Consequently, the emphasis is on the outer stucco as the rain screen. From the staining seen at the base of the walls (shown in Figure 16), it is apparent that water is penetrating the first layer of stucco and draining down the back wall. Any deficiencies in the polyurethane and/or back layer
of stucco will have the effect of bringing water into contact with the concrete blocks, which can then enter the wall through capillary effect or air pressure differences.

Figure 16. Water stains at the base of the wall
The flashings installed on the windows are insufficient for the needs of the envelope. Gaps between the window frame and the flashing are common, and the overhang for the metal is insufficient to prevent water from flowing upward (due to strong wind) and behind the rain screen. These deficiencies are shown in Figure 17.

Figure 17. Gap behind the flashing (left) and insufficient overhang (right)

Evidently, there is more than one potential pathway for direct water penetration in the wall assembly from outside. Given the general quality of the design and of the craftsmanship it is reasonable to say that it is likely to happen, at least locally. Image #10 in Table 1 shows vertical
cold spots aligned with the corner of the window, strongly suggesting water infiltration there. Further exploration of the walls would be required to determine the extent of the problem.

5.3 Condensation

So what causes these condensation problems to become that severe? After all, many buildings in Montreal are built with similar concrete walls and floors, with concrete floors and balconies that create thermal bridges. The downtown of Montreal has many high-rise apartment buildings very similar to our building in terms of structure, and as far as we know we never hear about water dripping down the ceilings of these buildings. Spancrete, the manufacturer of the concrete slabs of our project, claims to have built billions of square feet of building space around the world, and hasn’t been sued yet for condensation on its slabs.

What is specific to our construction that could account for this unusual situation? We believe it is the following: the combination of a cold climate, thermal bridging, and a wall assembly that is susceptible to water penetration yet doesn’t have the opportunity to breathe and dry out.

We have shown that the exterior walls are likely to allow liquid water to leak in the assembly from the exterior; there is also another likely way that water penetrates the wall: from water vapor diffusing through the assembly and condensing inside the wall). As we saw with the Condense analysis, the walls as designed are sensitive to interstitial condensation. The arrangement of the insulation inside the wall creates a temperature profile, seen in Appendix D, in which half of the temperature drop is occurring before the concrete slab, and half after. Thus the blocks are relatively colder than they would be if all the insulation was located on the exterior side of the blocks. Being cold, the concrete blocks present an opportunity for condensation; the software predicts condensation in them starting at least at –10 ºC. The interior portion of the insulation actually plays against the wall’s performance in terms of condensation, because if it weren’t for it the concrete blocks would simply be at (almost) the room temperature, and would not be a cause for condensation.

Of course the exterior temperature is rarely below –10 ºC. But condensation is likely to occur in the concrete blocks even at higher temperatures anyway, because of the phenomenon of air exfiltration: as we saw the walls present many opportunities for flow between inside and outside. Thus, in winter, there are likely many little streams of moist, warm air from inside exfiltrating through the cracks in the walls toward the exterior. As this moist air hits the cold concrete, the moisture contained in the air condenses inside on the concrete’s surface and is later absorbed by capillarity in the concrete.
Thus we have ample reasons to believe that the concrete blocks in the assembly are constantly receiving an inflow of water. This occurs in winter from condensation and in summer from rain infiltration. This water penetration is not unusual as such in buildings; it frequently occurs without any serious consequences. For example brick veneer may absorb some water in surface on rainy days, but it will release this water at an equivalent rate on sunny days. The critical point that creates a catastrophic issue here is this: once this water has been allowed in, it can only escape the assembly with great difficulty. That is because the concrete blocks are lined on each of their faces with practically impermeable materials: expanded polystyrene on one side and sprayed polyurethane on the other.

If these materials allow water in, why don’t they allow it out? The water vapor tends to move from inside to outside due to the vapor pressure being lower outside than inside, not the opposite. This process continues for as long as the vapor pressure in the concrete is lower than the one in the interior air. Also, exfiltrating moist air can deposit water in the concrete by condensation much faster than what can be diffused back in the room. Similarly, if liquid water infiltrates the wall from outside through cracks, it does so much faster than what can be diffused back outside, particularly with the presence of two stucco layers encasing a layer of polyurethane. There is no air cavity worth mentioning between the stucco and the concrete blocks, which normally promotes air circulation to allow the back wall to dry during sunny days in case it gets wet for any reason.

