RESEARCH REPORT

Drying of Walls: Prairie Region

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DRYING OF WALLS: PRAIRIE REGION

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PRAIRIE REGION

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SUMMARY

Field tests were carried out on the drying performance of different exterior wall assemblies in a prairie climate. The initial moisture load on the walls was achieved by building each test panel with wood studs that had a moisture content at approximately fiber saturation. Three of the six panels were similar to panels that had undergone tests in Atlantic Canada. These three exterior wall assemblies had sheathing that was either high permeance (rigid glass fiber insulating sheathing), low permeance (expanded polystyrene foam), or a low to medium permeance (waferboard with asphalt building paper). The remaining three panels were built with waferboard and building paper, but were finished with stucco rather than vinyl siding that was used with the first three panels. One of the panels (panel 5) had an intentional air gap between the sheathing and insulation, with a slot vent at the top and bottom of the cavity. One of the stucco panels was built with dry wood, for comparison and to observe any effects of moisture absorption from the outdoor environment. All six panels were placed in duplicate pairs on the north and south faces of a heated test hut.

Stud moisture content, temperatures, and cavity relative humidities were monitored through one complete heating season, starting on August 1, 1989 and continuing through to May 22, 1990. From the measured data, stud drying rates and cavity/outdoor vapour pressure differences were estimated during the initial drying phase. For most panels, during this initial period, stud moisture contents decreased monotonically with time. Effective permeances of the exterior assemblies were calculated and compared with permeances based on standard calculations. Estimated permeances for the low and medium permeance assemblies, based on measured data were in the range of 50 to 200 perms and were reasonably close to calculated values.

Panel 5, with the vented cavity, had far and away the largest effective permeance of any of the panels tested. This effective permeance (based on measured drying rates and vapour pressure differences) was an order of magnitude larger than the calculated value, which

suggests that diffusion was not the dominant moisture transport mechanism; rather, air motion caused by wind and solar heating of the exterior sheathing (on the south face) resulted in an enhanced moisture drying rate.

Daily averaged heat flux measurements on each north test panel confirmed that the cavity wall thermal resistances were approximately equal to the calculated values and remained constant throughout the test period. Moisture in the studs and sheathing did not reduce the thermal resistance of the cavity insulation. Heat flux and temperature measurements in panel 5 suggest that air motion through the vents did not cause a significant loss in thermal resistance or, if it did, that the effect is very localized. More detailed measurements would be necessary to confirm this conclusion.

Overall, in a prairie climate, any significant moisture in a wall cavity will produce sustained cavity/outdoor vapour pressure differences that will result in drying throughout the winter period. In the prairie climate, none of the exterior wall assemblies produced cavity conditions that posed a serious problem for the long term integrity of the wall.

RÉSUMÉ

L'assèchement de divers murs extérieurs a fait l'objet d'essais sur place dans le climat des Prairies. La charge d'humidité initiale des murs a été atteinte en réalisant chacun des panneaux d'essai avec des poteaux dont la teneur en eau voisinait le point de saturation des fibres. Trois des six panneaux ressemblaient à ceux qui avaient subi des essais dans les provinces atlantiques. Les trois murs comportaient un revêtement d'ossature à haute perméabilité (panneau rigide de revêtement isolant en fibre de verre), à faible perméabilité (mousse de polystyrène expansé) ou de faible à moyenne perméabilité (panneau de copeaux recouvert de papier de construction bitumé). Les trois autres panneaux comportaient un revêtement d'ossature en panneau de copeaux revêtu de papier de construction, mais un parement de stucco plutôt qu'un bardage de vinyle à l'instar des trois premiers. L'un des panneaux (panneau no 5) comportait un vide d'air intentionnel entre le revêtement d'ossature et l'isolant, de même qu'un orifice de ventilation ménagé au sommet et à la base de la cavité. L'un des panneaux de stucco a été réalisé avec du bois sec, pour faciliter la comparaison et pour observer les effets d'absorption d'humidité depuis le milieu extérieur. Les six panneaux ont été placés par paires identiques du côté nord et du côté sud du bâtiment d'essai chauffé.

La teneur en eau des poteaux, la température et l'humidité relative de la cavité murale ont fait l'objet d'un contrôle pendant une saison de chauffage complète, du 1^er^ août 1989 jusqu'au 22 mai 1990. D'après les données mesurées, le degré d'assèchement des poteaux et les écarts de pression de vapeur d'eau entre la cavité et l'extérieur ont été évalués au cours de la première phase d'assèchement. Pour la plupart des panneaux, au cours de cette première étape, la teneur en eau des poteaux a accusé une baisse très graduelle au fil du temps. La perméabilité proprement dite des revêtements d'ossature a été calculée et comparée avec celle fondée sur des calculs standards. La perméabilité estimative des revêtements de perméabilité faible à moyenne, d'après les données mesurées, s'échelonnait entre 50 et 200 perms et s'apparentaient aux valeurs calculées.

Le panneau no 5, avec cavité ventilée, avait la plus forte perméabilité parmi les panneaux à l'essai. Cette perméabilité proprement dite (fondée sur le degré d'assèchement mesuré et les écarts de pressions de vapeur d'eau) était d'un ordre de grandeur supérieur à la valeur calculée, ce qui porte à croire que l'humidité ne se déplace pas surtout par diffusion, mais plutôt que le mouvement d'air occasionné par le vent et l'insolation du revêtement d'ossature (du côté sud) a contribué à accroître le degré d'assèchement.

Les mesures de flux thermique prélevées tous les jours sur chaque panneau d'essai orienté vers le nord ont confirmé que la résistance thermique de la cavité murale correspondait à peu près aux valeurs calculées et demeurait constante pendant toute la période d'essai. La teneur en eau des poteaux et le revêtement d'ossature n'ont pas réduit la résistance thermique de l'isolant thermique de la cavité. Les mesures de flux thermique et de température prélevées dans le panneau no 5 portent à croire que le mouvement d'air par les orifices de ventilation n'a pas abaissé de façon appréciable la résistance thermique, sinon qu'il n'aurait eu qu'un effet très localisé. Des mesures plus détaillées s'imposeraient pour confirmer cette conclusion.

