FIELD MONITORING OF CELLULOSE IN WALLS - EDMONTON

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EXECUTIVE SUMMARY

A test program was completed to evaluate the effect of wet-sprayed cellulose insulation on the performance of wall components in wood framed construction. Of particular concern to this program was the rate of drying and the effect of moisture on building components within the wall. In addition, tests were completed on the house to evaluate the effect of wet-sprayed cellulose on air leakage.

The test house was a typical Alberta residential house, completed with conventional wood framing techniques. To evaluate the effect of cellulose on the air tightness of this home, gaskets and sealing of electrical outlets were not incorporated in the construction.

Wood moisture sensors were installed in seven different wall sections or orientations. Point-in-time monitoring of the sensors continued for a period of one year. Initial wood moisture contents were relatively dry.

Application of the cellulose was observed and samples tested for conformance to manufacturer's recommendations.

Wet-sprayed cellulose increased wood component moisture contents to approximately fibre saturation, within 30 days of installation. Framing components dried to near preinstallation moisture contents within 6 months. The rate of drying was affected by ambient conditions, ventilation of the cavity, orientation, time allowed to dry prior to gypsum board installation and construction conditions.

Air leakage tests of the house determined an air leakage rate of 2.0 air changes/hour at 50 pascals. Various sources of air leakage were detected, most unrelated to the wall cavities. The cellulose provided some resistance to air flow at rim joists, however, pressure drop tests across the wall section indicated that the cellulose cannot be considered an air barrier. Exterior sheathing provided a majority of the air resistance across the wall sections tested.

The occupants noted that heating costs for this house were modest and the house was relatively quiet.

Examination of sections of the exterior walls one year after construction gave limited evidence of deterioration.

1.0 INTRODUCTION

The purpose of this test program was to evaluate the effect of wet-sprayed cellulose insulation on the performance of wall components in wood framed construction. Cellulose insulation is a fibrous material that may be spray-applied into a cavity to be insulated. Current uses in western Canada have primarily involved this material in dry application methods on horizontal surfaces, such as attics. Wet-sprayed cellulose involves mixing dry cellulose insulation with a binder during the manufacturing process. A water mist is added to the insulation as it is blown into the cavity, activating the binder and causing the material to form a cohesive set. Cellulose manufacturers claim various advantages with this method over batt insulation in vertical cavities including: complete filling of the cavity with insulation, reductions in air leakage, reduced noise transmission and moisture absorption by the insulation.

Of particular concern to this program was the quantity of moisture within the wall cavity as a result of wet-spraying techniques, specifically, the rate of drying and the effect of moisture on building components. Cellulose manufacturers have claimed that moisture incorporated in the spraying process does not significantly affect the performance and durability of the wall assembly. Test results from the CMHC/CHBA Atlantic Canada Moisture Research Project indicated that wet-sprayed cellulose test walls, constructed with wet framing lumber, waferboard sheathing and wet-sprayed cellulose insulation, required in excess of 1 year to commence drying. In the prairies, dryer timbers and plywood sheathing are generally used. The climate is also drier. All of these may reduce the time required to complete drying. Wood moisture contents of studs and sheathing were monitored to evaluate the drying characteristics of these walls.

In addition, this test project assessed the effect of wet-sprayed cellulose on the air leakage characteristics of typical residential walls. Manufacturers' claims suggest improvements in the air tightness of walls with wet-sprayed cellulose insulation over batt insulation products. Air tightness tests were incorporated into the program to evaluate these claims.

2.0 HOUSE CONSTRUCTION

The test house was a typical Alberta residential home constructed of typical wood framed materials and techniques and occupied by a family. It was located in Sherwood Park, Alberta, approximately 20 kilometers east of downtown Edmonton. It was a two-storey, single-detached home, facing west of north west in a residential neighborhood. Single floor area was approximately 130 square meters, as illustrated in Figure 1.

The house was completed with typical residential wood framed construction techniques. Standard wall sections consist of: gypsum board, 2 mil polyethylene, 38x140 mm kiln dried spruce studs on 400 mm centers, insulation (RSI 3.5), 11 mm spruce plywood sheathing, building paper, and vinyl siding, as illustrated in Figure 2. Ceiling space was insulated with dry-blown cellulose, while the walls and rim joists were sprayed with a wet-sprayed cellulose.

The foundation was a full concrete basement, 200 mm in thickness, sloping to a rear level exit. Dampproofing was applied to the interior surface below grade. The basement was framed with 38x89 mm studs at 400 centers, furred 30 mm in from the concrete wall and insulated. Sill plates were wrapped in polyethylene. Basement level insulation was totally exposed to the interior in most locations, for the duration of the project.

This residence was constructed as a Total Environment Control Home (TEC) by Lincolnberg Homes of Edmonton. Standard energy efficient features in these homes include: R2000 air tightness requirements, induced draft furnace, continuous central exhaust system, gasketed rim joists and attic junctions, and sealed electrical outlets. This home was deliberately constructed without the sealing of electrical outlets and the attic and subfloor/rim joist junctions were not gasketed, to evaluate the effect of cellulose on air tightness in this home.

The following table outlines the relevant construction schedule, as well as the day count utilized for this program:

Day 0	November 5/87	Sensors installed.
Day 5	November 10/87	Wood walls and rim joists sprayed.
Day 11	November 16/87	Gypsum Board installation initiated.
Day 14	November 19/87	Gypsum Board installation completed. Gypsum Board mudding in progress. House heated with propane heaters. Siding installation initiated.
Day 31	December 8/87	Interior painting completed.
Day 42	December 17/87	Basement walls sprayed with cellulose.
Day 48	December 23/87	Residence occupied.

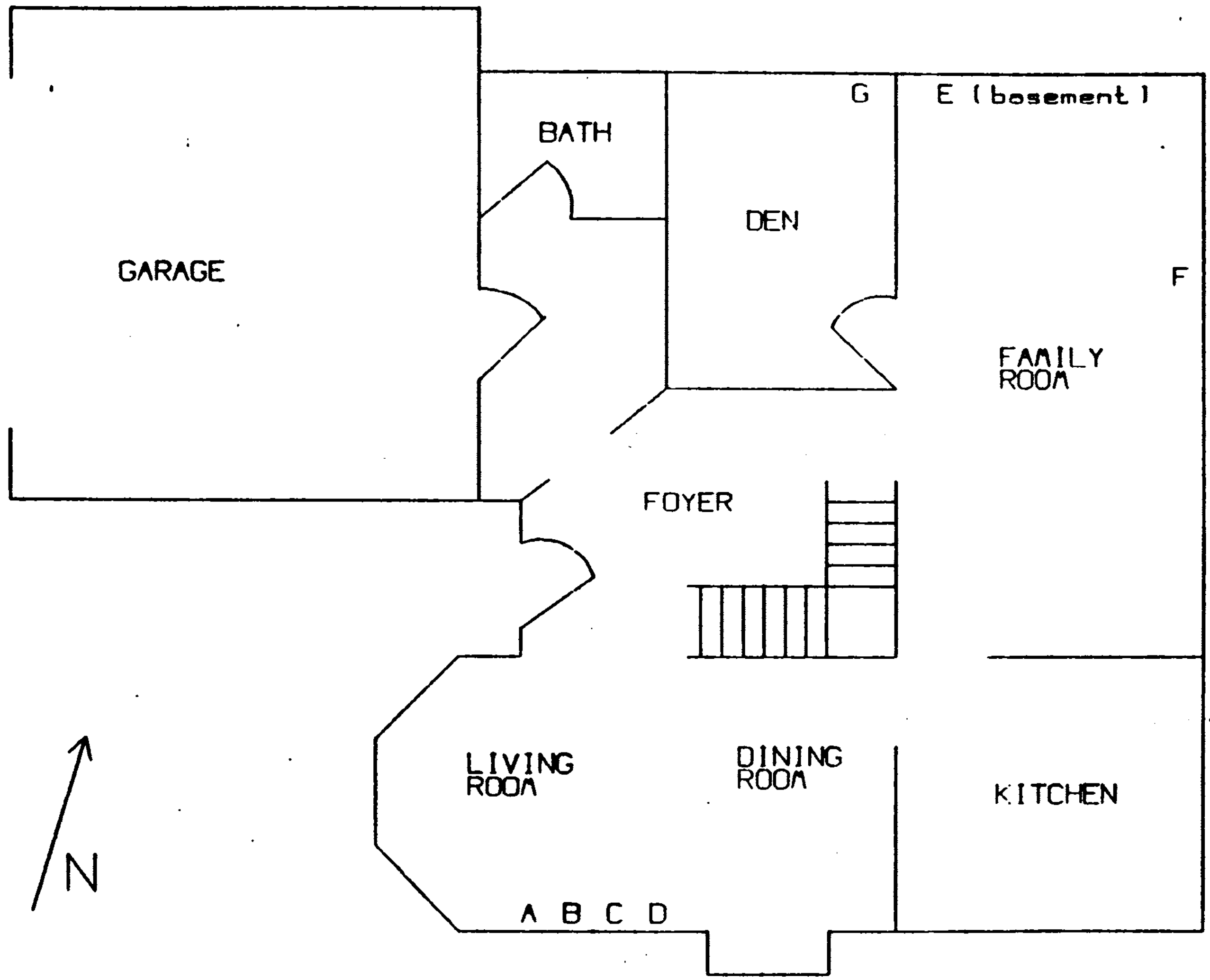

FIGURE 1 - MAIN FLOOR PLAN
SENSOR LOCATIONS

3.0 EVALUATION

3.1 MOISTURE CONTENT MONITORING PROGRAM

3.1.1 MONITORING METHODOLOGY

Monitoring locations were established in seven different wall sections or orientations to determine their effect on the drying characteristics of walls. Test sections chosen were those least affected by windows, appliances, interior furnishings and wiring. Wall sections, sensor numbers and locations are summarized by Table 1 and illustrated in Figures 1 and 2.

Wall Sections A, B, C and D were located on adjacent stud cavities of the south wall. The south wall was chosen for detailed comparisons between varied construction techniques, while subjected to similar interior and exterior conditions. Removal of the polyethylene was evaluated in Sections B and C. Section C represented maximum possible ventilation through the exterior wall. Section D represented a tightly sealed cavity with minimum potential for moisture removal. Sections E and F were of standard construction techniques, providing a comparison between east and north facing walls. Section G monitored the basement stud walls.

Each monitoring section consisted of moisture and temperature probes in the wall stud, sill plate and exterior sheathing (except the basement locations) as summarized by Table 2. Sensors were embedded in the wall stud at 150 mm above the sill plate, centered on the timber width. Section A on the south wall and the basement walls had sensors placed 12 mm in from the exterior and interior faces of the stud, at both 150 mm and 1200 mm heights. Sensors in the sill plate were centered on the base of the cavity. Probes in the exterior sheathing were set midway between studs, level with the wall stud probes.

Moisture probes were constructed of insulated metal pins and a plastic molded cap section, which secured the pins at a 25 mm spacing and sealed wire connections from moisture. Pins were installed parallel to the wood grain, to a depth of approximately 9 mm.

To facilitate temperature corrections, thermocouples recorded temperatures adjacent to each moisture probe. They were embedded into the wood at a depth of 9 mm and along the same isotherms as the moisture probes.

To minimize electrical interference in the data recording, all cables were shielded. To isolate cavities, wire penetrations through the studs of adjacent monitoring sections, were sealed.

