Long-Term Field Monitoring of an EIFS Clad Wall[1]

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ABSTRACT

A popular retrofit option is to install an exterior insulation finish system to the walls of existing buildings. This study evaluates the thermal and moisture performance of such a system with a vented wall assembly. In addition to being a case study, this field monitoring was intended to verify computation methods of building envelope performance. The long term monitoring was designed to be non-destructive so that the building envelope performance is not affected by the measurements that are made, and to allow easy removal of sensors for recalibration and retrieval at the end of the test period. The field monitoring is planned for two years to capture a wide range of environmental conditions. This paper discusses the instrumentation used in the study and presents interim results of the thermal resistance of the wall and surface moisture.

RÉSUMÉ

Une solution de rénovation souvent utilisée consiste à installer un parement extérieur isolant sur les murs de bâtiments existants. L'étude décrite évalue la performance hygrothermique de ces parements combinée à un mur à cavité ventilée. En plus de permettre une étude de cas, la surveillance in situ effectuée vise à vérifier certaines méthodes informatiques d'évaluation de la performance de l'enveloppe des bâtiments. La surveillance à long terme devait être non destructive pour éviter de nuire à la performance de l'enveloppe et pour faciliter l'enlèvement des capteurs afin de les réétalonner ou de les retirer définitivement à la fin de la période d'essai. La surveillance in situ s'étalera sur deux ans pour permettre la saisie d'un vaste éventail de conditions environnementales. Ce document traite des instruments utilisés pour l'étude et présente des résultats provisoires sur la résistance thermique du mur et sur l'humidité des surfaces.

INTRODUCTION

This paper concentrates on the evaluation of an upgraded vented wall assembly with an exterior insulation finish system (EIFS) cladding. The evaluation includes the potential for energy savings due to increased thermal resistance, and reduced air movement through the walls. In addition, possible shortcomings will be identified, for example, condensation which could lead to reduced insulation effectiveness or structural degradation (by corrosion of steel components, or damage to gypsum board). The study is part of a program of field monitoring being carried out by the National Research Council of Canada (NRC) to develop design guidelines and methods of performance evaluation for retrofitted masonry walls.

During the retrofit construction, instrumentation to monitor temperature, heat flow, moisture, and air pressure was installed in the wall assembly. Air pressure measurements will be used, in a future paper, to evaluate pressure equalization potential of the wall cavity. The instrumentation is continuously monitored over an extended period to allow the seasonal variation of wall performance to be evaluated. This paper describes the instrumentation and presents interim results of the thermal resistance of the wall and surface moisture.

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BUILDING RENOVATION

The building is located on the Montreal Road campus of the NRC in Ottawa, Ontario, Canada. The climate in Ottawa varies from warm, humid summers to cold and damp winters. According to the Supplement to the National Building Code of Canada, the design (2.5%) climatic parameters for Ottawa are 4634 heating degree-days (base 18°C), a temperature range from 30°C (86°F) in July to -25°C (-13°F) in January, 22 m/s (49.5 mph) average wind speed, and 846 mm (33.3 in.) average annual precipitation.

The three to four storey building was originally constructed in 1953 and the exterior wall was made out of two layers of hollow clay tiles, with a total width of about 406 mm (16 inches). The outside finish of the building was a white painted stucco. To reduce heating and cooling loads, and control air and moisture flow through the envelope an additional wall assembly with EIFS cladding was added to the exterior of the building in the summer of 1993. The new wall system also has a stucco finish so that the building retained its characteristic style. New windows were also installed. The total floor plan area of the building is about 2800 m^2 (30,000 ft^2). The building has a central air conditioning system with distribution throughout the building.

The wall, Figure 1, was assembled from the original wall outward in a series of steps, as follows:

1. A polyethylene/modified bitumen adhesive membrane air/vapour seal. This membrane was intended to act as the plane of airtightness for the building envelope.

2. Galvanized sheet steel angles (32 mm x 126 mm (1.25 in. x 5 in.) and 0.91 mm (20 gauge) thick) were attached vertically 406 mm (16 in.) on centre. These angles allowed for the gap between the steel studs and the existing brick wall to vary. This was required to make the exterior finish even and true because the original wall was not plumb (up to ± 75 mm (3 in.) from plumb). Standing the steel studs off the wall also provided an air cavity (of about 38 mm (1.5 in.) average thickness) between the exterior gypsum sheathing and the mineral fibre insulation installed into the stud space. The unevenness of the original wall caused air cavity thickness variation of 15 to 50 mm (1/2 to 2 in.)

3. Galvanized steel studs (31 mm x 91 mm (1.2 in. x 3.5 in.) and 0.91 mm (20 gauge) thick) were attached to the angles. The studs had holes (approximately 28 cm^2 (4.3 in^2) in area) punched in the centre web every 700 mm (28 in.). These holes were covered by the mineral fiber board insulation in most places, except where the unevenness of the existing wall resulted in a large gap between the studs and the existing wall. The holes allowed for air to flow horizontally from one cavity compartment to another, which is an important aspect affecting the effectiveness of potential pressure equalized rainscreen wall systems.

4. Galvanized steel tracks (29 mm x 93 mm (1.1 in. x 3.7 in.) and 0.91 mm (20 gauge) thick) were installed at the top and bottom of the wall assembly and above and below each window. Circular vent holes for the cavity were punched out of the bottom track sections. The vent holes were the standard drain holes that are typical of a cavity wall system. The holes were 13 mm (1/2 in.) diameter and about 150 mm (6 in.) on centre. For the purposes of this study, additional venting holes were cut out of the bottom track on the west side of the building (at the test section only). These changes will be discussed later on the experimental installation section.

5. Mineral fibre insulation board, 64 kg/m^3 (4 lbs/ft^3) nominal density and 100 mm (4 in.) thick, was installed between the studs. This insulation was mounted flush to the polyethylene/bitumen membrane covering the existing wall.

6. Exterior grade fiberglass-faced gypsum sheathing board, nominally 13 mm (1/2 in.) thick, was screwed to the steel studs.