For all these reasons, we believe that the core of the wall assembly, the concrete blocks, is left in an almost perpetual state of dampness. They constantly receive more water than what they can release. So the building as a whole becomes like the traditional damp clay jars that are used in Africa to keep the food cold: a porous container, always wet, constantly losing water by evaporation. It is known that when any water evaporates from a surface it results in a cooling effect. In our case, the result is that in winter the highest part of the energy spent on heating goes not to heat the room, but to provide energy for evaporating the water in the concrete blocks. It is known, moreover, that new concrete buildings typically require more energy to heat during their first winter, in order to allow all the water present in the concrete to evaporate. In our case the evaporation is a never-ending process.

Another aspect of the problem is the heat storage capacity of the concrete; because of its high density, concrete requires a lot of energy to be raised to a higher temperature (even more so if it contains water in its pores). This fact can turn out all right if, once the concrete has reached a certain temperature, the heating system is left on in order to maintain the higher temperature in the concrete by only compensating for the losses. But if, as might be the case in our building, the
heating is turned on and off at cyclical intervals (like at night) then all the heat that is stored in the concrete will escape during the off time and a lot of energy will be again necessary to raise back the temperature of the concrete when heating is turned back on.

This problem is inherent to concrete walls, but can be alleviated if enough insulation is judiciously located on the exterior side of the concrete: this way the concrete stays warm easily and actually regulates the room’s temperature in a beneficial way. In our case, in order to heat the concrete, the heat has to go across the resistance offered by the expanded polystyrene layer so part of the insulation works against the wall.
6 SUGGESTIONS

Some further investigative steps might prove useful in proving the accuracy of our findings or showing which factor is predominant. These include:

- Opening up walls to look for signs of dampness in the concrete blocks around windows and at the slab-wall connections. In particular, looking at the slab-wall connection for deterioration of the Masonite boards.
- Using electro-magnetic water detection devices to try to detect damp areas in walls.
- Examining the roof surface and the parapet to rule out possible infiltration from there.

Here is a list of low cost corrective measures that may help alleviate the dampness-related problems.

- Encourage the occupants to leave the heating on at all times in the winter in order to maintain the concrete mass at a high temperature. This will avoid wasting energy raising the temperature of the concrete instead of heating the room every time the heating is turned back, and if the concrete remains hot long enough it may have a chance to evacuate the humidity it contains.
- Moving closets away from exterior walls, which are inherently colder. Providing larger ventilation holes between the closets and the room.
- Making sure the joints between the balconies slabs and the walls are very well sealed.
- If the drywalls are removed and inspection reveals that the molds find their food ad dampness source in the Masonite boards at the slabs-wall junction, carefully seal off that joint to isolate the dampness source. Then disinfect the area with proper liquid solution.
- Eventually, if the heating system needs to be replaced, replace with a hot-air central HVAC system, which will heat, de-humidify, and remove dust from the air. Removing the moisture and contaminants from the air by filtering would reduce the amount of food available for molds.
- If roofing requires maintenance: install rigid insulation boards between the concrete slabs and the waterproofing.
6.1 Re-building

Eventually, it may be decided to undertake major renovation work to rebuild parts of the envelope if the costs associated to the heating of the apartments and the regular cleaning of the moldy areas justify it. The decreased comfort level of the occupants may also be taken into consideration; mold can lead to severe allergic reactions. Once an allergy to mold appears, the affected person becomes very sensitive even to low mold concentrations.

We designed a possible corrective measure to solve the specific deficiencies of the envelope that we have identified to be, in our opinion, at the origin of the various problems. This measure entails tearing down parts of the wall and rebuilding it, so it is relatively costly; but we don’t really believe that the situation could actually be solved without such an intrusive action. A cross-section of the proposed modified wall assembly is shown below in Figure 18 and Appendix I.

![Figure 18. Modified wall assembly](image-url)
Since the main issue seems to be related to an accumulation of humidity in the concrete blocks due to their location between two impermeable layers, it is crucial to remove one of the insulating layers. It is unrealistic to remove the outer layer: the foamed polyurethane would need to be scraped carefully by hand, and to really make sure the concrete can breathe the old stucco would also need to be scraped off painstakingly (it adheres to the concrete blocks). So we suggest removing the interior insulation completely, which consists of boards that can be easily removed. New drywall would be re-applied directly on furring laid on the concrete.