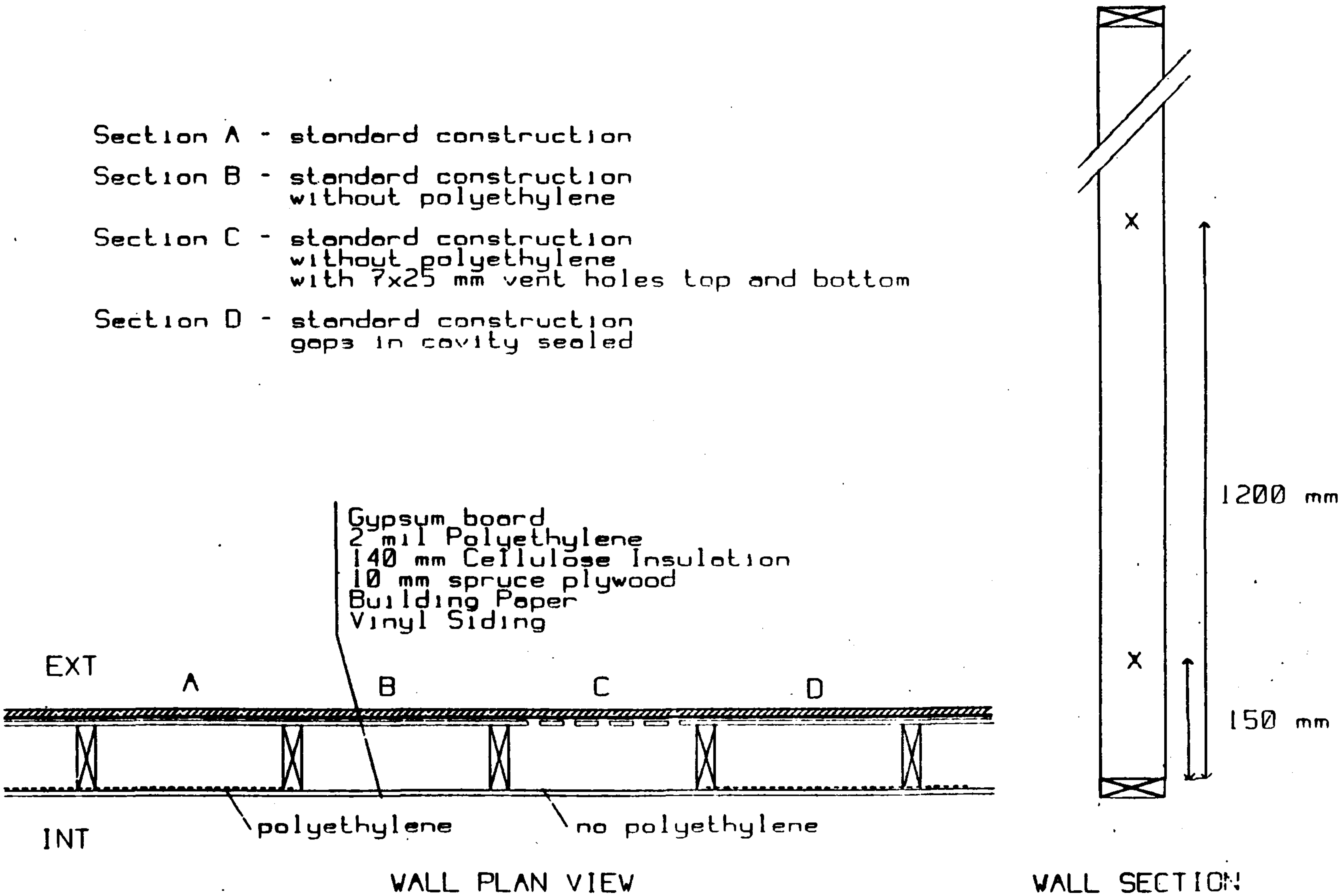

FIGURE 2 - WALL SECTIONS

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For the initial two months of this project, wood moisture contents and temperatures of the south wall sections were continuously monitored with a 32-channel data-logging system. In spite of attempts at shielding, difficulties were encountered with "noise" in the data transfer lines causing wide fluctuations in the recorded moisture data. This data was therefore utilized to supplement the point-in-time measurements.

Point in time measurements were made on approximately a monthly basis for the one year duration of this project. In addition to wall temperatures and moisture contents, interior and exterior temperatures and humidities were recorded.

3.1.2 MOISTURE CONTENT CORRECTIONS

"Moisture Content" of wood may be defined as a ratio of the weight of water over the dry weight, expressed as a percentage, for a specific section of wood. Moisture content may be determined by oven drying and weighing a sample and/or through the use of a portable moisture meter. An electrical resistance moisture meter was utilized to determine wood moisture contents for this project. Previous research has determined that under steady-state conditions, placing the probes to a depth of 1/4 to 1/5 of the timber cross section, provides a reasonably accurate average moisture content for the wood. As with all test equipment, there is some variability in the test results. Moisture meters operate most accurately between moisture contents of 7% and fibre saturation (25 to 30%).

Moisture content readings are affected by variations in temperature, wood species and free moisture within the cells. Substantial moisture gradients may exist in plywoods, therefore, indicated moisture content will vary with slight adjustment of the probe depth. In addition, resin glues in plywoods may artificially increase the indicated moisture contents.

All data presented in this report has been corrected for species and temperature. Species corrections were based on recommendations by Delmhorst Instruments, the equipment manufacturer. Temperature corrections were based on research completed by Mr. van Rijn and Mr. Pouyez of Forintek Canada. Using the moisture meter, a limited number of oven-dried laboratory calibrations determined reasonably similar results to these corrections.

TABLE 1

Wall Sections and Sensor Locations

Section A - South Wall - Standard Construction.
- A1 - Plywood sheathing - 1200 mm above sill plate
- A2 - Wall stud - 1200 mm above sill plate - 12 mm from exterior
- A3 - Wall stud - 1200 mm above sill plate - 12 mm from interior
- A4 - Plywood sheathing - 500 mm above sill plate
- A5 - Wall stud - 150 mm above sill plate - 12 mm from exterior
- A6 - Wall stud - 150 mm above sill plate - 12 mm from interior
- A7 - Sill stud - 12 mm from exterior
- A8 - Sill stud - 12 mm from interior

Section B - South Wall - Polyethylene not installed.
- B1 - Plywood sheathing - 150 mm above sill plate
- B2 - Wall stud - 150 mm above sill plate - centered
- B3 - Sill plate - centered

Section C - South Wall - Polyethylene not installed and 7 ventilation holes, 25 mm in diameter, drilled through sheathing at top and bottom of stud space.
- C1 - Plywood sheathing - 150 mm above sill plate
- C2 - Wall stud - 150 mm above sill plate - centered
- C3 - Sill plate - centered

Section D - South Wall - Gaps in sheathing and stud sealed.
- D1 - Plywood sheathing - 150 mm above sill plate
- D2 - Wall stud - 150 mm above sill plate - centered
- D3 - Sill plate - centered

Section E - East Wall - Standard Construction.
- E1 - Plywood sheathing - 150 mm above sill plate
- E2 - Wall stud - 150 mm above sill plate - centered
- E3 - Sill plate - centered

Section F - North Wall - Standard Construction.
- F1 - Plywood sheathing - 150 mm above sill plate
- F2 - Wall stud - 150 mm above sill plate - centered
- F3 - Sill plate - centered

Section G - North Basement Wall - Furred stud wall.
- G1 - Wall stud - 1200 mm above sill plate - 12 mm from exterior
- G2 - Wall stud - 1200 mm above sill plate - 12 mm from interior
- G3 - Wall stud - 150 mm above sill plate - 12 mm from exterior
- G4 - Wall stud - 150 mm above sill plate - 12 mm from interior
- G5 - Sill plate - 12 mm from exterior
- G6 - Sill plate - 12 mm from interior

3.1.3 INITIAL MOISTURE CONTENTS

Framing members used in the construction of this home were grade stamped as kiln-dried spruce wall studs, standard-dry spruce sill plates and spruce plywood. These were reported to be typical of timbers utilized for construction by Lincolnberg Homes. Average corrected initial moisture contents recorded on random samples throughout the house, were as follows:

Wall framing
- wall studs - shell (5 mm depth) - 11%
  - core (25 mm depth) - 14%
- sill plates - shell - 13%
  - core - 16%
- plywood sheathing - 9%

Basement framing
- wall studs - shell - 10%
  - core - 12%
- sill plates - shell - 15%
  - core - 16%

Framing members specifically monitored for this program, indicated initial average moisture contents of 15% for the wall studs, 15.5% for the sill plates and 9% for the plywood. Therefore, the lumber monitored by this test program was of similar initial moisture content as lumber utilized throughout the house.

3.1.4 WOOD MOISTURE CONTENT DATA

Figures 4 through 13, included in Appendix A, present plots of the wood moisture content vs. time, for the various sections and combinations of sections. Moisture contents presented have been corrected for temperature and species. A majority of the moisture contents are based on point-in-time measurements, therefore peaks and slopes are not necessarily absolute.

The main-floor, wood-framed wall monitoring locations were averaged to produce Figure 4, which illustrates the norm for moisture gain and loss. There was insufficient data to provide a statistical comparison, however, the data produced similar trends at each comparable location monitored. Figure 4 may be interpreted as follows:

- Prior to cellulose application moisture contents were not constant, plywood moisture contents indicated a slight increase while the framing members decreased.

- Plywood moisture gain/loss was more rapid and of greater magnitude than the timbers. The wall and sill timbers indicated similar moisture gain/loss characteristics.

- Plywood moisture contents increased to 26% after 30 days, followed by drying to near original moisture levels, after approximately 160 days, and drying an additional 1% over the remaining period.

- Framing moisture contents increased to between 20 and 22% within 10 days of cellulose application, drying to 2% above original installation within 80 days and drying an additional 3% for the duration of the project.

- Rate of plywood moisture loss was affected by the freezing temperatures of January and February 1988 (Figure 3), while the sill plates were affected by a subsequent thaw, indicating a secondary moisture gain in some locations.

- Plywood sections dried to within 1% of the original moisture content, while the framing dried 2 to 3% below original.

The remaining test wall sections are comparable to the average moisture gain/loss characteristics of Figure 4, with the following departures:

Figure 5: Section A - South Wall - Standard Construction.
- Plywood moisture content gain was greater (6%).
- Sill plate moisture content loss characteristics were at a lower level.

Figure 6: Section B - South Wall - Polyethylene not installed.
- Moisture loss occurred more rapidly.

Figure 7: Section C - South Wall - Polyethylene not installed and ventilation holes drilled through sheathing.
- Total moisture gain 3 to 5% less.
- Moisture loss occurred more rapidly, similar to Section B.

Figure 8: Section D - South Wall - Gaps in sheathing & stud sealed.
- -Secondary moisture gains for plywood and sill plate subsequent to warming temperatures (days 120 to 180).

Figure 9: Section E - East Wall - Standard Construction.
- -Plywood peaked at a lower moisture content while framing members peaked higher and more rapidly.
- -Moisture loss curves affected by ambient freezing and thawing conditions.
- -Secondary moisture gains for all components, subsequent to warming temperatures (days 120 to 180).

Figure 10: Section F - North Wall - Standard Construction.
- -Plywood peaked 3% lower while sill plate peaked 8% higher.
- -Secondary moisture gains for all components, subsequent to warming temperatures (days 120 to 180).
- -Drying to near original conditions required 190 days.

Drying of the basement walls is summarized by Figure 11. Interior/exterior and upper/lower sensors were averaged to represent wall studs and sill plates. Negligible moisture gain was noted for the initial 20 days. According to the recorded data, moisture contents peaked at 18%, 120 days after installation. Based on the data trends, a peak may have occurred approximately 60 days after installation, which coincided with the ambient freezing temperatures. Drying to near-original moisture contents occurred 150 days after installation. Secondary moisture gains were indicated during the summer months, presumably as a result of condensation on the concrete surfaces. A gradual drying occurred over the remaining period, to near installation conditions.

A comparison of all sensors placed 12 mm from the interior of the wall stud and 12 mm from the exterior of the stud, for both the wood framed walls (Sections A and E) and basement walls, is plotted in Figure 12. Moisture gain/loss characteristics were similar for interior and exterior edges. Exterior sections of the wood wall framing gained additional moisture, while interior sections dried slightly more rapidly. Basement framing gains and losses were cyclic with the ambient conditions.

Figure 13 provides a comparison between upper (2400 mm) and lower (150 mm) sensor locations. Similar moisture gain and loss characteristics were indicated. Upper sensors dried at a faster rate in the wood-framed walls, while the lower sensors in the basement wall displayed a slight increase in moisture gain.

3.2 CELLULOSE

3.2.1 OBSERVATIONS

The cellulose was sprayed by applicators from Can-Cell Industries Ltd. of Edmonton. The manufacturers trade name for the material is "Weathershield TA". Cellulose and binder arrived on site premixed and bagged. Interior preparations included: protection of electrical outlets, windows, doors and other moisture susceptible materials. In addition, areas that were difficult to effectively spray (such as corners with a narrow opening and window perimeters) were insulated with batts of fiberglass insulation. Floors were brushed clean to facilitate reuse of excess material without contamination.

Cellulose fibre was pumped from a truck-mounted unit through a pneumatic hose. The applicator operated an external mix nozzle, which projected the dry cellulose and water spray through an orifice. The water spray activates the binder mixed in with the cellulose.

Cellulose was sprayed directly into the wall cavity, filling the stud space. Excess material was removed from the wall with a wall scrubber, an electrically driven rotary brush which scrubs the cellulose to a plane even with the inner face of the wall studs. Excess material was reused by manual placement and slight tamping into the bottom of a stud cavity.

Application of insulation to two floor levels and basement rim joists was completed within eight hours, using a crew of three. Ambient conditions were slightly above freezing (1 to 3°C), with light easterly winds.

Insulating the basement was completed in a similar manner. The stud space and furred area were filled with cellulose. Interior temperatures in the basement, during spraying, were 5 to 10°C.

3.2.2 MATERIALS TESTS

During the spraying application, samples of the sprayed cellulose were collected, to determine material properties.