7. Rigid extruded polystyrene boards, 25 mm (1 in.) thick, were secured to the steel studs by screws that passed through the gypsum sheathing.

8. A plastic mesh was fastened to the polystyrene boards as a base for the exterior finish.

9. The exterior finish was an acrylic based stucco about 7 mm (1/4 in.) thick. It was applied in two coats, with the second coat containing the finish colour. Vertical expansion joints for the exterior finish were cut into the polystyrene insulation, but not as deep as the gypsum sheathing.

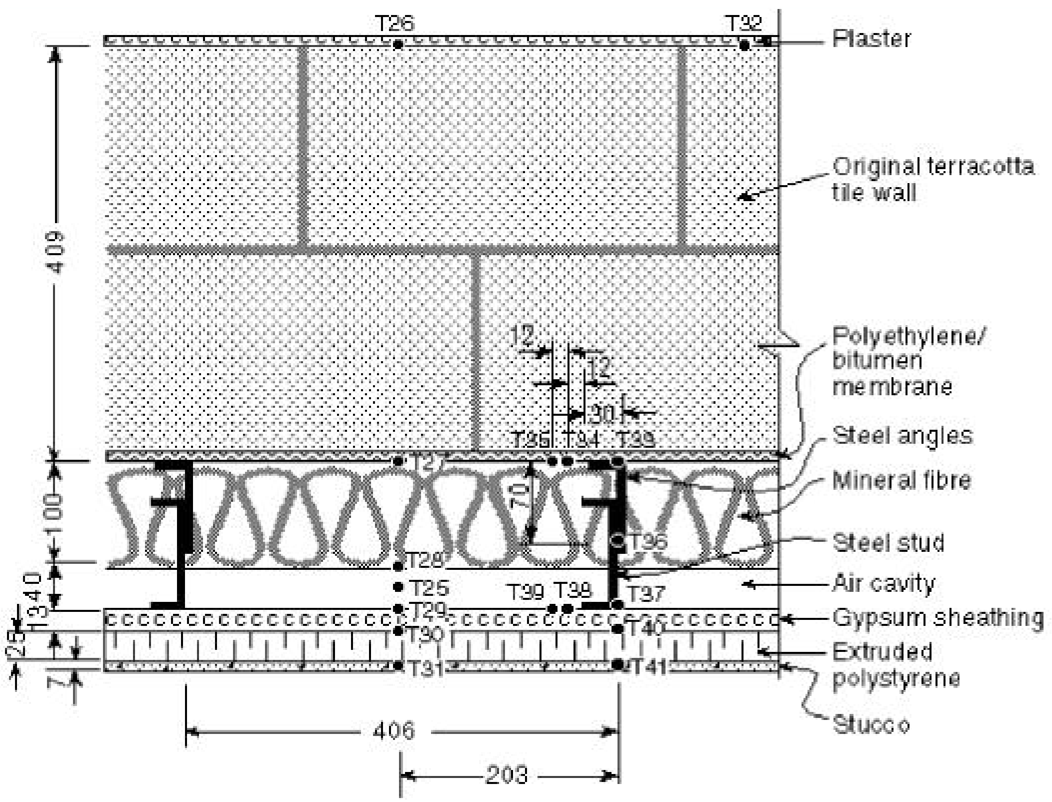


Figure 1. Plan view of east wall cross-section, including thermocouple array.

Selection Of Wall Test Sections

Two wall sections were chosen for monitoring; one on the West side and one on the East side of the building. These locations were chosen based on the prevailing wind direction (North West) and on the height of the cavity in the wall.

West Side

On the West side of the building the test section consisted of three stud spaces. The central stud space was instrumented and the remaining two stud spaces act as a guard stud space to each side. The three stud spaces formed a sealed compartment that was created by the following modifications: A seal of the same bitumen/polyethylene material as applied to the original walls was applied to the full height of the studs at the edges of the guard stud spaces; a closed cell foam gasket was placed along the flange of the two guard studs (between the stud and the exterior gypsum sheathing). These seals prevented air movement between the test section and the rest of the wall system as is required for pressure equalization systems.

The bottom track on the west side test section had additional holes that increased the effective vent area (Figure 2). The additional vents consisted of two rows of holes. The first row of holes were 13 mm (1/2 in.) diameter on 25 mm (1 in.) centres and the second row of holes were 19 mm (3/4 in.) diameter on 50 mm (2 in.) centres. These holes provided a total of 55 cm^2 (8.5 in.^{2}) of vent area per stud space. This was about an order of magnitude (13 times) more than with unaltered bottom track (4.3 cm^2 (0.6 in.^{2})). However, the effective area of the extra venting area may be reduced by the partial blockage by the mineral fibre insulation and by the flashing installed below the bottom track.

East Side

On the East side of the building there were no changes to the cavity. It was typical of construction in the rest of the building. There was no horizontal compartmentalization, and the vent holes are the 13 mm (1/2 in.) diameter drain holes 150 mm (6 in.) on centre.