The lost insulation would be replaced by adding more outside. Since the foamed polyurethane would be left in place, the new insulation has to be laid next to it. A difficulty arises from the fact that the surface of the polyurethane is irregular; to function properly, there must be no air gaps at the interface between insulation materials. The only ways to solve this problem would be to either spray more polyurethane on top of the old one, or to lay fiberglass batt insulation on top of the old polyurethane: the soft consistency of the fiberglass wool would conform to the irregular shape of the polyurethane. Laying fiberglass batts would probably be cheaper and more feasible. Then an air barrier would seal the assembly, backed by the vertical furring. The new insulation would be encased as shown between wood studs laid horizontally and nailed to the existing vertical studs. The new studs would also support the furring to which the siding would be attached.

The thermal and moisture resistance of the proposed assembly (assuming fiberglass batts were chosen) have been tested with Condense. The results are shown in Appendix D. The new resistance to heat flow would be RSI 4.4 or R 25. Even in the extreme condition tested (-23 ºC outdoor temperature and 60% indoor RH), no condensation occurs inside the wall from diffusion of water vapor through the assembly. Note that the exterior cladding is not included because of the presence of an air cavity behind the cladding as explained below; the air cavity is at the same conditions of temperature and vapour pressure as outside, so the cladding does not affect the vapour diffusion through the wall.

The advantages would be as follows:

- Since the insulation is outside, the concrete blocks remain hot (close to the room’s temperature). Therefore water cannot condensate in them, by diffusion or air exfiltration.
- An air cavity is created between the furring and the siding. In case any water leaks through the siding, it will run down along the siding instead of infiltrating the rest of the assembly by capillarity (a problem in the old system). The cavity also promotes air movement behind the siding and would allow any vapour diffusing from the assembly to evaporate freely. Finally
the cavity equalizes the pressure behind the siding with the one inside the building; when wind blows on the wall, the pressure difference across the siding may lead to some water being pushed through the siding by the force of the wind. But since no pressure difference exists between the air in the cavity and the air inside the house, water will not be pushed through the rest of the wall.

- Since the concrete blocks will stay warm, condensation on the window frames is unlikely to occur: contrary to the situation in the present assembly, the frames will be in contact with hot surfaces and will remain hot.
- Since the concrete will remain at an elevated, more constant temperature, it will be less likely to suffer from damages caused by the constant contraction/expansion due to the temperatures changes of the present assembly (in the present assembly only half of the insulation is located outside, so the concrete is more exposed to temperature changes).

Note that the actual thickness of the outside insulation, as noted above, is uncertain and depends totally on the skill and the care taken by the person who installed it. Thus, it is not impossible that in certain areas this insulation be almost inexistent. In such areas the concrete would then be left to sustain entirely the effect of the cold temperature in winter, with the possibility of free-thaw cycles.

It is not unreasonable to expect that this freeze-thaw possibility, and the expansions due to temperature changes may, in the long term, create problems that would become more costly to solve than rebuilding the envelope now before the problems develop further.
APPENDIX A: PLAN OF THE SITE
APPENDIX B: CROSS-SECTIONAL DRAWING OF SLAB/WALL JUNCTION
APPENDIX C: SLAB JUNCTION DETAIL
APPENDIX D: CONDENSE ANALYSIS

Outside: 0 °C, 90% RH
Inside: 21 °C, 60% RH

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>RSI</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior air film</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Ranging cement, 13.0 mm</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>Air space, 0.0 mm</td>
<td>0.11</td>
<td>0.7</td>
</tr>
<tr>
<td>Styrofoam polyurethane 52kg/m³, 50 mm</td>
<td>2.50</td>
<td>14.2</td>
</tr>
<tr>
<td>Ranging cement, 13.0 mm</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>Concrete blockgeneric, 190 mm</td>
<td>0.20</td>
<td>1.1</td>
</tr>
<tr>
<td>Polyisobutylene coated 11, 50 mm</td>
<td>1.30</td>
<td>7.4</td>
</tr>
<tr>
<td>Gypsum panel generic, 16.0 mm</td>
<td>0.10</td>
<td>0.6</td>
</tr>
<tr>
<td>Interior air film</td>
<td>0.15</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Total Thermal Resistance: 4.44 25.2

There is condensation in the glen assembly at this location.
The condensation rate is 2.86x10⁻⁵ litres/m²/day.
The estimated cost for the materials in this assembly is 197.45 $/m².
The heat loss rate is 4.72 W/m².
The deacondit temperature is 0.5 degrees Celsius.