Density samples were obtained by spraying the material into a confined portable cavity, utilizing similar spray patterns to the wall sections. Moisture contents were determined based on original sample weight (wet basis) while density was calculated based on a dry basis. Average results, based on three samples, were as follows:

Sampling Date	Location	Density	Moisture Content
Nov. 10/87	Main floor	46 kg/m^3	53 %
Dec. 23/87	Basement	48 kg/m^3	54 %

Adhesion tests were attempted, however, the cellulose bond was below measurable limits of adhesion test equipment. In this application, cellulose adhesion was required to support the material weight. Adhesion appeared to be adequate, particularly in a confined space. The basement walls were left unfinished through the duration of the project. The cellulose remained adequately adhered to the framing.

According to the manufacturers literature, cellulose should be spray applied at a density of 48 kg/m^3 ± 5 kg/m^3 and a moisture content of 50 % ± 10 %. Based on the test samples, the material was applied within manufacturers recommendations, in both density and moisture content.

3.3 AIR LEAKAGE

3.3.1 BLOWER DOOR TESTING

Fan door air tightness tests were conducted by Howell-Mayhew Engineering Inc., in accordance with CAN/CGSB - 149.10-M86, utilizing Minneapolis Blower Door equipment. Test reports are attached in Appendix B.

The initial test was completed November 13, 1987, following spraying of cellulose to the walls and the basement rim joists. Ceiling gypsum board was installed but not taped or insulated. Wall gypsum board and polyethylene were not installed. A majority of the exterior doors and windows were in place. Remaining major openings were temporarily sealed. A rate of 6.6 air changes/hour (AC/h) at 50 Pascals (Pa.) was determined. The large air change rate was due to various sources of leakage through temporary seals and incomplete sections. This was not a representative test of the cellulose or house.

A second air leakage test was completed January 6, 1988 shortly after the house was substantially completed. A rate of 1.58 AC/h at 50 Pa. was determined.

Subsequent air leakage tests were completed September 15 and 20, 1988 and January 5, 1989. Rates of 1.95, 2.01 and 2.00 AC/h at 50 Pa. were determined. These tests are representative of the completed house with the walls and insulation in a relatively dry state.

3.3.2 SMOKE TESTING

During the air leakage testing of January 6, 1987, smoke test methods were utilized to visually confirm and determine locations of air leakage of the basement and main floor level of this residence. The following sources of air leakage were observed at 50 Pa. pressure:

Major leakage
- basement-level door perimeter
- basement aluminum windows
- fireplace flue

Moderate leakage
- conduit and mechanical penetrations through rim joists
- main level French doors
- kitchen casement window

Minor leakage
- rim joist at garage overhang
- exterior wall electrical outlets
- main floor windows

Of particular interest were locations of duct openings to the exterior, cut coarsely through the rim joist. The rim joist cavity above the concrete wall was wet-sprayed with cellulose, to approximately 250 mm depth. Minimal air exfiltration was observed around a duct centered in the cavity. Air leakage was noted, however, at an adjacent duct opening where a 50 mm gap between the duct and timber was difficult to adequately fill with cellulose.

Each of the wall sections were examined for traces of smoke currents indicating air leakage. Air leakage at these sections was limited to some electrical outlets. Wall Section C displayed slightly greater air leakage than other sections.

3.3.3 WALL PRESSURE DROP TESTS

Pressure drops across wall sections were determined in conjunction with air leakage tests completed January 5, 1989. The purposes of these tests were to evaluate which components within this wall envelope are functioning as the air barrier and the relative effectiveness of cellulose in reducing air flow.

Figure 14 illustrates the testing method and the assembly utilized to measure pressure drops across the wall components. A blower door fan created a pressure differential across the wall, varying between 20 and 60 Pa pressure. A pressure tap (10 mm diameter tube) was inserted into the wall cavity to various depths, corresponding to each of the wall components. Pressure differentials across each section were recorded with an incline manometer. The tap entry into the wall was substantially sealed and pressures stabilized for each test.

Six tests were completed across various wall sections. Table 3 presents the pressure drop data. Sections tested with gypsum board, but without polyethylene installed, indicated pressure drops equal to those with the gypsum board and polyethylene combined. Testing from exterior to interior produced similar values.

It should be noted that resistance to air flow, varied by up to 15 % with each wall section tested. Installation of pressure taps during construction would have provided more accurate results as some errors are anticipated due to imperfections in the pressure tap seal. These results are not conclusive and may vary with each house built.

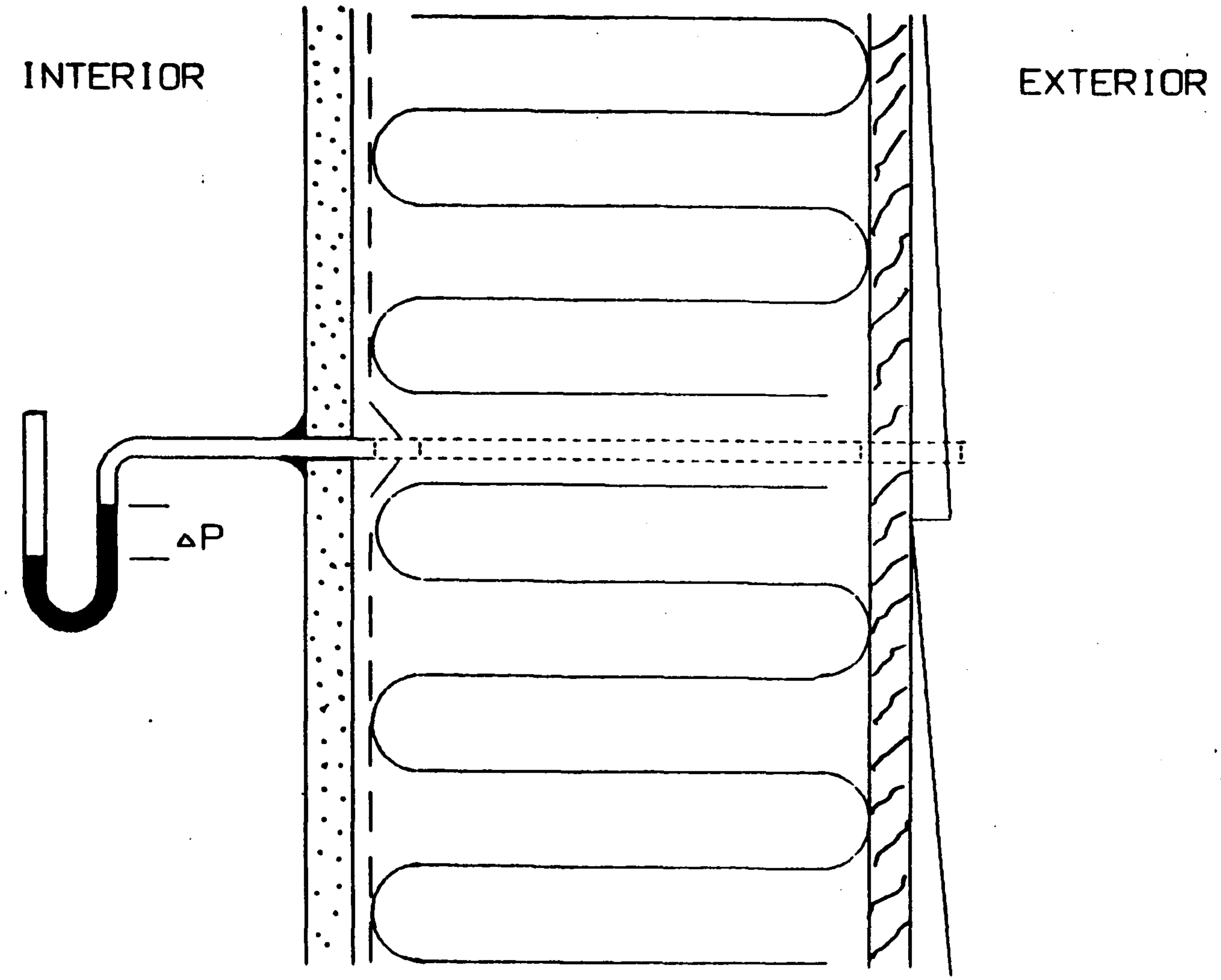

FIGURE 14 - PRESSURE DROP TESTING

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Table 3 indicates that, for this test home, the exterior sheathing was the principal air barrier. Gypsum board, polyethylene and cellulose provided further air resistance, in decreasing magnitudes. Subsequent inspections noted that the plywood joints, originally 3 mm in width, were nearly tight, contributing to the air tightness of the exterior sheathing. Interior gypsum board had various electrical penetrations through it, while cavities were interconnected by holes for wiring.

Air tightness of this home may have been significantly different if electrical outlets had been sealed and joints between plywood increased.

TABLE 3

PERCENTAGE OF TOTAL PRESSURE DROP ACROSS WALL

Pressure Drop (Pa)	Gypsum Board	Polyethylene	Cellulose	Plywood Sheathing
20	40 %	15 %	0 %	45 %
30	37 %	13 %	3 %	47 %
40	35 %	15 %	5 %	47 %
50	30 %	18 %	4 %	48 %
60	28 %	22 %	7 %	47 %

3.4 RELATED INFORMATION

3.4.1 INTERIOR AND EXTERIOR ENVIRONMENTS

Heating in the home was controlled by a programmable, set-back thermostat. Temperatures were maintained at 22°C, between 6:00 am and 10:00 P.M., and setback to 17°C in the evenings.

A ventilation exhaust system was connected to the kitchen, bathroom and laundry rooms. The system runs continuously at low speed, but switches to high speed at relative humidities in excess of 50%.

Exterior conditions are represented by climatic data from Environment Canada recorded at the Edmonton Municipal Airport, approximately 20 km west of the site. Mean daily temperatures for the monitoring period are presented by Figure 3, Appendix A.

Interior temperatures and humidities were recorded for each monitoring date, using a sling psychrometer, and are reported in Table 2.

3.4.2 OCCUPANTS' COMMENTS

Occupants of this test house noted the following:

- Heating costs were quite modest for the 260 square meter house. Natural gas consumption for the first year was 152 gigajoules or 0.026 gigajoules/heating-degree-day for a total cost of $417.00, which included domestic water heating for a family of four.

- In comparison to the owners' previous residences, this home was very quiet. Cellulose manufacturers have claimed improved soundproofing over fiberglass insulation.

- They recommend cladding the cellulose in the basement to minimize the release of fibres into the air and damage by contact. While exposure to cellulose fibres is not known to be hazardous, the insulation binder incorporates chemicals which may not be as innocuous.

3.4.3 EXAMINATION OF EXTERIOR WALLS

On January 5, 1989, at the completion of the project, siding and exterior plywood sheathing were removed from sections of the north and south walls, near the test locations. The purpose of this inspection was to determine the current condition of the wall assembly one year after cellulose application and note any indications of deterioration.

Three sections of plywood (approximately 0.5 meters square each) were removed from the existing walls: two on the south wall and one on the north. Cellulose was removed allowing the wall cavity and components to be examined.

Examination of the cellulose in the stud cavities indicated that it was fully adhered to the head plate and that there was no indication of settlement. In addition, a majority of the basement wall cellulose was left exposed and gave no indication of settlement.

Numerous siding and sheathing fasteners were removed during the inspection. Mild surface corrosion was noted, sufficient to remove the galvanized dip coating on approximately 1/3 of the siding nails. Corrosion was slightly more pronounced on fasteners recovered from the north face and was limited to the embedded portion of the fastener. Two of the fasteners removed, had experienced some pitting. Staples, which fastened the plywood sheathing, were free of visible corrosion.

A very small fungi growth was noted on the north wall, at the contact surface between plywood sheathing and the exterior stud face. The growth was approximately 10 mm in diameter and was limited to the surface fibres.

Remaining wall components were free of moisture related abnormalities. Plywood surface fibres in contact with the cellulose were light yellow in color. Surface fibres appeared slightly swollen. The plywood adhesive and plies appeared to be unaffected by the moisture.

Interior gypsum board appeared normal in locations with and without the polyethylene installed.

4.0 REVIEW AND DISCUSSION

4.1 MOISTURE CONTENTS

Initial wood moisture contents suggest that the wall studs had gained moisture since the kiln drying process. Sill plates and plywood were at moisture contents consistent with air dry conditions. Initial moisture losses, indicated prior to cellulose application, suggest a slight drying out of the frame lumber following assembly of the walls, adjusting to ambient conditions. Relative humidities of 40 to 70% imply wood equilibrium moisture contents in the range of 8 to 13%.

Application of the cellulose provided an abundance of excess moisture in the wall cavity. Evaporation readily occurred during the initial 6 days prior to gypsum board installation. Following gypsum board installation, moisture flow continued from the cellulose to the framing and gypsum board, until a temporary equilibrium was reached, near the maximum moisture contents indicated by the plots. Subsequently, evaporation was then the principal drying mechanism, until an equilibrium moisture content was achieved between the wall section and air.