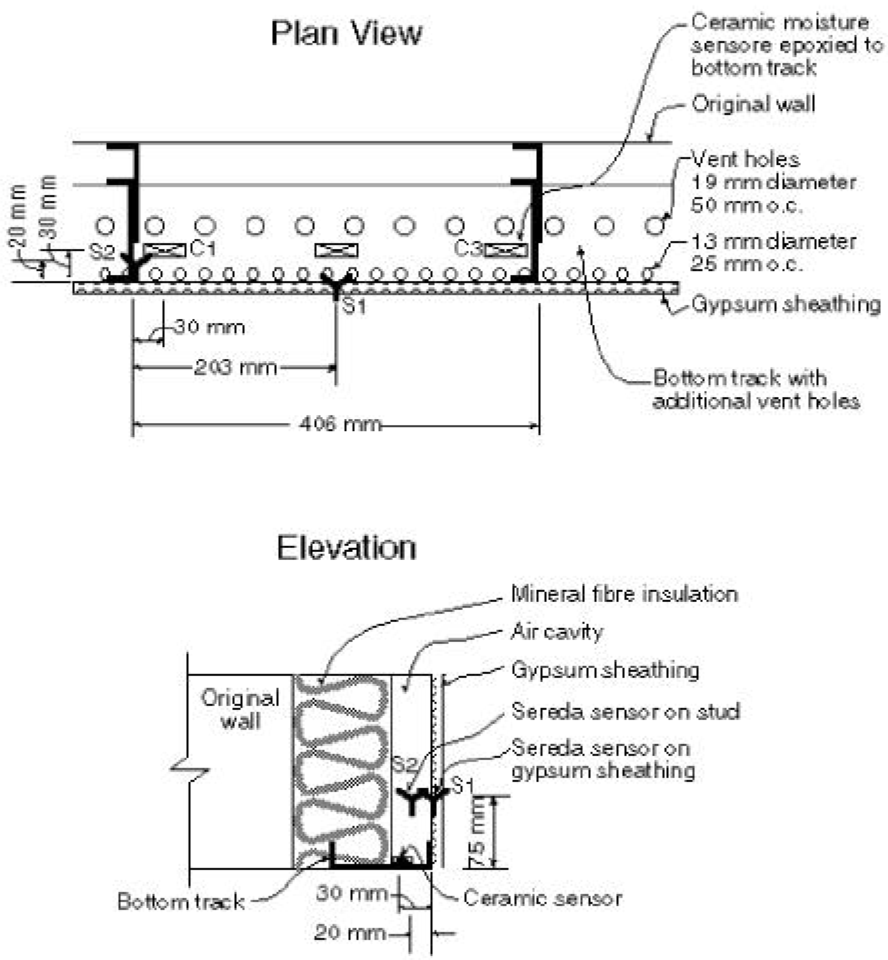


Figure 2. Sensor and vent hole locations at bottom of west wall.

DESIGN AND INSTALLATION OF SENSORS

Temperature Measurement

Type T Shielded thermocouple wire was used to reduce any electrical noise superimposed on the thermocouple signal. The thermocouples were bonded (with epoxy resin) to the surface and covered with a cloth construction tape. The thermocouple wires were installed in such a way that they would have a minimal effect on the measured temperatures, e.g., the wires were located as far away as possible from other thermocouples. In addition, the wires were run along isotherms near the measurement points.

For thermocouples installed at the gypsum sheathing/air space and gypsum sheathing/insulation interfaces, shallow grooves were cut into the gypsum sheathing, and the thermocouple wire was laid into these grooves. After bonding the wire to the gypsum with epoxy the wires were taped over with cloth construction tape. This left a flat surface on the back of the gypsum so as not to affect surface boundary layer development, and thus the surface heat transfer rate and temperature. For thermocouples placed between the gypsum and the exterior insulation the above method was also used so that the gypsum and insulation would lie flat together and not be pushed apart resulting in an air gap between these two components.

For the interior and exterior air temperatures, radiation shields were used so that the thermocouple registered the true air temperature. This is particularly important for exterior measurements where solar radiation can significantly increase the indicated temperature. At each Relative Humidity (RH) measurement location, the air temperature was measured so that the dew-point temperature and vapour pressure could be calculated.

To obtain estimates of the thermal resistance of each layer of the wall section (including the original wall) an array of thermocouples was installed approximately half way up both the East and West cavities. The thermocouples were arranged as shown in Figure 1 (east wall test section). This arrangement consists of a set of thermocouples on the centreline (T26 to T31, mid way between the studs) and a set of thermocouples along a stud (T32 to T41). Each set of thermocouples measured the temperature at each material interface to allow calculation of thermal resistance of each wall component. Differences between these two sets of thermocouples showed the magnitude of the thermal bridging effect of the steel studs. Additional thermocouples (T34, T35, T38 and T39) mounted on the existing wall and on the back of the exterior gypsum next to the studs measured how far the thermal bridging effect penetrates laterally from the studs.

Ambient Weather Conditions

The ambient conditions were monitored at a meteorological station about 150 m (500 ft) to the northwest of the building. Measurements, at 6 m height, included the temperature and RH of the outdoor air, wind speed, wind direction and rainfall. On the walls of the building solar radiation meters were mounted (at about mid-height of the wall) to monitor radiation directly at the wall surface.

Pressure Measurement

Pressures were measured within the cavity and on the exterior surface of the building relative to the interior pressure at each pressure measurement location. The pressure transducers (±1 kPa (±4 in. water) range and specified accuracy 0.14% of full scale) were mounted on the interior wall for easy recalibration and removal at the end of the experiment. PVC (10 mm (3/8 in.) I.D.) tubing extended through the wall from the pressure transducers to the measurement location. The tubing was sealed to the bitumen/polyethylene using a flange covered by another piece of membrane, caulking and construction tape to prevent air leakage around the tubing. The tubing was also sealed to the exterior stucco to prevent air leakage into the cavity from outside. Simple tests were performed using a dynamic pressure generating apparatus to estimate the attenuation of higher frequency pressure fluctuations. The results of these experiments showed that at frequencies below 5 Hz the tubing had little measurable effect on the frequency response of the pressure transducers.

The pressure differences were measured at three heights: near the top, middle and bottom of the cavity. These measurements will be used to investigate any spatial variation in pressure equalization as the measurement point is moved further from the vent holes at the bottom of the cavity. Each pressure transducer had a solenoid that acts to short circuit the transducer so that zero pressure difference readings may be taken. These zero readings allowed for any zero offset and any zero drift to be subtracted from each pressure measurement.

Rain Gauges

One external source of moisture for the building is rain. Rain gauges are commercially available for measuring vertical rainfall on horizontal surfaces, however the vertical walls of the building are exposed to the horizontal component of wind blown rain. NRC constructed rain gauges specifically to monitor rain driven by wind onto vertical surfaces. The rain gauge was based on one developed in Sweden in 1973. The rain gauges had a rain collector consisting of an aluminum backing plate with a section of diagonally cut 390 mm (15 in) diameter PVC pipe. The collected rain exited at the bottom of the collector through a short section of copper tubing. The tubing supplied a tipping bucket system that monitored the flow of water out of the pipe. A simple magnetic switch emitted an electrical pulse every time the bucket tips.