Scale: 1 = 10

Legend:
- Temperature
- Vapor pressure for continuity of flow
- Saturated vapor pressure
APPENDIX E: CONDENSE ANALYSIS

Outside: -10 ºC, 90% RH
Inside:  21 ºC, 60%RH

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>RSI</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior air film</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Foamed glass, 13.0 mm</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>Concrete block, 160 mm</td>
<td>0.60</td>
<td>1.1</td>
</tr>
<tr>
<td>Total Thermal Resistance</td>
<td>4.45</td>
<td>25.3</td>
</tr>
</tbody>
</table>

There is condensation in the given assembly at this location.

The condensation rate is 1.998E-01 litres/m2/day.

The estimated cost for the materials in this assembly is 157.45 $/m2.

The heat loss rate is 6.97 W/m2.
The dew point temperature is 10.3 degrees Celsius.

Scale: 1 = 10

Legend:
- Temperature
- Vapor pressure for continuity of flow
- Saturated vapor pressure

34
APPENDIX F: CONDENSE ANALYSIS

Outside: -20 ºC, 90% RH
Inside: 21 ºC, 60% RH

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>RSI</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior air film</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Plaster cement, 13.0 mm</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>Air space, 5.0 mm</td>
<td>0.13</td>
<td>0.7</td>
</tr>
<tr>
<td>Spray foam, polyurethane 32kg/m3, 50 mm</td>
<td>2.50</td>
<td>14.2</td>
</tr>
<tr>
<td>Plaster cement, 11.0 mm</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>Concrete block, 180 mm</td>
<td>0.20</td>
<td>1.1</td>
</tr>
<tr>
<td>Polystyrene expanded, 71.50 mm</td>
<td>1.30</td>
<td>7.4</td>
</tr>
<tr>
<td>Gypsum board, 10.0 mm</td>
<td>0.10</td>
<td>0.6</td>
</tr>
<tr>
<td>Interior air film</td>
<td>0.15</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Total Thermal Resistance</strong></td>
<td>4.45</td>
<td>25.3</td>
</tr>
</tbody>
</table>

There is condensation in the given assembly at this location. The condensation rate is 3.035E+00 times/m2/day.

The estimated cost for the materials in this assembly is 197.43 $/m2.

The humid air rate is 3.21 W/m2.

The dewpoint temperature is 9.0 degrees Celsius.

Scale: 1 = 10

Legend
- Red: Temperature
- Green: Vapor pressure for condutlty of flow
- Dashed green: Saturation vapor pressure
APPENDIX G: CONDENSE ANALYSIS

Proposed modifications

Outside: -23 °C, 90% RH
Inside: 21 °C, 60%RH

There is no condensation for these conditions.

The estimated cost for the materials in this assembly is $160.90/m².

The heat loss rate is 10.00 Watt/m².

Scale 1 = 10

Legend
- Temperature
- Vapor pressure for continuity of flow
- Saturated vapor pressure
APPENDIX H: EXISTING WALL DETAIL

- EXPANDED POLYSTIRENE, 2"
- CONCRETE MASONRY UNIT
- GYPSUM BOARD, 3/4"
- STUCCO
- SPRAYED POLYURETHANE, APPROX. 2"
- OLD STUCCO
- STEEL MESH
- KRAFT PAPER

EXTERIOR

INTERIOR

15  55  200  50  20

15

all dimensions in mm unless otherwise indicated
APPENDIX I: PROPOSED MODIFICATIONS

INTERIOR

CONCRETE MASONRY UNIT

GYPSUM BOARD, 3/4"

200

15

55

64

55

200

EXTerior

SIDING

FURRING

AIR BARRIER

FIBERGLASS BATT 3"
LAID HORIZONTALLY

SPRAYED POLYURETHANE,
APPROX. 2"

OLD STUCCO

2" X 3" STUDS
NAILED TO EXISTING
VERTICAL STUDS

400MM C/C

all dimensions in mm unless otherwise indicated