Ambient freezing temperatures occurred while the cellulose was damp. Freezing temperatures were experienced by the walls during the evenings, until Day 14, at which time heaters were installed. Cooler exterior temperatures directed moisture flow to the exterior, contributing to the increased plywood moisture contents. Temperature recordings indicated that portions of these walls were frozen during the cooler ambient temperatures, generally warming to above freezing through daily solar gains. Plots indicate cooler temperatures affected the rate of moisture loss. Warmer ambient temperatures indicated an increase in moisture at some sensors after 120 days. This may be a result of thawing of frozen moisture within the wall cavity.

A moisture equilibrium of the wall framing members appeared to have been achieved after approximately 80 days while the plywood required 160 days. Limited further drying was experienced for the remaining six month period.

Moisture gain by the walls components was predominately through moisture loss by the cellulose. However, there were other minor contributors of moisture to the wall cavity. Temporary propane heating, mudding of the gypsum board and air leakage through the wall cavity, may have contributed some additional moisture to the wall cavities.

4.2 AIR LEAKAGE

A comparison in air tightness between this home and others built by Lincolnberg Homes cannot be made. Lincolnberg's TEC homes must meet an air change rate of 1.5 or less prior to occupancy. This test house was constructed to TEC standards, with significant departures in the air sealing methods to evaluate the performance of the cellulose insulation. Initially, an air change rate of 1.58 at 50 Pa. was recorded. Subsequent tests indicated an air change rate of 2 at 50 Pa. once the walls were considered dry. Cause of the change in air tightness over the first six months, is uncertain. It may be related to swelling and shrinkage of the materials or increased air permeance of the cellulose as it dries.

Based on the findings from this project, cellulose insulation was not an effective air barrier. Wet-sprayed cellulose insulation provides some resistance to air flow due to the dense application and fibre layering. The degree of resistance varies with pressure differentials, density, thickness and, possibly, fiber size. The resistance provided was not of comparable magnitude to gypsum board, plywood or other common air barrier materials. Laboratory tests undertaken by CMHC, have also indicated that cellulose was not an effective air barrier.

Improved air tightness from cellulose insulation, has been documented by others, through blower-door air leakage testing. This may be attributable to the complete filling of the wall cavity which provides full support of the polyethylene under negative wind pressures. In addition, thick, dense sections of cellulose, in locations such as rim joists, will provide improved resistance to air leakage over conventional insulating methods. Thermal resistance of the wall cavity was likely improved over conventional methods due to a complete filling of the wall cavity. Convective loops, normally experienced by an incomplete filling of the cavity, would be minimized.

4.3 EFFECTS OF HIGH MOISTURE CONTENTS

This test program has illustrated that wet-sprayed cellulose, applied to framing lumber with low moisture contents in a dry climate, will increase wood moisture contents up to 30% followed by a drying period of up to six months. The walls were examined for the following forms of moisture related deterioration:

- corrosion of metal fasteners;
- wood fungi;
- dimensional changes; and,
- deterioration of the plywood bond.

4.3.1 CORROSION

Examination of the walls noted that approximately 30% of the siding nails displayed some evidence of corrosion. Corrosion occurred at the point of penetration into the wood. Conditions conducive to corrosion exist in most siding applications. Nails are generally galvanized and moisture is limited, reducing the potential for corrosion. Corrosion of only some fasteners in this application, indicates variability in the protective coating of the fasteners used and/or the amount of moisture present.

4.3.2 WOOD FUNGI

Favorable moisture conditions for fungal growth occurred for a period of time in each of the wall sections monitored, with the exception of the basement walls. Favorable ambient temperatures did not coincide with high moisture content periods. However, components within the wall were at favorable temperatures while the cellulose was wet and during solar heating of the exterior cladding.

According to the cellulose manufacturers, Borate was mixed with the raw cellulose to inhibit the fungal growth. In spite of this, a trace of fungi was observed in one of the three locations examined, between the plywood and timber on the north face. It is assumed that the Borate may not have penetrated through to this location, which was not in direct contact with the cellulose.

4.3.3 DIMENSIONAL CHANGES

Dimensional changes in timber occur with variations in wood moisture content. Longitudinal changes are usually very small (less than 1%). Changes in dimension occur primarily across the grain, increasing in proportion to the moisture content, up to 24%. A drop in wood moisture content from 24 to 6% may cause an 8% dimensional change, or up to 6 mm on a 140 mm stud. For the moisture contents recorded, a maximum dimensional change of 5% across the grain may have occurred. Similarly a 1/4 to 1/2% change in width and length may have been experienced by the plywood. Once dried the timbers would normally return to their original dimensions.

Visual inspection of the timbers in the existing walls showed that the wood was free of the abnormal shrinkage, checks or warping.

4.3.4 DETERIORATION OF THE PLYWOOD BOND

Exterior use plywood adhesives are generally water resistant phenol-formaldehyde resins. Prolonged exposure to moisture may result in dissolving of the glue. Wetting and drying produces shrinkage stresses which can lead to delamination of the plies.

Inspection of the in situ panels noted that the plies were firmly adhered and appeared to be unaffected by the moisture exposure.

5.0 CONCLUSIONS

This project evaluated the effect of wet-sprayed cellulose insulation on the performance of wall components in wood framed construction. A typical Alberta residential home was monitored as a test house, for a period exceeding one year. Moisture contents within the wall cavity and air leakage characteristics were evaluated. Initial wood moisture contents were relatively dry.

The following conclusions were determined from this study, based on the previously outlined parameters:

-Spray-applied cellulose insulation significantly affected the framing moisture contents, which increased to near fibre saturation within 30 days;

-Moisture content data, recorded for this test house, indicated that framing components dried to near preinstallation conditions within six months of installation, which included ambient freezing conditions;

-The rate of drying was affected by ambient temperatures and humidity, air tightness of the wall cavity, orientation of the wall and installation conditions;

-Sill plate and wall stud moisture gain/loss characteristics were similar, suggesting that a majority of the sprayed moisture did not drain;

-Insulation exposed to the interior for the duration of the monitoring period, dried out more rapidly than the closed-in cavities;

-Increased opportunity for ventilation and construction without polyethylene, appeared to improve the rate of drying;

-Comparisons between sensor placement on the studs (i.e. interior vs exterior and upper vs lower) showed similar results;

-Cellulose insulation was not an effective air barrier, however, some resistance to air flow was noted;

-Exterior plywood sheathing and gypsum board provided a majority of the air resistance through the wall sections tested;

-Homeowner's comments suggest improvements with sound isolation and heating costs may be achieved by wet-sprayed cellulose;

-Deterioration of the walls one year after construction was very limited. Surface corrosion of some fasteners and one small spot of fungi were observed in the three sections examined.

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APPENDIX A

DATA PLOTS

TABLE 2
WOOD MOISTURE CONTENT DATA

RECORDING DATE																	
DATE	NOV 5/87	NOV 10	NOV 10	NOV 13	NOV 19	NOV 20	DEC 8	DEC 17	JAN 6/88	JAN 29	MAR 9	APR 19	MAY 18	JUN 30	SEP 15	OCT 24	JAN 5/89
TIME	9:30	8:00	16:00	14:00	14:00	17:00	13:00	16:30	14:00	16:00	15:00	16:00	16:00	16:00	15:00	14:30	10:00
DAYS	0	5	5	8	14	15	33	42	62	85	125	166	195	238	315	354	427
SENSOR LOCATION																	
A1	9	11	14	12	24	22	30	33	22	22	9	8	9	8	8	8	9
A2	14	11	11	12	18	25	24	23	19	18	16	13	13	12	13	12	13
A3	15	13	15	22	20	19	18	18	17	13	13	11	12	12	11	11	13
A4	10	10	12	20	24	23	32	30	22	23	16	10	10	10	9	10	10
A5	15	13	14	15	17	17	24	25	21	21	18	14	13	13	12	12	13
A6	14	16	16	19	20	18	19	19	18	16	14	19	18	18	18	15	15
A7	15	15	16	16	24	23	18	19	17	14	13	12	11	12	11	12	13
A8	15	13	5	13	15	22	18	19	17	14	12	11	12	11	11	11	13
B1	9	11	12	17	23	23	26	28	20	14	10	8	9	10	10	10	10
B2	15	17	17	19	20	20	21	21	20	17	13	13	13	13	13	13	13
B3	16	15	16	16	19	19	19	19	18	15	14	13	12	12	12	13	14
C1	10	10	10	15	21	23	22	18	13	12	10	9	8	10	10	10	9
C2	16	14	16	16	18	19	19	20	18	15	14	13	12	12	12	13	13
C3	16	15	15	17	17	17	17	19	17	13	13	12	12	12	12	13	12
D1	9	9	11	16	17	21	23	26	22	19	21	10	10	10	10	9	9
D2	17	15	13	16	16	17	21	21	17	15	14	13	14	13	13	13	12
D3	16	15	16	17	19	21	21	22	17	17	23	22	13	13	12	13	13
E1	9	9	13	18	19	21	23	21	20	20	12	12	12	10	10	10	10
E2	15	15	15	18	24	24	21	20	18	15	17	17	16	14	13	13	13
E3	16	16	15	21	25	24	20	19	16	15	17	17	15	14	13	13	12
F1	9	9	12	14	17	20	23	21	19	19	22	16	10	9	7	9	10
F2	15	15	16	17	21	23	21	19	16	15	20	19	15	15	14	14	13
F3	16	16	16	16	20	25	29	27	25	23	29	18	16	16	15	15	14
G1								12	13	13	14	18	13	16	16	15	14
G2								11	12	18	17	12	15	12	14	12	12
G3								12	13	18	18	14	12	14	16	14	14
G4								11	12	18	18	15	15	14	15	13	12
G5								14	14	17	18	16	16	18	17	16	14
G6								14	13	15	18	13	13	18	16	14	11
INTERIOR TEMP	15	13	14	13	14	13	18	15	18	21	19	21	20	19	19	19	20
EXTERIOR TEMP	2	3	12	6	2	5	4	-6	-12	-17	8	7	15	21	17	8	-12
INTERIOR HUMIDITY	65	53	55	60	55	41	13	21	20	19	31	45	38	75	69	3	18
EXTERIOR HUMIDITY	72	41	50	75	51	55	43	36	45	41	60	81	41	82	78	56	85

(BASEMENT WALLS WERE SPRAYED DEC 17/87)