The rain gauges were calibrated by pouring measured amounts of water into the collector and counting the number of pulses produced by the switch on the tipping buckets. Approximately 6 ml (1/3 $in.^3$) of water was required to tip the bucket, which is therefore the resolution of rain measurement. This corresponded to a water layer 0.05 mm (2/1000 in.) thick over the 0.12 m^2 (186 $in.^2$) catchment area of the rain gauges (or 0.42 mm per m^2).

Three rain gauges were mounted on each of the two test sides of the building in order to monitor the surface wetting patterns. On the east side of the building the rain gauges were mounted near the top and at one-third and two-third of the wall height. On the West side of the building, two rain gauges were mounted near the top of the wall about 2500 mm apart (6 stud spaces). This horizontal spacing will allow the examination of horizontal variation of rain striking the building. The third rain gauge was mounted about two thirds the way up the wall.

Surface Wetting

In addition to the rain gauges, surface wetting patterns were measured using two types of surface moisture sensors: electrochemical cell (ECC) and ceramic (resistance). The ECC (also called Sereda) sensors are small (approx. 18 mm x 10 mm (11/16 in. x 3/8 in.)) and light (few grams) [see ASTM standard G 84-89]. They contain two different metals, copper and gold, in an interlaced pattern plated onto an insulating substrate. When moisture condenses on the sensor it activates the cell, producing a small voltage (0 to 100 mV) across a 10 MΩ resistor. The ECC sensors were epoxied to the outer finish of the EIFS. Three sensors were mounted on the East face and four on the West face. On the East face, each ECC sensor was mounted just above the rain gauges to examine the correlation between measured rain fall and surface wetting. On the West side, the top two sensors were mounted above the rain gauges and the other two are lower down on the wall.

Additional surface moisture measurements were provided by measuring the resistance across pieces of ceramic material. These ceramic resistance sensors, made at NRC, consist of two wires fastened with conductive epoxy to opposite sides of a 5 mm thick block cut from a clay brick (size approximately 19 mm x 10 mm x 5 mm (0.75 in. x 3/8 in. x 3/16 in.)). When the ceramic material becomes wet, its electrical resistance decreases and this drop in resistance is used to indicate the presence of moisture. The ECC and ceramic sensors were placed side by side in some locations in order to investigate the sensitivity and time response of the two sensor types.

Relative Humidity - Inside the Air Cavity

The relative humidity (RH) of the air in the cavity was measured at five locations on each test side. The locations were at different heights to determine the variation of moisture in the cavity air. Combining the RH measurements with the temperature on the surfaces of the cavity allows the calculation of the possibility of condensation forming on the cavity surfaces. The RH of the outside and indoor air were also monitored so that rates of moisture exchange by diffusion or air flow could be estimated.

Polymer resistance RH sensors (specified accuracy ±1% to 2%) were used because they provide a continuous electrical output that is suitable for remote, long term monitoring. The RH sensors required periodic recalibration and will be removed at the end of this study. To fulfill these requirements, a system was developed to allow for easy removal and installation of the sensors without damaging the wall system. The RH sensors were inserted into the cavity air space through holes from the interior of the building. To keep the installation tidy and to prevent air and moisture entering the wall system around the sensors, PVC pipes were installed into the holes in the walls. The PVC pipes were sealed to the interior and exterior surfaces of the original wall to prevent air and moisture movement. The electronics for the RH sensor were mounted on the interior wall next to measurement location. This interior mounting of the electronics allowed for easier troubleshooting and testing because the output and power supply were easily accessible. It was important to calibrate the RH sensors with their extension rods because the calibration depended on the wire length between the sensor and the electronics. This dependence on wire length is because the sensors used AC excitation and were therefore sensitive to the capacitance and impedance (therefore the length and orientation) of the connecting wires. The RH sensors were calibrated using saturated salt solutions and temperature controlled small environmental chamber.

Wetting of Cavity Surfaces

ECC sensors were installed in the cavity to detect surface condensation. They were mounted in pairs 75 mm (3 in.) above the bottom track. One sensor was on the back of the gypsum sheathing and the other was mounted on the steel stud, as shown in Figures 2 and 3 (sensors # S1, S2, S11 and S12).

Ceramic sensors were installed in the bottom track of both the East and West cavities. These ceramic sensors were intended to detect any condensation or water flow in the cavity. On the West side three sensors were installed; one near each stud at the ends of the cavity and one on the centreline of the cavity. On the East side only two were installed; one near the left stud (looking from outside) and one on the centreline, as shown in Figure 3 (C5 and C6).

In the East cavity a different kind of moisture sensing device was installed in order to be tested. It consisted of a side by side wire pair whose insulation had been removed ("nicked") at regular intervals - approximately 0.5 mm (1/64 in.) every 5 mm (3/16 in.). The wire covers almost the width of the stud space. If there is moisture between these exposed wires the resistance between the wires would fall. A resistance drop is therefore indicates the presence of moisture. For both the ceramic and nicked wire sensors. The installation included putting a layer of insulation epoxy between the sensor and the steel bottom track to prevent short circuits.