Dans l'ensemble, pour le climat des Prairies, toute teneur en eau appréciable dans la cavité murale donne lieu à des différences de pressions de vapeur d'eau entre la cavité et l'extérieur qui favorisent l'assèchement pendant tout l'hiver. Dans ce climat, jamais l'état de la cavité des murs extérieurs n'a sérieusement compromis la solidité du mur à longue échéance.

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1.0 INTRODUCTION

The moisture drying performance of exterior wall assemblies has been the subject of much debate and speculation within the building science community and the construction industry. In almost all climatic regions of Canada, there is evidence of some moisture damage to the exterior envelope of a building. For exterior walls, moisture-related problems range from the nuisance of peeling paint to rotting of studs and wood-based exterior sheathing. Moisture damage to exterior walls is prevalent in climates with a high occurrence of wet, cold weather during winter and spring and little sunshine. The maritime regions of Canada, particularly Newfoundland, have been found to have the highest occurrence of exterior wall damage [1].

There are several different sources of moisture in exterior walls. These can be classified into seasonal and initial sources. Seasonal sources tend to occur at particular times during the year and produce recurring moisture loads on the wall assembly. The most common type of seasonal source is exfiltration of warm, moist air from the inside of a house to outdoors during cold weather. Exfiltration arises from the wind and stack induced pressure differences that, on average, tend to be higher in the winter than in summer. Moisture that is transported with exfiltrating air is deposited on the cold exterior surfaces of wall assemblies and tends to produce localized moisture damage. In maritime climates, another equally important seasonal moisture source is wind-driven rain during cold weather. The wind pressure can force water through the exterior sheathing into the wall cavity. With little or no vapour pressure difference between the cavity and outdoors, the rain water will require a long time to diffuse out of the cavity.

In a recent study of wall assembly modifications to alleviate moisture problems, conducted at three sites in Atlantic Canada [2], the field tests were set up to impose a significant <u>initial</u> moisture load on the wall assemblies. In a field survey of locally available lumber, it was found that stud moisture contents were near saturation. In the field tests, moisture contents of the wall studs were, in some cases, well above fiber saturation (greater than 30% MC). Given the total volume of wood used in a wall, this represented a large initial moisture load that had to be removed over the course of the tests. Some of the wall panels that were tested had conventional wood-based sheathing (waferboard), while other panels had insulating sheathing, both semi-rigid glass fiber board and extruded polystyrene foam. There was a considerable variation in the drying rates of the panels and some concerns were raised about possible rotting of studs and growth of organisms.

As a result of these tests, there was also some concern that a similar situation with regard to initial moisture load may occur in other regions of Canada. Three separate field studies were initiated to investigate these concerns. First, two field tests were commissioned to investigate the drying performance of different wall assemblies in a prairie climate (Edmonton, Alberta) and a climate typical of central Canada (Waterloo, Ontario). Test panels that were selected included three panel assemblies used in the Atlantic Canada study and a minimum of three panels that were typical of local building construction. The third field study involved a cross-Canada survey of lumber moisture content, as delivered from the sawmills and as used on construction sites. This report details the results of the drying performance of walls in a prairie climate. Results of the other two studies are summarized in reports which will be available from CMHC.

2.0 TEST FACILITY, INSTRUMENTATION, AND METHODOLOGY

In this section, details of the wall test panels, test facility, instrumentation, and procedures are presented.

2.1 Wall Panels

Six different wall panels were selected for the drying tests. Three of the panels were similar in construction to panels that were tested in the Atlantic Canada study [2]. This provided a comparison for the effect of regional climate on drying rates. The exterior sheathing assembly for these three panels were:

a) an insulating exterior sheathing consisting of 38 mm (1.5″) semi-rigid glass fiber board, vapour permeable air barrier, and vinyl siding (light grey colour);

b) an insulating exterior sheathing consisting of 38 mm (1.5″) extruded polystyrene foam, vapour permeable air barrier, and vinyl siding (light grey colour);

c) exterior sheathing consisting of 9.5 mm (3/8″) waferboard, asphalt building paper, and vinyl siding (light grey colour).

The first two panels were constructed of 38 mm by 89 mm (2″ by 4″) spruce studs, and the third panel was constructed of 38 mm by 140 mm (2″ by 6″) spruce studs. For the third panel, the oriented strand board was applied as two separate sheets with a 3.2 mm (1/8″) horizontal gap at mid-height of the panel (manufacturer's specifications require a 3.2 mm gap). The wall cavities of each panel were filled with glass fiber batt insulation and the interior was finished with 4 mil polyethylene vapour barrier and 12.7 mm (1/2″) gypsum wall board. The interior surface of the wall board was left unpainted. The polyethylene sheet was brought to the exterior of the wall panel and sealed along the lateral edges of each panel with acoustic sealant. Since the panels were sealed on the interior side and lateral edges, all moisture in the panels had to escape through the exterior sheathing. Each panel had three cavity spaces and measured 1.2 m wide by 2.3 m high (4′ by 7 1/2′). Details for these three panels are shown in Fig.1.

The three remaining panels that were constructed using 38 mm by 140 mm (2″ by 6″) spruce studs with exterior sheathing components that are commonly used in the prairie region. Waferboard, 9.5 mm (3/8″) thick, was applied to the studs, with a 3.2 mm (1/8″) horizontal gap at mid-height. The sheathing was covered with asphalt building paper and an exterior stucco finish. The exterior finish was applied in two coats, with an initial base coat supported by a wire mesh and a finish coat which was applied after the base coat had cured for two days. The exterior stucco finish had a light grey colour, similar to the vinyl siding used on the other panels.