FIGURE 3
MEAN DAILY EXTERIOR TEMPERATURES
EDMONTON MUNICIPAL AIRPORT

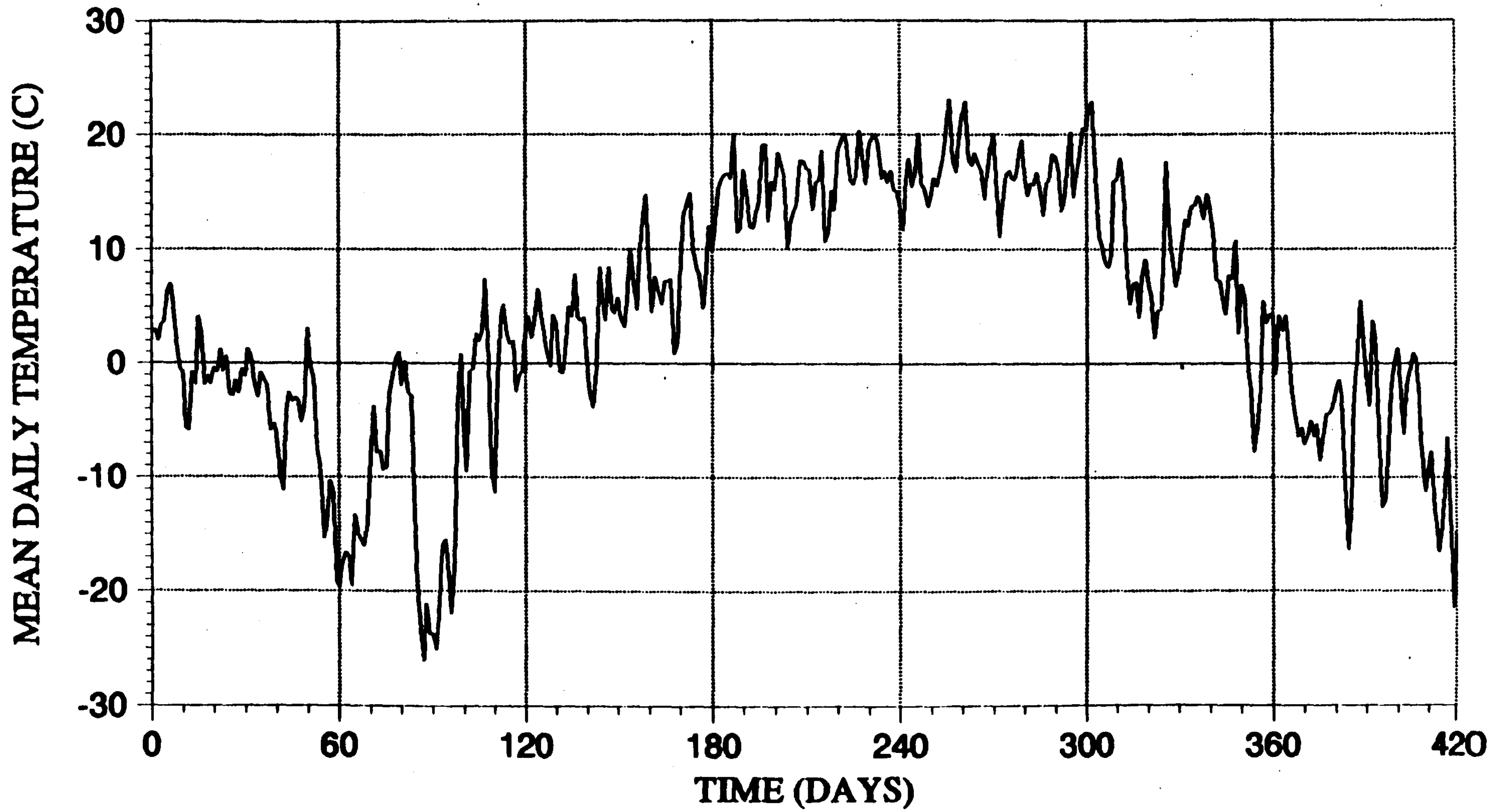

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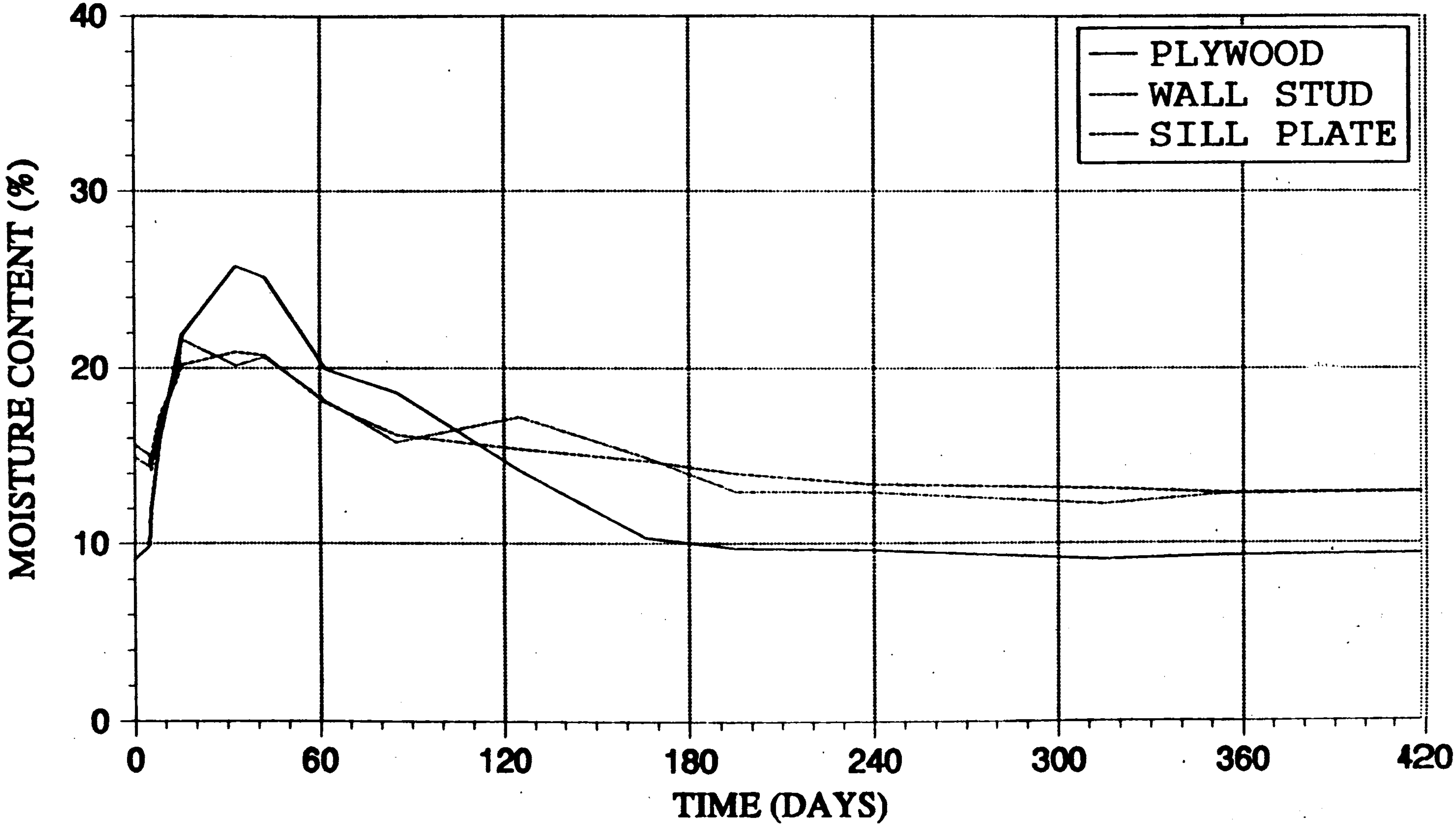
FIGURE 4
AVERAGE WALL MOISTURE CONTENTS



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J-[illegible]