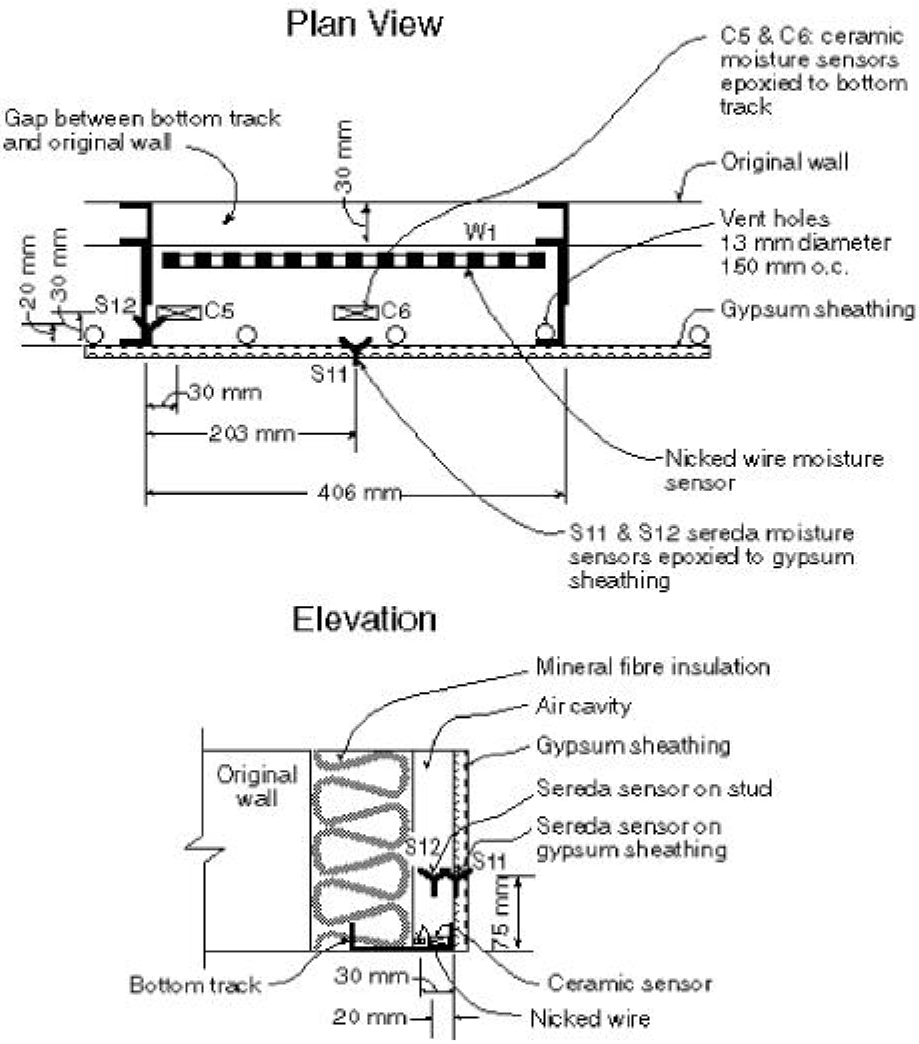


Figure 3. Sensor and vent hole locations at bottom of east wall.

Heat Flux Measurement

A heat flux sensor was installed on the inside surface of the wall on each of the wall test sections. These sensors were installed above the location of the thermocouple arrays (mid-way between the studs) for heat transfer and thermal bridging measurements. The heat flux sensors were covered with thin (3 mm (1/8 in.)) aluminum plates, painted same colour as the wall, to hold them firmly against the wall. This allowed for good thermal contact without damaging the interior finish of the building. The heat flux sensors consist of a thermopile encapsulated in plastic and surrounded by a guard area. The overall diameter of the sensor is about 200 mm (8 in.) with a sensing diameter of about 50 mm (2 in.) at the centre. The thermopile consisted of two arrays of thermocouple junctions separated by an insulating layer. The heat flow through the unit is proportional to the difference in voltage generated by the two thermocouple arrays. The units were individually calibrated by the manufacturer (specified accuracy ±5%), and were verified at NRC using the guarded hot plate apparatus.

DATA ACQUISITION SYSTEMS

Two data acquisition systems were used in this study because the pressure monitoring system was required to operate at a different speed. The output from the systems are combined during data analysis.

System 1 - Thermal and Moisture Monitoring

This system recorded the temperatures, relative humidity, solar radiation, and moisture (except rain gauges). The system scanned through all of the readings in about 9 seconds. This included a one second wait after each relay closed for the resistance measurements. This one second wait protected the system from measuring the switching noise that can be present on the relays. Every hour, an hourly average was calculated (of approximately 400 readings from each sensor). These hourly averages were saved in a data file.

System 2 - Pressure and Rain Gauge Monitoring

This system monitored the pressure differences and the rain gauges. The rain gauge pulses were monitored using a pulse counter. Counting the number of pulses in a given time period allowed the calculation of the rainfall rate.

The pressure difference data acquisition system had two modes of operation, normal and a high wind mode. The two modes of operation differ in the amount of data saved. Most of the time the system operated in normal mode. The data was taken at about 42 Hz and averaged over 10 minutes (approximately 25,000 pressure measurements). The high wind mode was triggered when any of the transducers shows a measured pressure difference in excess of 200 Pa (0.8 in. water). During a high wind event, the system records 15,000 individual pressure measurements which are all saved to disk. This procedure took about 5 minutes and 30 seconds. This data will allow the dynamic response of the wall cavity to be examined and the extreme peak values to be observed.

Ambient Weather Conditions

The system measuring the ambient weather conditions was an existing system already taking data for other projects. Hourly and ten minute averages of temperature, relative humidity, wind speed, wind direction, and rainfall are stored by this system.

INTERIM RESULTS

Effective Thermal Resistance

The thermal resistance was calculated using the measured temperatures across the wall and heat flux. Although this appears to be a straightforward calculation, it is complicated by the thermal mass lag effect of the clay tile wall. Figure 4 shows the temperature difference measured across the whole wall and the heat flux for the west wall. This figure illustrates the diurnal change of temperature difference from day to night and the corresponding change in heat flux. The thermal mass makes the heat flow about 12 hours out of phase with the temperature difference, i.e., the maximum heat flow occurs at minimum temperature difference and the minimum heat flow occurs at maximum temperature difference. Effective thermal resistance must therefore be calculated by taking long time averages of both temperature difference and heat flux. Brown and Schuyler (1982) described the procedure for calculating in-situ thermal resistance of walls (also see ASTM Standards C1046-90 and C1155-90).