One of the three stucco panels had a 38 mm (1.5″) vertical air gap between the sheathing and internal wall cavity. Horizontal battens, 38 mm (1.5″) wide were nailed across the studs at a vertical spacing of 60 cm (2'), to provide the gap between the sheathing and wall cavity. A fiber screen was stapled flush with the studs to keep the glass fiber insulation in the wall cavities. Vent openings through the stucco, at the top and bottom of the panel, vented the air gap directly to the exterior. The bottom vent was 38 mm (1.5″) high and ran across the entire width of the panel. This allowed any free standing water inside the cavity to drain out.

The top vents were 25 mm (1″) diameter holes through the stucco and sheathing, with one hole per stud cavity. A screen covered each vent opening, to prevent entry of insects. As in the other panels, a 3.2 mm (1/8″) horizontal gap at mid-height was left between the two sheets of waferboard. Details of these three panels are shown in Fig.2.

Five of the panels were constructed with spruce studs which had an initial moisture content near fiber saturation (between 30 and 35% MC). Wet wood (studs plus top and bottom plates) provided the initial moisture load in the wall panels. In order to achieve these initial moisture contents, lumber for studs and plates was pre-cut to the desired length and then submerged in a large trough of water. The wood was kept in the trough for a period of 2 to 3 weeks, to ensure that the core lumber had absorbed a sufficient amount of water. Moisture contents were periodically checked by removing 60 cm (2′) lengths of lumber that were immersed at the same time as the other material. The moisture content distribution over the cross section of the lumber was measured by taking thin sections of wood from the middle portion of the 60 cm (2′) samples and weighing the thin sections before and after drying in an oven. The wood was kept in the trough until the core lumber reached approximately 40% MC; the outer layer of the lumber had moisture contents in the range of 50% MC.

The assembly and instrumentation of all twelve panels required about 2 weeks, during which time, some moisture loss occurred. However, this was minimized by keeping each panel in a 6 mil polyethylene bag until the field test began. One of the stucco exterior panels (panel 6) was constructed of 38 mm by 140 mm (2″ by 6″) lumber which was not pre-soaked. This served as a control for comparing the drying performance with the other panels and indicated if any re-wetting occurred from the outdoor environment. When the panels were completed, they were transported to the test site.

2.1.1 Wall Panel Instrumentation

Each test panel had a number of sensors mounted to measure wood moisture content, temperature, relative humidity, wall heat flux, and cavity pressure.

Wood moisture content measurements were made by adapting a Lignometer H30 meter (Lignomat) to provide a voltage output in addition to the usual analog meter reading. This meter operated by sensing the electrical resistance between two short metal pins inserted into the wood. The resistance measurement depends on pin size and spacing. The pin size was 6.4 mm long by 3.2 mm diameter (1/4″ by 1/8″) and spaced at 31.8 mm (1 1/4″), centre to centre. For most of the moisture content measurements, the pins were pushed into pre-drilled holes and the end of each pin was set flush with the surface of the studs. With this pin arrangement, the meter was calibrated over a range of moisture contents for spruce wood samples. Samples were taken from the same lumber that was used to construct the panels. Small wood samples were immersed in water, to increase moisture content, and left in a sealed plastic bag in order to reach a uniform moisture content. Moisture contents were determined gravimetrically after drying the samples in an air oven. Calibration was carried out with wood samples from 5 to 40% MC, which covered the anticipated range of wood moisture contents during the tests; calibration tests are detailed in Appendix A. The output was found to be linear, with a maximum non-linearity of 5% MC at the higher limit of the calibration range. It should be noted that above fiber saturation and below approximately 7% MC, moisture content measurements using electrical resistance are not reliable.

All temperature measurements were made with copper-constantan thermocouples (type T). Temperatures were calculated from voltage readings using standard thermocouple calibration equations.

Relative humidity was measured using RH-8 Macro-Molecular Humidity sensors (General Eastern) and an HMC-V signal processor. The sensors were calibrated using saturated salt solutions which maintained a constant relative humidity in a sealed air space above the solutions. As detailed in Appendix A, several different salts were used to provide a range of relative humidities from 12% to 97%.

In each wall panel, one of the central studs was instrumented to measure wood moisture content, temperature, and relative humidity. One group of these three sensors was placed 20 cm (8″) from the top plate. A second group of sensors was placed on the same central stud, 20 cm (8″) from the bottom plate. At each location, a hole, slightly smaller than 3.2 mm (1/8″) diameter, was drilled 6.4 mm (1/4″) deep into the stud. Moisture pins were pushed to the bottom of these holes so that the end of each pin was flush with the surface of the studs. The exposed surface of the pins was sealed with silicone sealant to prevent false resistance readings due to surface moisture. Each pair of pins was oriented parallel to the isotherms; this ensured that both moisture pins were at the same temperature. The thermocouple head was bonded to the surface of the stud, half-way between the moisture pins. This temperature was used to make temperature corrections to the moisture content readings. The relative humidity sensor was placed against the surface of the stud next to the moisture pins. The top and bottom sets of sensors were placed at the mid-point of the outer third (cold side) of each stud, as shown in Fig.3. During cold weather conditions, the imposed temperature gradient on the studs forces a large fraction of the moisture in the studs to the cold side; thus, measurements of wood moisture content were made in this region. A third group of sensors was placed on the cavity side of the exterior sheathing, at mid-height. For those panels with non-wood sheathing, only temperature and relative humidity were measured at this location.

In addition to these measurements, detail measurements on the moisture distribution within the studs were carried out in panels 1, 2, and 3. Six pairs of moisture pins were located 20 cm (8″) from the top and bottom of the central stud. The location and spacing of the pins are shown in Fig.3. Three of the six pairs of pins were set flush with the surface of the stud (as described above) and spaced evenly across the width, as shown in Fig.3. The second three pairs were also evenly spaced across the stud; small holes were drilled down to the centre of the studs and moisture pins were placed at the bottom of these holes and sealed with silicone sealant. The moisture distribution readings were recorded once a week, using a switch box and a separate Lignometer. In order to correct the moisture readings, temperature at each location was estimated by assuming a linear temperature distribution from the warm side of the stud (room temperature) to the cold side where the temperature was measured. In addition to these measurements, moisture pins were placed in the middle of the top and bottom plates of panel 2, and read manually at the same time as the moisture pin arrays.