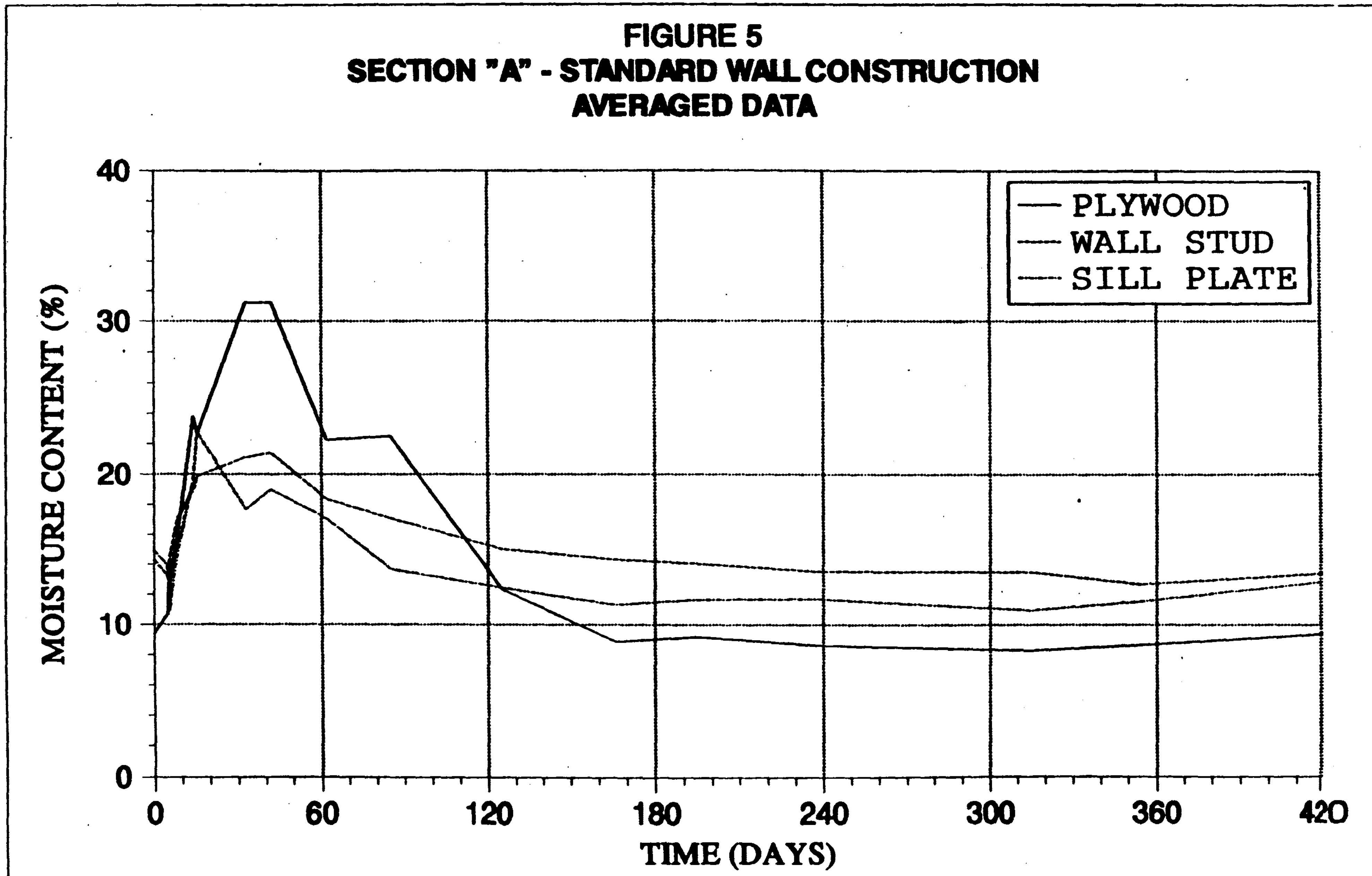

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FIGURE 6
SECTION "B" - SOUTH WALL
POLYETHYLENE NOT INSTALLED

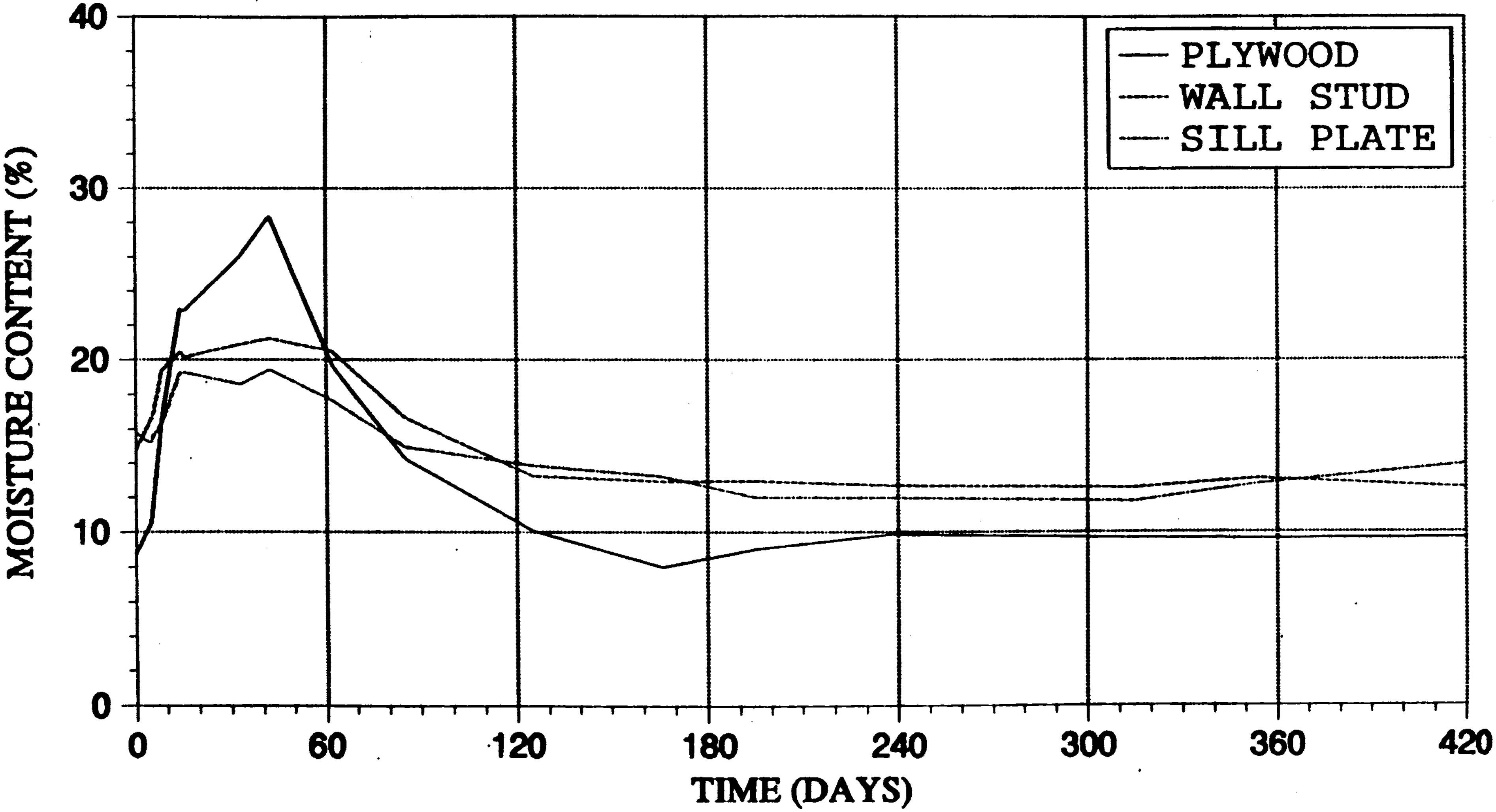

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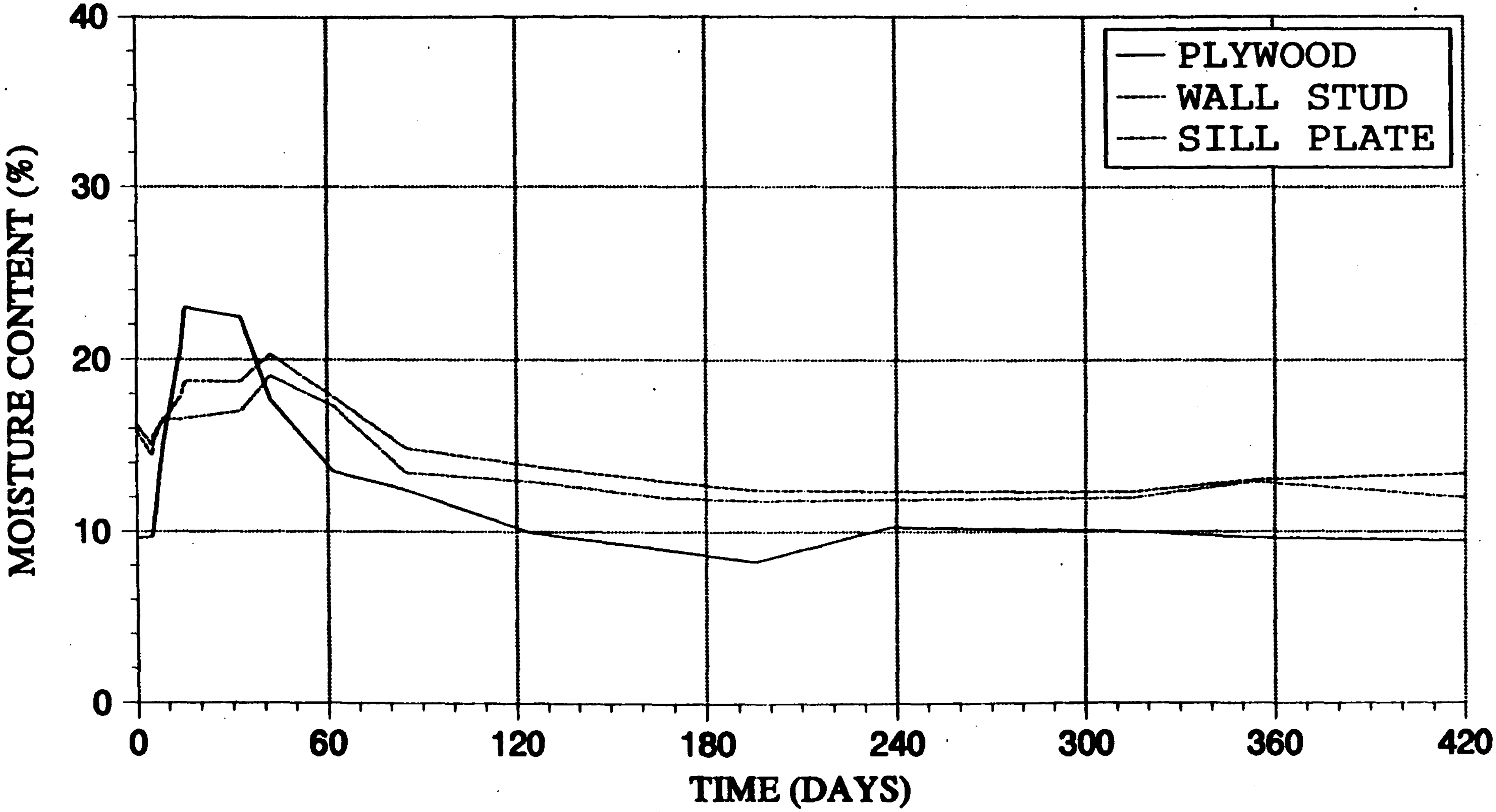
FIGURE 7
SECTION "C" - SOUTH WALL
POLYETHYLENE NOT INSTALLED - VENTILATED



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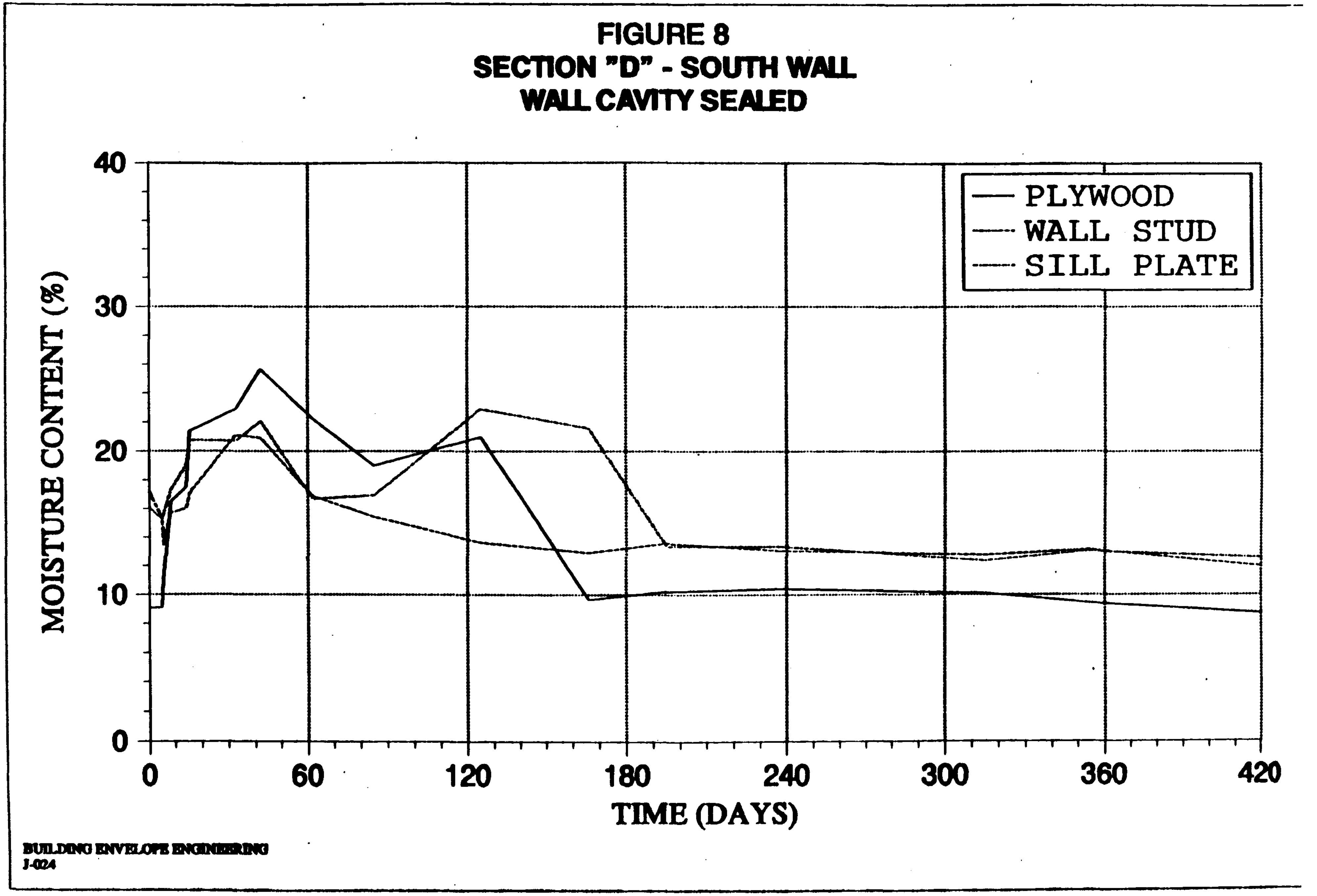
FIGURE 8
SECTION "D" - SOUTH WALL
WALL CAVITY SEALED
MOISTURE CONTENT (%)
TIME (DAYS)
PLYWOOD
WALL STUD
SILL PLATE
0
10
20
30
40
0
60
120
180
240
300
360
420
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FIGURE 9
SECTION "E" - EAST WALL
STANDARD CONSTRUCTION