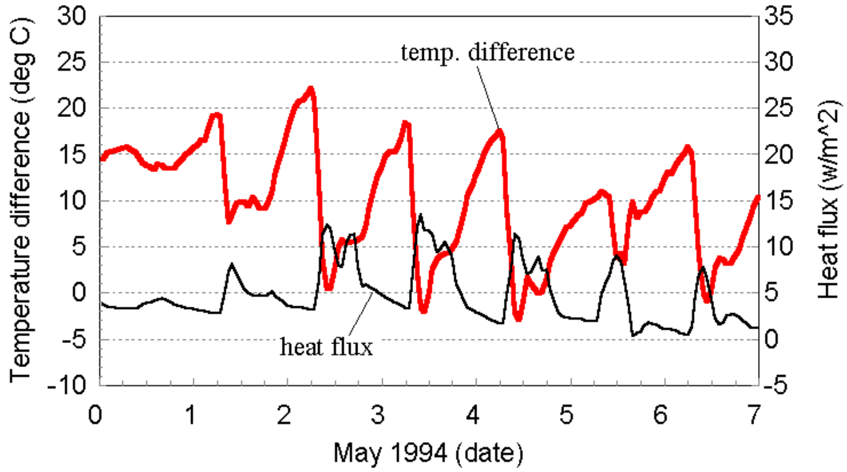


Figure 4. Effect of wall thermal mass on the relationship between temperature difference across the wall and heat flux (midway between the studs).

One week of temperature and heat flux measurements was found to be the minimum and one month being preferable. The thermal resistance of the wall was found to be RSI 3.38 (R 19.2) (not including air films). Using the thermocouples on each side of the clay tile wall, the thermal resistance of the original wall was found to be RSI 0.77 (R 4.4). Therefore the renovation increased the effective thermal resistance by almost a factor of five, which implies significant energy savings. It should be noted that this applies only to sections of the exterior wall which are solid (opaque).

Because of the arrays of thermocouples were installed in the walls, it was possible to calculate the effective thermal resistance of each component of the wall. These were compared to design values (using the ASHRAE handbook and manufacture data), see Table 1. The table contains values for the east wall test section only, but the measured results for the west wall are within 18% of these values and are not shown for brevity. This difference may be attributed to variations in the wall assembly and heat flux sensor installations. On the east wall section, the heat flux sensor was installed close to a window (in an office) and is further away from the temperature array (1160 mm) than that in the west wall (in a stairwell) where the distance between sensor and the temperature array was 200 mm.

Table 1. Thermal resistance of wall components (not corrected for temperature)

Component	Measured RSI (R)	Design RSI (R)
Clay tile	0.77 (4.4)	0.64 (3.6)
Mineral fibre insulation	1.60 (9.1)	2.90(16.4)
Air gap	0.10 (0.6)	0.15 (0.9)
Gypsum sheathing	0.07 (0.4)	0.08 (0.5)
Extruded polystyrene	0.84 (4.8)	0.87 (4.9)
Total	**3.38(19.2)**	**4.64 (26.3)**

For the clay tile, gypsum sheathing and extruded polystyrene insulation, the design values compare well to the measured values. The differences between measured and design values for the air gap are due to uncertainties in the thickness of the air gap (as noted earlier this ranged from 15 mm (1/2 in.) to 50 mm (2 in.) due to variations in the original clay tile wall) and convective air flow within the cavity. More critical is the low measured thermal resistance of the mineral fibre insulation. The measured value is 45% less than the nominal value. The most probable explanation is that there may be air gaps between the insulation board and the original wall, and between the insulation board and the studs. These air gaps combined with the other face of the insulation being exposed to the air cavity, means that the likelihood of air convection through the insulation is high. This convection acts to reduce the effective thermal resistance of the insulation.

Laboratory experiments by Brown et al. (1993) have shown that installation defects can reduce insulating value by up to 36% even without a surface exposed to an air cavity. This result was at a temperature difference across the insulation of 55 K (99°F). In the results presented for the current study, the average temperature difference is only 10 K (18°F) and the reduction in insulating value due to installation defects would be considerably less. It is beyond the scope of preliminary results presented here to perform a more sophisticated analysis of these results.

Moisture Performance

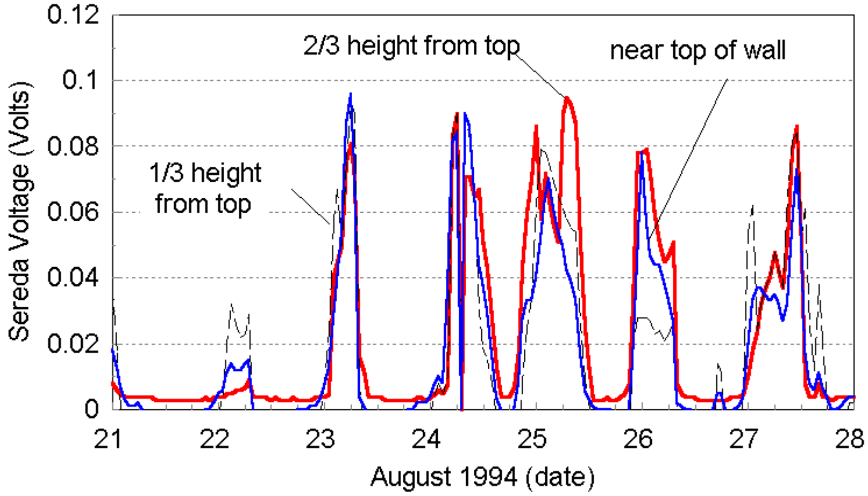
Exterior Wetting

Exterior wetting of the wall is from two sources: rain and condensation. The measured rainfall in this study is the horizontal (wind-driven) component of the rain, only. Driving rain is important in considering rain penetration of the building envelope because it coincides with high wind pressures across the EIFS cladding. To get an indication of the possible magnitude of the problem, Table 2 gives the number of hours in which driving rain was measured by the rain gauges over seven months at four different locations. Comparing the top and bottom rain gauges for the west wall shows that more rain strikes the top of the wall. The results in Table 2 show that, driving rain strikes the top of the building about 17 to 20 hours per month in average.