The heat flux through the centre of the middle stud space was measured by custom-made heat flux plates. The gauges are 6 cm by 6 cm (2.4″ by 2.4″) and operated by sensing the temperature difference across a 5 mm

(0.2″) air gap. The small temperature difference across the air gap was sensed by a number of copper-constantan junctions which were arranged in series. Thus, the voltage output generated by a small temperature difference was amplified by the heat flux plate. Each plate was calibrated in a small guarded hot box. The heat flux plates were bonded to the drywall on the interior face of the panels, at mid-height.

Wall cavity pressure differences under natural conditions were measured using a low range differential pressure transducer (Validyne), which was calibrated over a pressure range of 0 to 50 Pa, with a resolution of 0.1 Pa. A small diameter plastic tube 12.7 mm OD (1/2″) connected the central wall cavity to the hut interior. Pressure differences were measured between the wall cavity and interior. These pressure readings were taken separately by recording the output on a strip chart recorder.

2.2 Test Facility

The panels were installed in a test hut that was constructed specifically for this study and located at The Alberta Home Heating Research Facility, Ellerslie, Alberta, just south of the city of Edmonton. The test hut, shown in Fig.4, has a rectangular floor plan, 2.4 m wide by 12.2 m long (8′ by 40′). The long dimension of the hut was oriented east-west, so that the panels faced north and south. The hut was constructed of 38 mm by 89 mm (2″ by 4″) studs with glass fiber batt insulation, polyethylene vapour barrier and 12.7 mm (1/2″) painted drywall. The exterior of the hut consisted of waferboard, asphalt building paper, and grey vinyl siding. The insulated floor of the hut rested on a welded steel frame which was supported about 30 cm (1′) above grade. Openings in the north and south faces of the hut measured 2.4 m wide by 2.3 m high (8′ by 7.5′) with four of these openings on each side of the hut. Two test panels were inserted in each opening, so that a total of eight panels could be tested on each side. The interior of the hut was heated by a forced air, propane furnace that was vented to the outside. Air was continually circulated through a humidifier to maintain a nominal interior temperature of 20°C and relative humidity of 40%. When the test panels arrived at the site, they were placed in the test hut wall openings with the storage bags intact. After all panels were installed, the storage bags were removed and the exterior finish was applied (vinyl siding for panels 1 through 3 and stucco for panels 4 through 6).

Sensor outputs were connected to a PC data acquisition system through a 64 channel 8 bit A/D converter (Sciemetrics, Model 641) and three 24 channel relay boards (Metrabyte, Model ERB-24). The relay boards were used to multiplex signals from the moisture pins and relative humidity sensors. Sensor output was read sequentially by the data acquisition program, with a two second interval for each reading. This time interval was important for wood moisture measurements using resistance pins; when a DC voltage is applied to the pins, there is an initial short transient response in the electrical resistance. The steady electrical resistance after 2 seconds was the reading that was recorded. All data were stored as hourly-averaged values. Details of the data acquisition system are given in a separate instrumentation report in Appendix A.

2.3 Meteorological Measurements

Meteorological data at the site was collected during the test period in order to provide input data for the WALLDRY computer model [3].

A vane anemometer (Athabasca Windflo 540) was mounted 2.4 m (8′) above the roof of the test hut to measure wind speed. A variable resistance potentiometer wind vane was also mounted at the same location to monitor wind direction. Wind angles were measured relative to a zero direction corresponding to due north.

Ambient temperature and relative humidity were measured using the same type of sensors as for the wall panels (see Sec. 2.1.1). The sensors were housed in small box with side louvers; the box was attached to the north face of the test hut.

Diffuse and total solar radiation on a vertical surface were measured with pyranometers (Kipp and Zonen) mounted on the north and south faces of the test hut. The pyranometers were calibrated by Atmospheric Environment Services, Environment Canada.

2.4 Additional Tests

A number of additional tests were carried out on the panels at the end of the test period. These included pressurization tests to determine the air leakage characteristics of each panel and air extraction sampling of the wall cavities and sampling of the wood studs for micro-organisms.

The leakage characteristic of each panel was obtained by blowing air into the middle wall cavity and measuring the cavity/outdoor pressure difference and the corresponding volumetric air flow. Air entered the cavity through a short piece of 5 cm (2″) diameter PVC pipe that was sealed to the drywall; the pipe and vapour barrier were carefully sealed to the drywall to prevent any air leaking behind the vapour barrier. Air was forced into the cavity by a blower and the volumetric air flow was measured with a bellows-type dry gas meter, inserted between the blower and the cavity inlet. A control valve was placed between the blower and the dry gas meter to control the pressure in the wall cavity. The pressure difference between the cavity and outdoors was measured by connecting the cavity pressure tap (described in Sec. 2.1.1) and a pressure tap attached to the outside of the hut (separate taps were provided to the north and south faces). The output from the differential pressure transducer was measured with an averaging voltmeter that recorded a 100 sec time average for each pressure reading.

The cavity-outdoor pressure difference was varied from approximately, 1 to 15 Pa and the corresponding air flows were recorded. In most cases, a minimum of six different pressure differences were taken for each panel. To minimize the effect of atmospheric turbulence, leakage testing was carried out on calm days when the maximum wind speed was less than 1.5 m/sec (3.4 mph). This minimized wind pressure fluctuations which would have produced larger scatter in the data.

One final leakage test was carried out in panel 1 on the north side of the hut. Three separate blowers were connected to each of the three wall cavities. The flow through each blower was adjusted with a control valve to produce the same cavity-outdoor pressure difference in each cavity. Under these conditions, there was no pressure difference between the central and two adjacent cavities and hence, no inter-cavity leakage air flow. Air flow through the central cavity was measured with the dry gas meter and leakage characteristics determined from this data.