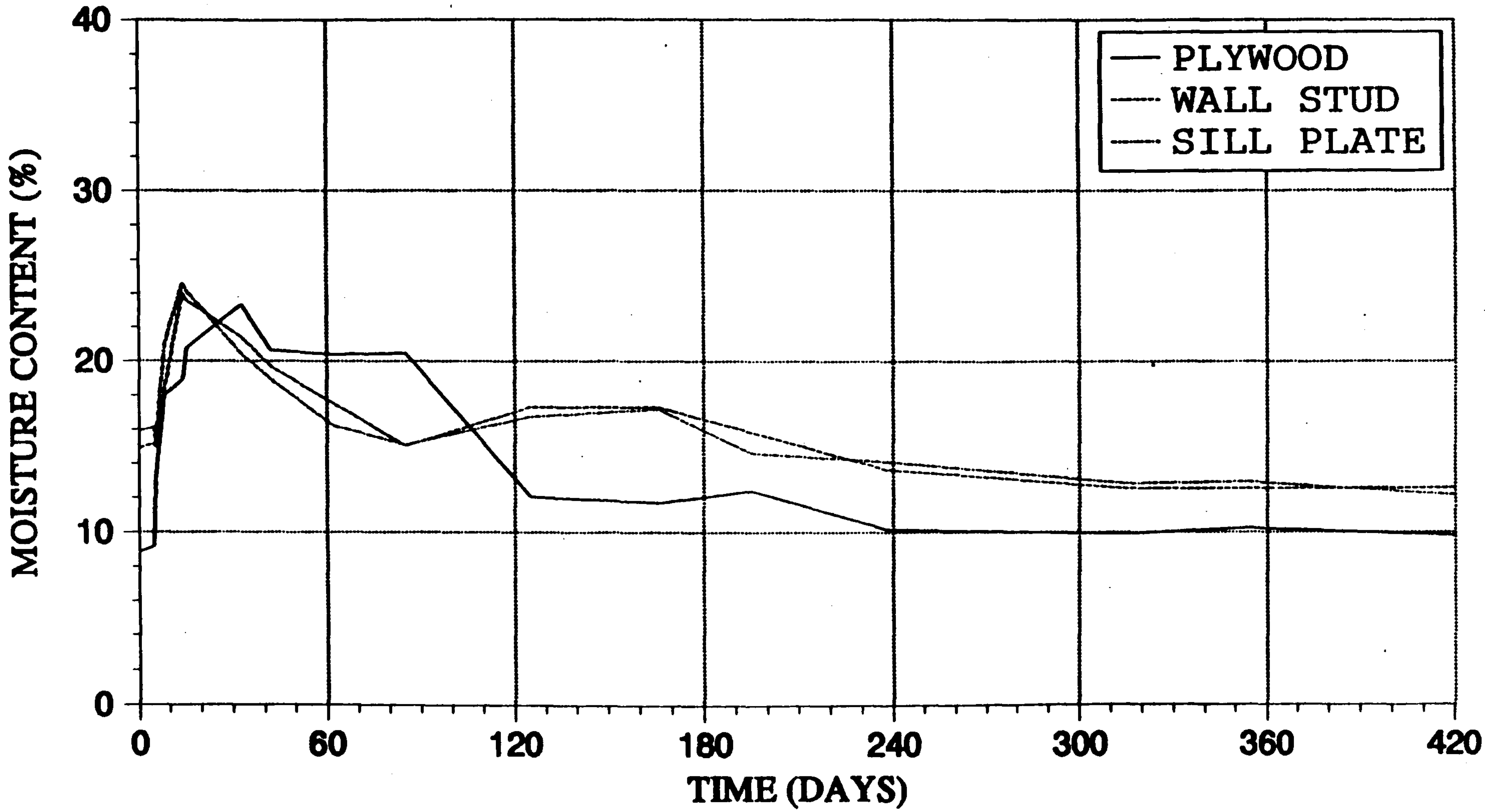

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FIGURE 10
SECTION "F" - NORTH WALL
STANDARD CONSTRUCTION

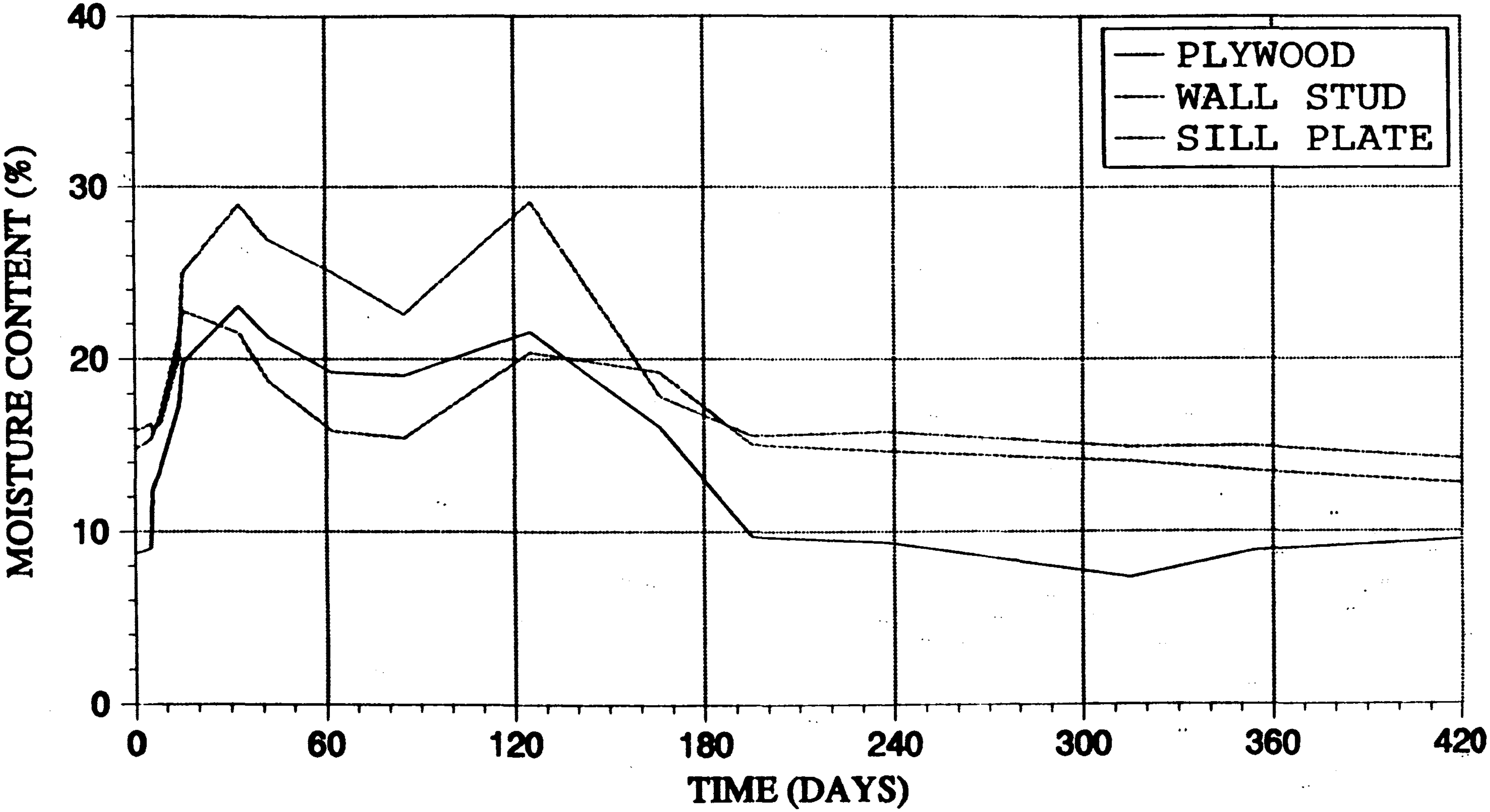

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FIGURE 11
SECTION "G" - NORTH BASEMENT WALL

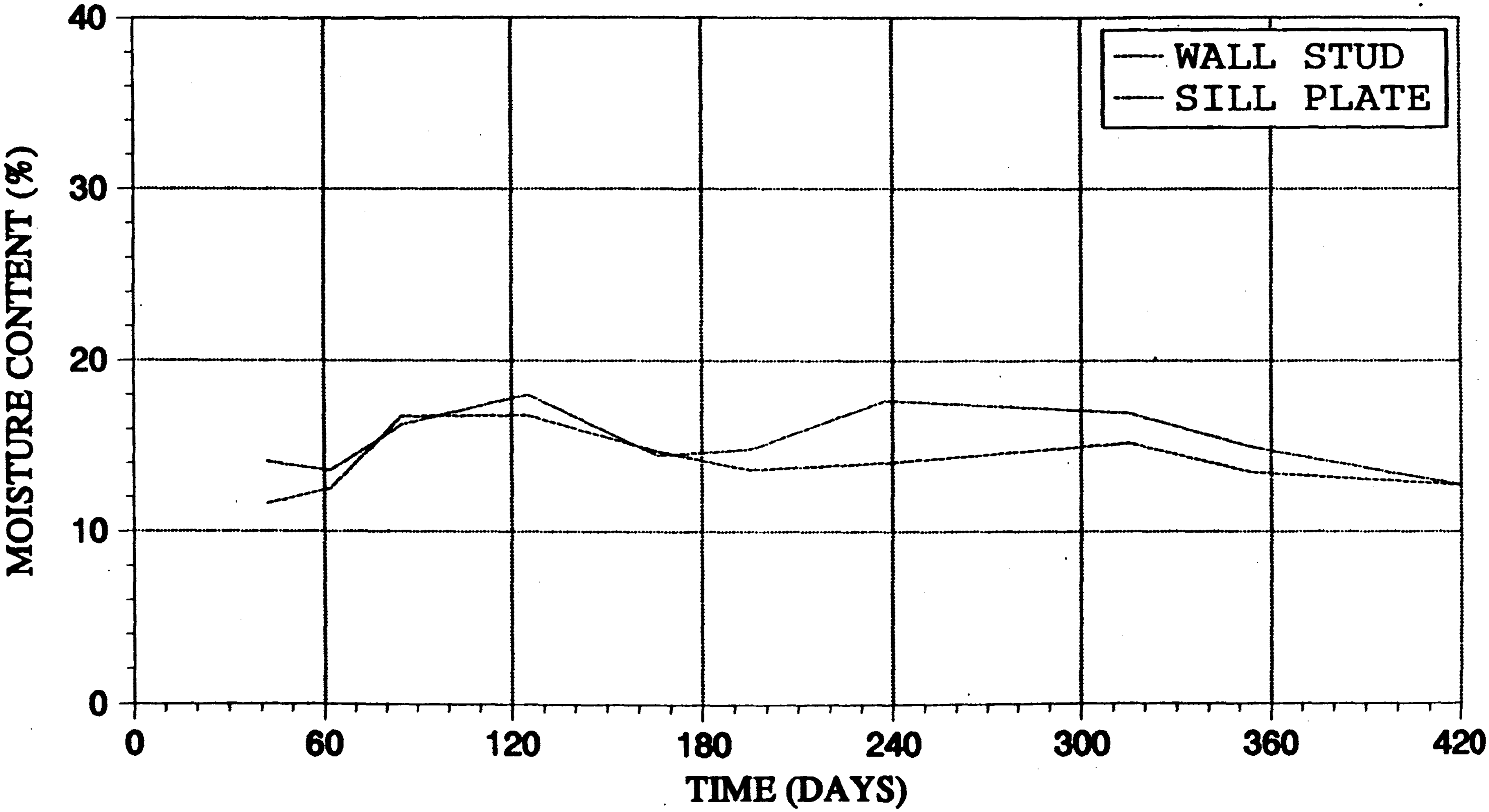

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FIGURE 12
AVERAGE INTERIOR VS EXTERIOR STUD EDGE
MAIN FLOOR LEVEL VS BASEMENT