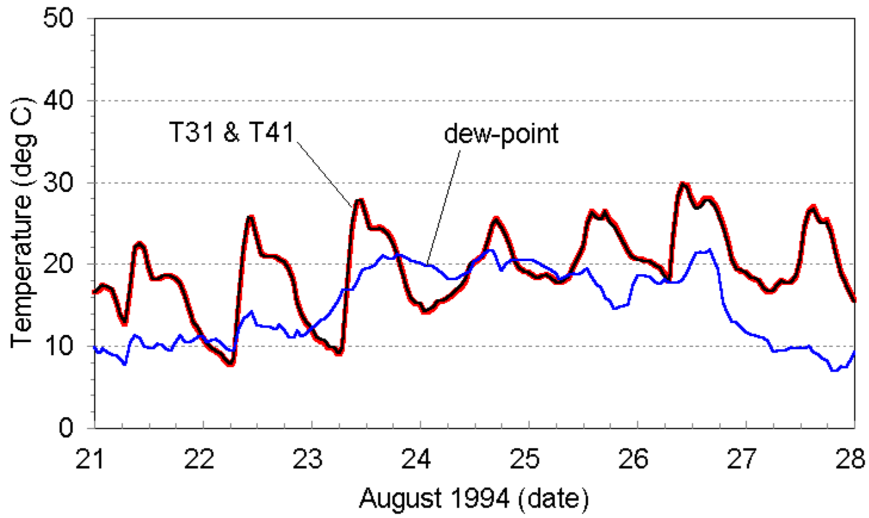
Table 2. Hours of driving rain

Sensor Location	April	May	June	July	Aug.	Sept.	Oct.	Total
West top	3	19	12	35	14	17	21	121
West top corner	3	26	13	20	-	-	-	62
West Bottom	1	1	-	3	-	-	-	5
East top	27	25	34	11	7	20	16	140

Exterior wetting of the building can also occur due to condensation. Condensation occurs during summer months when hot and humid days are followed by cool nights. Additional cooling of the exterior surface of the wall by radiation to the night sky produces a temperature depression on the wall about one degree Celsius (2°F) below the ambient air temperature. Rather than the localized effects of rain, which are concentrated near the top of the building, the exterior condensation occurs over the full height of the wall, as shown in Figure 5-a. In this figure, three exterior moisture sensors at different heights on the wall indicate the presence of moisture each night. This time-line plot starts at midnight, and each hour of the following week the hourly averaged sensor output is shown. The condensation is seen to occur during the night time hours, when exterior temperatures are lowest, relative humidity the highest, and surface temperature drops below the dew-point (see Figure 5-b). For the results shown in Figure 5 the night time relative humidity was 95% to 100%. The diurnal cycles in Figure 5 show that when the sun rises in the morning and heats up the wall (and the relative humidity of the air falls) the wall rapidly dries out.



a) Diurnal condensation on exterior of east wall

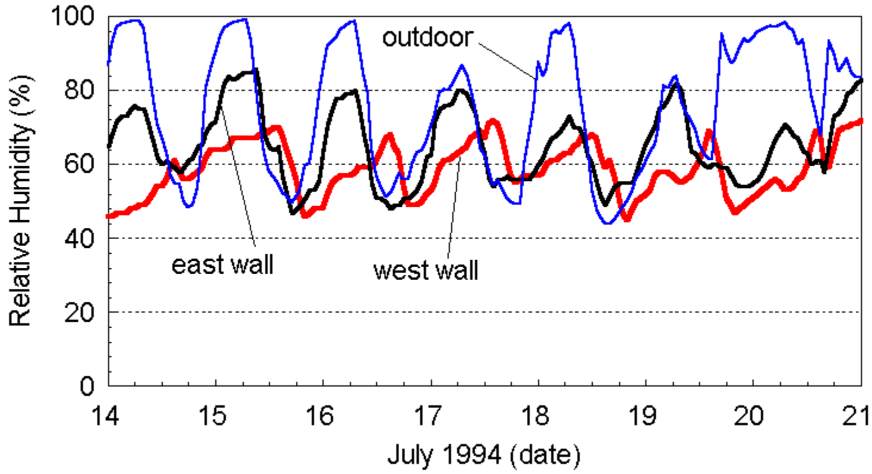


b) Exterior surface temperatures and dew-point of outdoor air

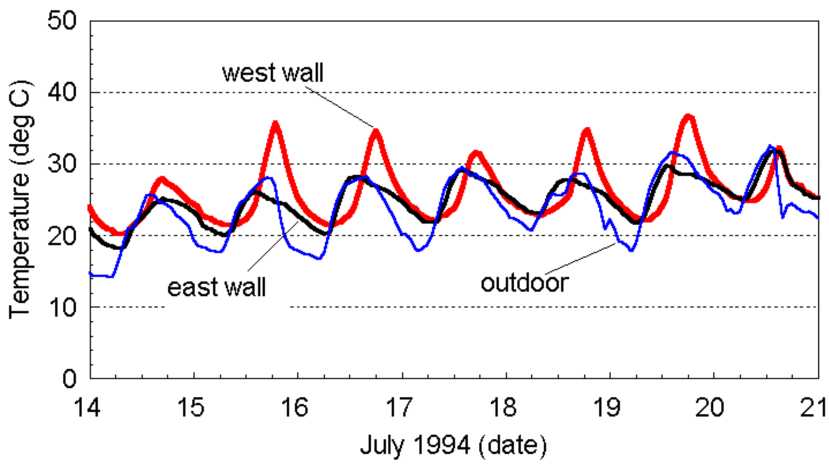
Figure 5. East wall exterior surface condensation and temperatures, and dew-point of outdoor air, for a selected period in August 1994.