Testing for the presence of micro-organisms was conducted near the end of the test period (May and June, 1990). For each panel, 40 litres (1.4 ft^3) of air were drawn from the central cavity with a small vacuum pump. Air passed through an 0.45 micrometer sterilized filter paper (Millipore) which trapped any micro-organisms in the air. The air sampling protocol was determined by Agriculture Canada and a summary is provided in Appendix B. The twelve filter samples were then immediately shipped to Agriculture Canada in Ottawa for analysis. Air samples were extracted from the twelve panels prior to the air pressurization tests.

At the very end of the testing period, samples of micro-organisms were taken from the surface of the wood studs. The drywall, vapour barrier, and batt insulation were removed, exposing the studs. At areas having visible fungal growth, several different samples were taken; microscope mounts prepared using scotch tape preparations, swabbing of contaminated areas, and chiselling wood samples from contaminated areas. In addition, random "clean" areas were sampled by swabbing and taking wood samples.

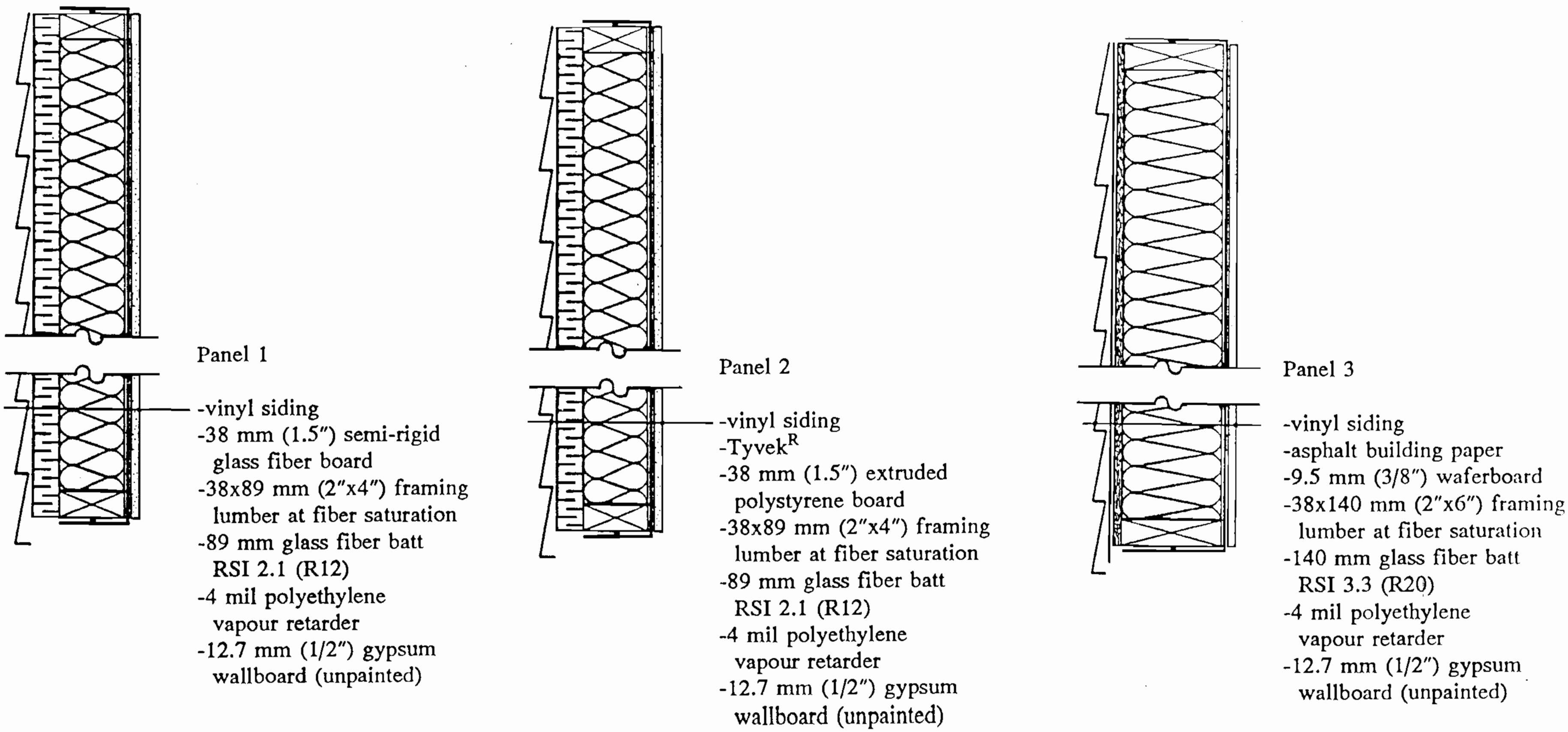


Fig.1. Schematic of wall components for panels 1, 2, and 3