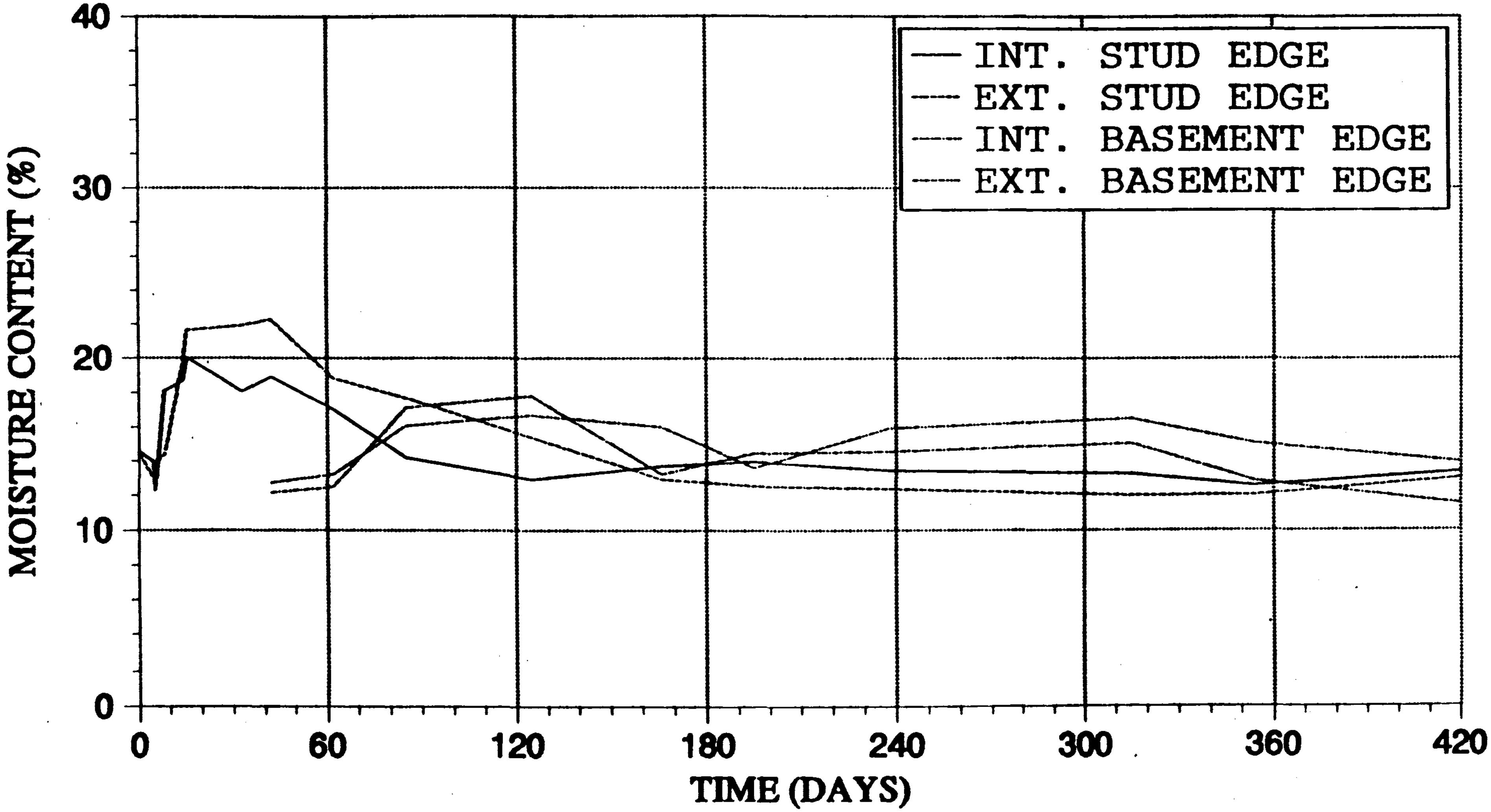

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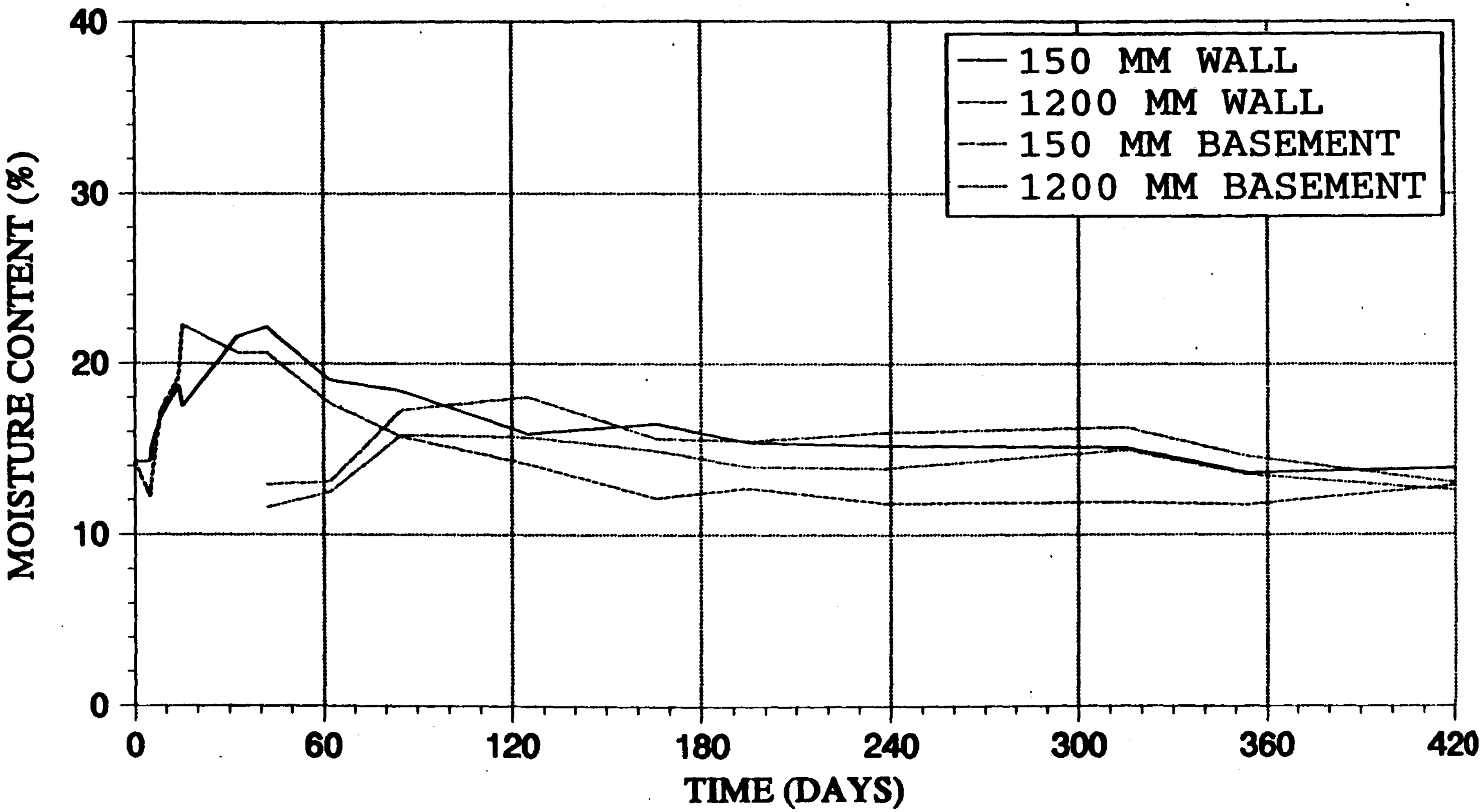
FIGURE 13
AVERAGE 150 MM VS 1200 MM SENSOR HEIGHT
MAIN FLOOR LEVEL VS BASEMENT



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APPENDIX B

BLOWER DOOR TEST DATA

howell-mayhew engineering, inc.

15006 • 103 AVENUE
EDMONTON • ALBERTA • T5P 0N8
(403) 484-0476

AIR LEAKAGE TEST REPORT

Name ______ ______

Address ______ ______

Sherwood Park

Surface Area ______

House Volume 32029

Air Density Correction Factor 0.983

Date NO 13 1987

Technician Wil Mayhew

Wind Speed 13 Km/h SE

Inside Temperature - 5°C

Outside Temperature - 5°C

Barometric Pressure 99.5 KPa

Fan Calibration

	Open Fan	Q(CFM) = 385.0 x (P).473
Low-flow plate:	0 holes plugged	Q(CFM) = 101.0 x (P).486
	4 holes plugged	Q(CFM) = 71.7 x (P).454
	6 holes plugged	Q(CFM) = 38.3 x (P).469
	7 holes plugged	Q(CFM) = 24.4 x (P).465
	8 holes plugged	Q(CFM) = 14.18x (P).477

Test #1

Depressurized ✓ Pressurized ____

P House (Pa)	P Fan (Pa)	Low-flow plate # holes plugged	Corrected flow (CFM)
58	140	—	3919
46	105	–	3420
39	75	–	2917
26	50	–	2408
19	35	–	2034

n = 0.6 (between 0.5 and 1.0)

r = 0.990 (greater than 0.99)

Q 50 = 3533 (cfm) ACH = 6.6

Q 10 = 1379 (cfm) ELA = 405 in²

Test #2

Depressurized ____ Pressurized ____

P House (Pa)	P Fan (Pa)	Low-flow plate # holes plugged	Corrected flow (CFM)

n = ______ (between 0.5 and 1.0)

r = ______ (greater than 0.99)

Q 50 = ______ (cfm) ACH = ______

Q 10 = ______ (cfm) ELA = ______

Comments (Reverse side: Major leakage sites, recommendations, etc.)

Air Tightness Test Report

R-2000

Builder / Company Name: BUILDING ENVELOPE ENG	Home Address:
Address (optional): 113, 1919-27 Ave NE	City: Edmonton Province: AB
City: Calgary Province: AB	R-2000 House No.:

❶ TYPE OF EQUIPMENT: Minneapolis Blower Door

DATE OF TEST: 06 JA88 TIME OF TEST: 1100

OUTDOOR TEMPERATURE: -14 °C

BAROMETRIC PRESSURE: 102.4

TYPE OF OUTDOOR PRESSURE TAP SYSTEM USED: FOUR WALL ☐ REMOTE ☑

WINDSPEED: 15 DIRECTION: W VARIABILITY: ___ (km/hr)

BUILDING VOLUME (including basement) ~~m³~~ (ft.³): 31447 Ⓐ

DOES EQUIPMENT AUTOMATICALLY CALCULATE "CORRECTED DATA"? YES ☐ NO ☐

BUILDING ENVELOPE AREA (including basement) ~~m²~~ (ft.²): 5542 Ⓔ

COMMENTS: Indoor Temp = 17 °C

NOTE: BUILDING VOLUME AND ENVELOPE AREA CAN BE TAKEN FROM HOT 2000 DATA SHEET.

❷ SEAL INTENTIONAL OPENINGS FOR AIRTIGHTNESS TEST

Opening	R-2000 preparation	
Fireplace - flue sealed with balloon		
• with damper	close	☐
• with doors	close	☐
Fireplace combustion intake ~~damper~~	sealed ~~close~~	☐
Fuel-fired furnace and / or stove flues	seal	☐
Furnace combustion air intake damper	close	☐
• without damper	seal	☑
Furnace draft control intake damper	close	☐
Floor drains	seal or fill with water	☑
Plumbing traps	seal	☑

Opening	R-2000 preparation	
Exhaust fans		
• with motorized damper	close	☐
• without motorized damper	no preparation	☐
Ventilator (without heat recovery) designed to operate continuously		
• intake and exhaust openings	seal	☑
Heat Recovery Ventilator		
• intake and exhaust openings	seal	☐
Dryer vents	sealed ~~no preparation~~	☐
Windows and doors	no preparation	☑
Window air conditioners	seal	☐
Attic hatch	close	☑

Please staple tape here when used. ↓

MEASUREMENTS

③ DETERMININATION OF BACKGROUND HOUSE PRESSURE
(to be subtracted from each recorded house pressure (column 2) to yield actual house pressure):

$$\text{BACKGROUND HOUSE PRESSURE (Pa)} = \frac{\text{INITIAL HOUSE PRESSURE (Pa)} + \text{FINAL HOUSE PRESSURE (Pa)}}{2}$$

$$= \frac{0 \text{ Pa} + 0 \text{ Pa}}{2}$$

$= 0$ Pa (Enter in column 3)

NOTE: 1 IN. WATER = 250 Pa

DEPRESSURIZATION TEST DATA

1	2	3	4	5	6
HOUSE PRESSURE, Pa (or inches of water)					Corrected
TARGET	RECORDED	BACKGROUND	ACTUAL	FLOW PRESSURE Pa	AIR FLOW RATE L/S (CFM)
50	52			105	857
45	47			90	795
40	41			75	728
35	34			65	[illegible]9
30	32			60	653
25	25			45	568
20	20			35	503
15					

NOTE: 1 L/S = 2 cfm

CGSB RESULTS

C 98.3

r 0.996

n 0.545

Max error of any pt. 2.2%

Relative Standard Error 0.02%

ELA 101.3 in^2

NLA 0.018 in^2/ft^2 Ⓓ

AC@50 1.58 Ⓒ

$$\frac{(C \times 50^n \times 60)}{\text{volume}}$$

TE #7B

howell·mayhew engineering, inc.
15006 • 103 AVENUE
EDMONTON • ALBERTA • T5P 0N8
(403) 484-0476

AIR LEAKAGE TEST REPORT

Name Lincolnberg (Vlooswyk) Date Sept 15 88.

House Address ______ , Sher Pk Wind Speed 25 Km/hr gusty

House Volume 31447 Barometric Pressure 92.84

Envelope Area ______ Outside Temperature 19.5°C

Technician Rick Thrall Inside Temperature 23°C

Air Density Correction Factor 1.04

Fan Calibration

	Open Fan	Q(CFM) = 385.0 x (P).473
Low-flow plate:	0 holes plugged	Q(CFM) = 101.0 x (P).486
	4 holes plugged	Q(CFM) = 71.7 x (P).454
	6 holes plugged	Q(CFM) = 38.3 x (P).469
	7 holes plugged	Q(CFM) = 24.4 x (P).465
	8 holes plugged	Q(CFM) = 14.18x (P).477

Test Data

Initial House Pressure ∅ Pa Final House Pressure ∅ Pa

Background House Pressure var Pa

P House (Pa)	Corrected P House	P Fan (Pa)	# holes Plugged	Corrected Flow (CFM)	Maximum Error
50		110	∅	1029	0.54
41		85	∅	908	1.11
35		70	∅	826	2.06
30		50	∅	701	4.25
26		40	∅	629	5.72
20		30	∅	547	2.25
15		25	∅	501	7.65

r = .990 (greater than 0.99) n = 0.652 (between 0.5 and 1.0)

C = 80.05 RSE = 5.46 %

Q 50 = 1023 cfm ACH = 1.95

Q 10 = 354 cfm ELA = 104 in2 about 10.8 in. dia hole.

Comments: (Reverse side: Major leakage sites, recommendations, etc.)

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(403) 484-0476

AIR LEAKAGE TEST REPORT

Name Lincolnberg (Vlooswyk) Date Sept 20, 88

House Address [illegible], Sher Rk. Wind Speed calm

House Volume 31447 Barometric Pressure 94.04

Envelope Area ______ Outside Temperature 2°C

Technician Rick Thrall Inside Temperature 21°C.

Air Density Correction Factor 0.97

Fan Calibration

	Open Fan	Q(CFM) = 385.0 x (P).473
Low-flow plate:	0 holes plugged	Q(CFM) = 101.0 x (P).486
	4 holes plugged	Q(CFM) = 71.7 x (P).454
	6 holes plugged	Q(CFM) = 38.3 x (P).469
	7 holes plugged	Q(CFM) = 24.4 x (P).465
	8 holes plugged	Q(CFM) = 14.18x (P).477

Test Data

Initial House Pressure ∅ Pa Final House Pressure ∅ Pa

Background House Pressure ∅ Pa

P House (Pa)	Corrected P House	P Fan (Pa)	# holes Plugged	Corrected Flow (CFM)	Maximum Error
60		195	∅	1274	2.82
52		145	∅	1103	0.36
43		100	∅	921	3.6
38		80	∅	826	4.87
32		65	∅	747	1.38
24		45	∅	624	3.08
18		30	∅	513	5.85

r = 0.993 (greater than 0.99) n = .783 (between 0.5 and 1.0)

C = 50.28 RSE = 6.36 %

Q 50 = 1073 cfm ACH = 2.01

Q 10 = 305 cfm ELA = 89.6 in2

Comments: (Reverse side: Major leakage sites, recommendations, etc.)

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(403) 484-0476

AIR LEAKAGE TEST REPORT

Name John Vlooswyk Date Jan 5, 89, 10:30 a.m.

House Address , SherPk. Wind Speed 10-15 Km.

House Volume 31447 cu ft Barometric Pressure 93.8 Kpa.

Envelope Area ______ Outside Temperature -12°C

Technician R. Thrall Inside Temperature 20°C

Air Density Correction Factor 0.93

Fan Calibration

	Open Fan	Q(CFM) = 385.0 x (P).473
Low-flow plate:	0 holes plugged	Q(CFM) = 101.0 x (P).486
	4 holes plugged	Q(CFM) = 71.7 x (P).454
	6 holes plugged	Q(CFM) = 38.3 x (P).469
	7 holes plugged	Q(CFM) = 24.4 x (P).465
	8 holes plugged	Q(CFM) = 14.18x (P).477

Test Data

Initial House Pressure ∅ Pa Final House Pressure ∅ Pa

Background House Pressure ∅ Pa

P House (Pa)	Corrected P House	P Fan (Pa)	# holes Plugged	Corrected Flow (CFM)	Maximum Error
56		170	∅	1135	.31
50		145	∅	1050	.13
44		125	∅	977	2.17
38		90	∅	833	3.17
32		74	∅	757	.22
26		55	∅	656	.52
22		43	∅	582	.67

r = 0.997 (greater than 0.99) n = 0.725 (between 0.5 and 1.0)

C = 61.39 RSE = 3.39 %

Q 50 = 1049 cfm ACH = 2.00

Q 10 = 330 cfm EqLA = 97 in2

Comments: (Reverse side: Major leakage sites, recommendations, etc.)