Interior Wetting

Because the EIFS clad wall system has an interior air cavity, condensation can occur within the wall system. In July 1994, the dew-point of cavity air reached 29.4°C and 26.5°C in the west and east wall cavities, respectively. The relative humidity (Figure 6-a) in the east wall cavity reached up to 90% and is generally higher than that in the west wall cavity while the air temperature (Figure 6-b) in the east wall cavity is lower than that in the west wall cavity. The variation in the air temperature and RH in the cavity basically follows the cyclic variation in outdoor air temperature and RH (Figure 6). The RH diurnal cycles in the west wall lag behind the RH diurnal cycles in the east cavity which is consistent with the sun shining on the east wall in the morning and shining on the west wall in the afternoon. It is also noted that high RH values in the east cavity coincide with low cavity air temperatures.



a) Relative humidity



b) Air temperature

Figure 6. Relative humidity and temperature of air at the bottom of wall cavities and outdoors, for a selected period in July 1994.

In this study surface moisture sensors monitored the time of wetness of the bottom track, stud and gypsum sheathing. The total number of hours per month during which moisture was detected over a period of 7 months are summarized in Table 3. The results show that condensation can be highly localized. For the west wall cavity, moisture was detected on the stud, but not on the gypsum sheathing and the opposite is true for the east wall cavity. However, moisture was detected on the bottom track in both the west and east cavities. The dew-point of cavity air at the bottom of the west wall cavity reached higher values than that at the bottom of the east wall cavity (Figure 7). Thus the potential for condensation would be higher in the west wall cavity, particularly on the steel stud because of its thermal bridge effect. Table 3 shows that some locations (bottom track) can average 100 hours per month with condensation on the surface. This is important information for estimating the occurrence of corrosion on the steel studs and bottom track (and thus any structural problems). Assessment of the potential for corrosion is beyond the scope of this paper and remains a topic for future consideration.

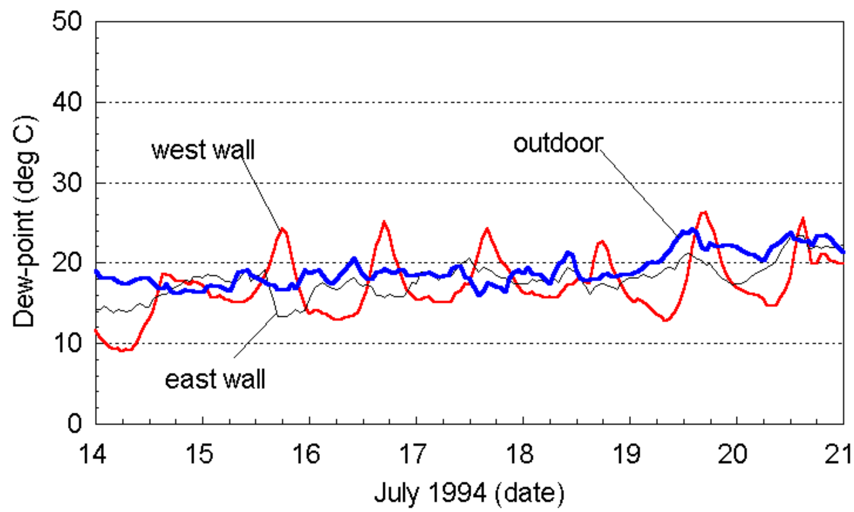


Figure 7. Dew-point of air at the bottom of the wall cavities and outdoors, for a selected period in July 1994.

Table 3 also shows the largest periods for which wetness is present at each location. For most of the sensors (except C1) this is 10 hours or less which, combined with further observations of the wetness time history, shows that the moisture is present in diurnal cycles. This is a similar result to the condensation on the outside of the wall as discussed earlier. At night the air in the cavity cools below its dew-point, leading to condensation. When the sun rises it heats up the cavity, thus reducing the relative humidity of the air in the cavity and drying out the cavity surfaces.

Table 3. Surface moisture inside wall cavity (hours)
(see Figures 2 and 3 for sensor type & location)

Sensor Location	**Sensor Label**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Avg.**	**Largest periods of wetness**
West Bottom Track	C1 C2 C3	82 - -	2 - -	104 - -	211 - -	159 4 -	43 - -	100 - -	**100** **0.5** **-**	**30** **4** **-**
East Bottom Track	C5 C6 C7	66 115 102	33 109 107	153 194 190	24 87 63	17 111 48	26 123 84	9 29 20	**47** **110** **88**	**6** **10** **10**
West gypsum sheathing	S1	-	-	-	-	-	-	-	**-**	**-**
East gypsum sheathing	S11	-	-	-	12	25	42	39	**30**	**4**
West Stud	S2	-	-	-	129	69	11	3	**53**	**8**
East Stud	S12	-	-	-	-	-	-	-	**-**	**-**

CONCLUSION

This paper discussed the instrumentation procedure for an EIFS clad wall system to observe heat, moisture and air pressure difference. The measurements performed for this study are the first long term field measurements of a vented wall assembly with an EIFS cladding. In order to evaluate the walls over a wide range of ambient conditions, this monitoring project is planned to run for at least two years. This time scale will provide a better measure of the durability of the new wall system.

The following test results are from a preliminary analysis of the measured data. The test results will be further analyzed, and will also be used to check analytical models of wall performance and to look at pressure equalization of the wall cavity.

- The EIFS clad wall system increased the effective thermal resistance of the wall by almost a factor of five.
- Long time averages (a month is recommended) are required to make thermal resistance calculation for walls when they have large thermal mass.
- Installation difficulties and exposed batt surfaces (to air cavities) can lead to a decrease in thermal resistance of mineral fiber insulation by about 45%.
- Most wind-driven rain strikes the building near the top of the wall where the wind pressure is high.
- Exterior condensation is common during summer months and occurs when cool, clear nights occur after hot and humid days.
- Surface moisture condensation within the cavity can be highly localized. Hence, many sensors need to be used to monitor moisture within wall cavities to reduce the possibility of missing condensation. Alternatively, model the wall analytically and use few sensors as a check on the model.
- Most cavity moisture is on a diurnal cycle of condensation at night and drying during the day during the warmer months.

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