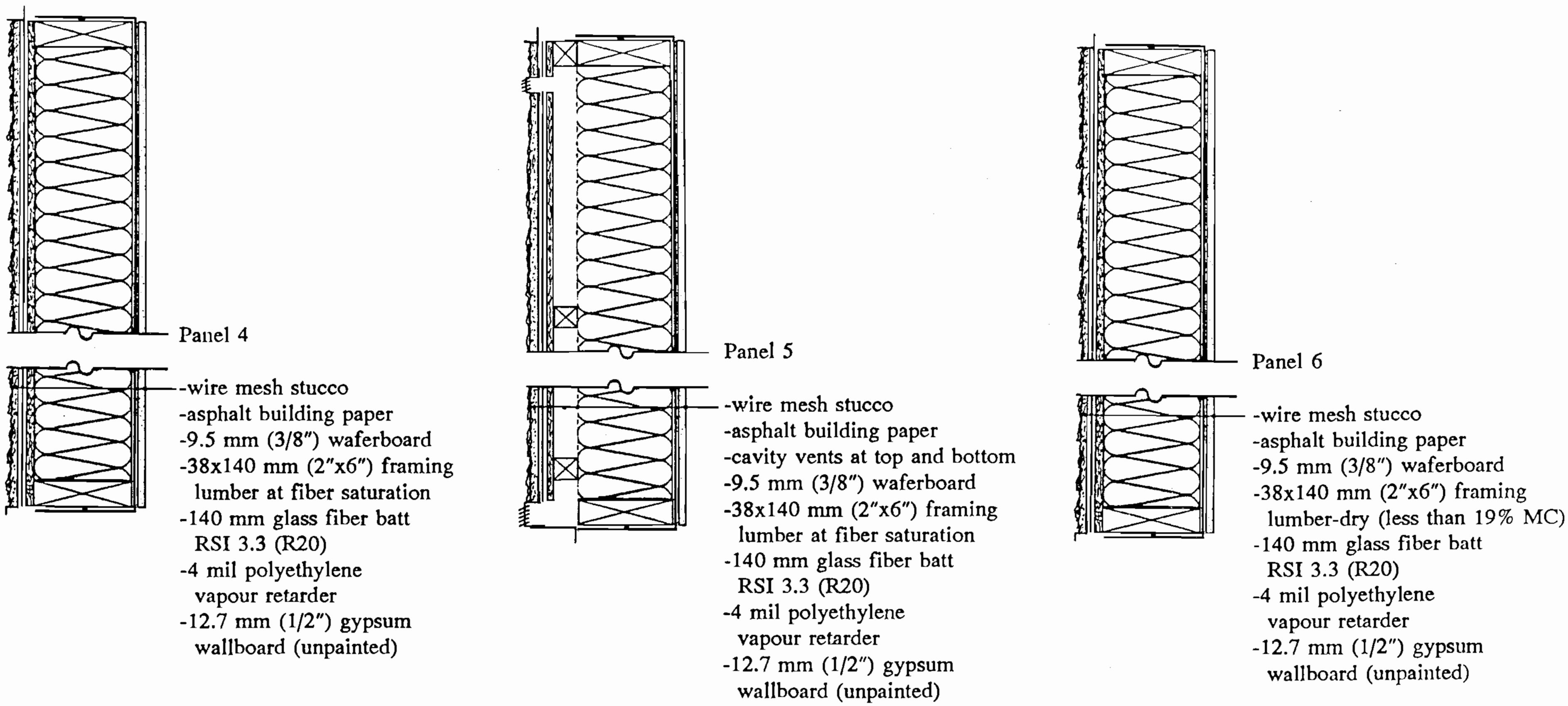


Fig.2. Schematic of wall components for panels 3, 4, and 5

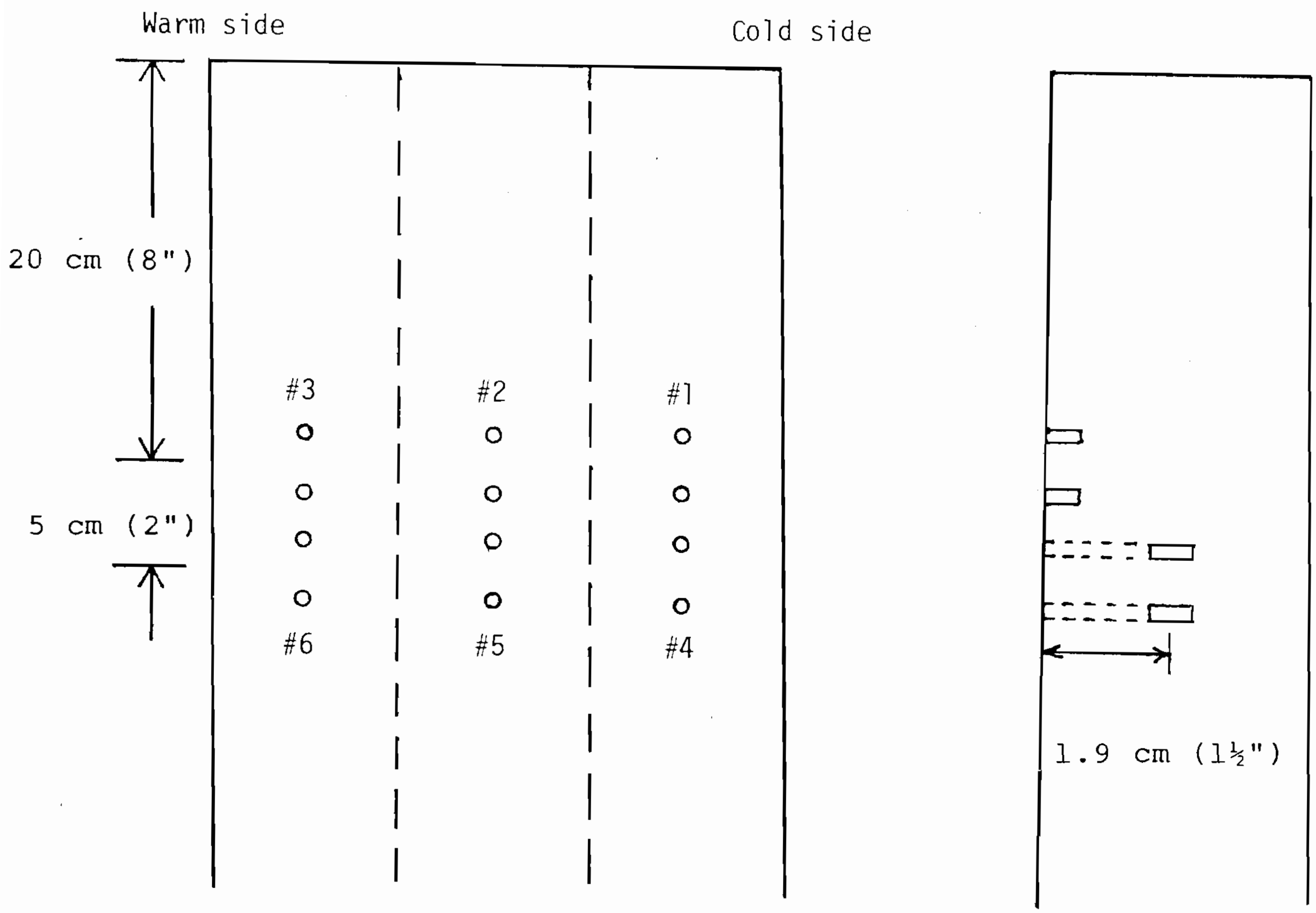


Fig.3. Schematic of moisture pin array

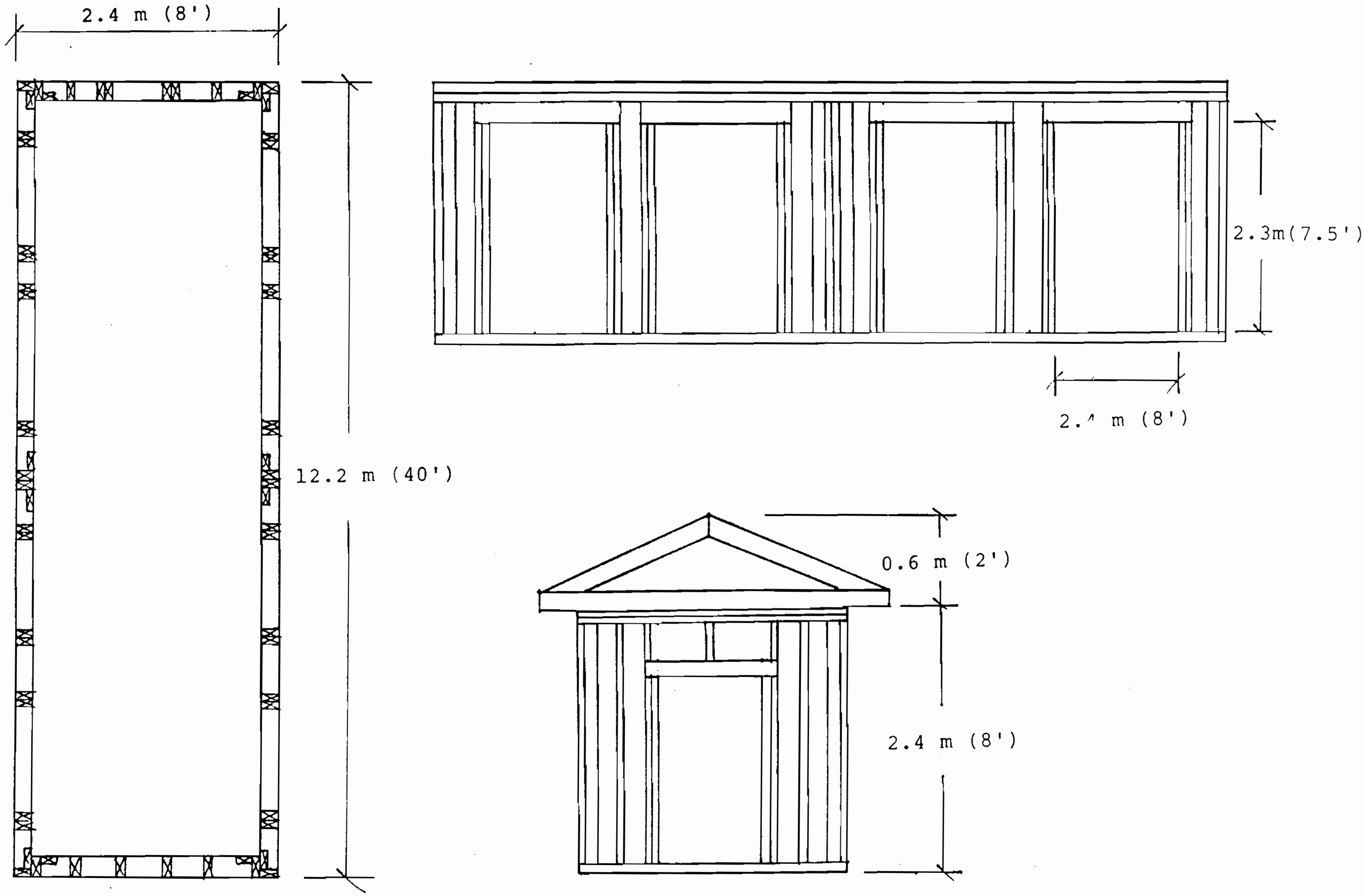


Fig.4. Moisture test hut details

3.0 RESULTS

Data collection at the test site began on August 1, 1989 and continued through to May 22, 1990. At this point, it was decided to terminate the tests because each wall panel had dried and there was no evidence of any re-wetting. In this report, the term "re-wetting" implies absorption of moisture from direct wetting, such as rain or moisture from condensation.

3.1 Wood Moisture Contents

Temperature corrected wood moisture contents in studs and sheathing are plotted in Figs. 5a through 5f for the test period (August 1, 1989 to May 26, 1990). Sheathing moisture contents are shown only for panels 3 to 6 which had waferboard exterior sheathing. In order to simplify the presentation of these data, wood moisture contents were averaged over a one week interval. Stud moisture contents generally do not respond rapidly to changes in ambient conditions; thus, weekly-averaged moisture contents are a convenient form for observing long term trends in the data.

For all test panels, drying of studs and sheathing commenced immediately after installation of the panels and continued, more or less throughout the entire test period. None of the panels showed a significant increase in moisture content during the initial month, as was evident in the Atlantic Canada tests [2]. However, there was a slight increase in wood moisture content during the initial week of testing. This was largely due to an initial redistribution of moisture within the studs when subjected to gradually increasing indoor/outdoor temperature differences. In most cases, stud moisture contents after this initial period were at or near fibre saturation, although some studs, for example panel S1, had initial moisture contents as low as 18% MC. It was difficult to ensure that all initial stud moisture contents were exactly the same value. Panel 6 was constructed of lumber that was not pre-soaked. Generally, wood purchased from the local lumber yard had low moisture contents (10 to 15% MC) and by the time panel 6 was assembled and installed, the studs had dried below 10% MC. Throughout the course of the test period, there was no evidence of a significant amount of re-wetting in panel 6, as can be seen in Fig. 5f.

The moisture content of the waferboard exterior sheathing is shown for panels 3, 4, 5, and 6 in Figs. 5c through 5f, respectively. For each panel, sheathing moisture contents increased in the initial month, reaching moisture contents between 20 and 30% MC. This initial increase is due to a re-distribution of moisture within the cavity, between the studs and sheathing. After this initial period, sheathing moisture contents decreased steadily throughout the test period, although there were periods when moisture contents did increase. For example, in panel N5 sheathing moisture content increased between week 15 and 18, indicating that some re-wetting had occurred. Clearly, moisture was absorbed from the outdoor environment because the studs were dry during this period. Panel 5 had vents at the top and bottom, providing a path for moisture to enter the cavity; however, this short term increase in sheathing moisture was followed by fairly rapid drying, since moisture escaped along the same path. Sheathing re-wetting was also observed in panel N6 (Fig.5f) which initially was completely dry. Again, moisture content changes occurred over relatively short periods of time and were dictated by ambient outdoor conditions. Similar trends for sheathing moisture content were observed in panels on the south face of the test hut. However, moisture contents were generally lower than in the north panels and drying occurred more quickly. Solar gain on the south panels helped dry the sheathing and prevent any re-wetting. This can be seen by comparing sheathing moisture contents in the north and south panels in Figs.5e and 5f.

Stud moisture content distributions are shown in Figs.6 and 7 for north and south panels 1, 2, 3, respectively. In each case, the top plot shows variations in surface moisture contents measured at the three locations across the stud, while the bottom plot shows moisture content differences between the middle and surface of the stud at each location. In the initial one to two month period, the stud moisture content gradient (from warm side to cold side) remained relatively constant, with some exceptions, even though moisture contents were decreasing. This would indicate most of the drying in this initial period occurred across the entire surface of the studs. When outdoor temperatures decreased the imposed temperature gradient across the stud resulted in moisture migrating to the cold side. For example, in panel N3 (Fig.6c) at week 6, moisture content at the central location suddenly decreased, while moisture content at the cold side <u>increased</u>. In this case, moisture was redistributed within the stud under imposed temperature gradients. A similar trend can be seen in panel S3 (Fig.7c), although solar gain on the south face delayed the time at which the redistribution occurred. Panel 2 also showed moisture being re-distributed within the stud; however, the time at which this occurred was later than panel 3 because the insulated exterior sheathing resulted in smaller temperature gradients across the studs than in panel 3. After moisture was forced to the cold side, the warm side and central portion of the studs were essentially dry (less than 10% MC) and drying occurred only from the cold side.

The bottom plots in Figs.6 and 7 show the moisture content difference between the mid-depth and surface of the studs at each of the three locations across the stud face. The differences were generally less than 5% MC throughout the entire test period. These small moisture content differences indicate that the resistance to moisture transport (related to the moisture diffusion coefficient within the wood) is small compared to other resistances in the moisture transport path. In these panels, the moisture transport path is from the studs to the air, trapped in the cavity insulation and then out through the exterior sheathing. The other resistances in this transport path are a surface resistance between the stud and cavity air, diffusion resistance through the insulation, and resistance of the exterior sheathing. The rate at which moisture is transported from the studs is dictated by the larger of these two resistances.

From the data presented above, an estimate was made for the average rate of moisture loss from each cavity. Moisture flowrate, $\dot{m}_w$ is

$$\dot{m}_w = m_s \frac{d}{dt}(MC)$$

where m_s is the mass of dry wood from which moisture is lost, MC is the moisture content of wood, and t is time. An initial average moisture flowrate was calculated by assuming that moisture loss occurred over the entire depth of each stud. For one cavity space the mass of dry wood, from which moisture was lost, was estimated to be 4.51 kg (9.9 lb) for panels 1 and 2, and 7.09 kg (15.6 lb) for panels 3, 4, and 5. The density of oven dry spruce that was used in the estimate was 430 kg/m^3 (26.8 lb/ft^3) [5]. The time rate of change of moisture content was estimated by taking the slopes of the initial portion of the drying curves shown in Figs. 5a through 5f. As discussed above, for most panels, drying seemed to occur at more or less constant rates in two distinct periods. A second average moisture flowrate was estimated by taking the slopes of the drying curves in these latter time periods. For this calculation, the mass of wood, from which moisture was lost, was assumed to be only the outer third of the stud (see discussion above of moisture distribution). The estimated average initial and secondary moisture flowrates are given in Table 1. Although there is some uncertainty in these estimates, the

Table 1. Estimated Initial and Secondary Rates of Moisture Loss from Test Panels

Panel	Initial Rate (gm/day)			Period (weeks)	Secondary Rate gm/day			Period (weeks)
	Top of stud	average	bottom of stud		top of stud	average	bottom of stud	
N1		25		0-8		dry		-
N2		9.5		0-12		6.0		12-20
N3		9.9		0-12		11		12-24
N4		8.6		0-6		9.9		6-12
N5		41		0-8		dry		-
S1		28		0-8		dry		-
S2	6.6	4.8	2.9	0-14		4.5		20-24
S3	0	3.8	7.5	0-9		11		10-16
S4	8.9	17	24	0-10		10		12-16
S5		55		0-5		dry		

differences in flowrates between panels are highlighted by the results. The largest moisture flowrates occurred in panels 1 and 5 with flowrates in the range of 20 to 50 gm/day; there were no secondary flowrates calculated for these two panels since the wood was dry after about two months. Initial moisture flowrates in panels 2, 3, and 4 were estimated and found to be approximately the same for the three panels. This would suggest that initially, panel 2 does not necessarily dry at a significantly slower rate than panels with conventional wood based exterior sheathing. Later in the drying period, panel 2 had a moisture flowrate about one half that of the other panels, but by this time wood moisture contents had decreased to approximately 20% MC, which is close to the recommended moisture content for framing lumber at time of construction. The other interesting comparison is the three to five times higher flowrate for panel 5 versus panel 4. The only difference between these two panels is the vents at the top and bottom of the wall cavity. Clearly, vent openings have a significant effect on moisture loss from the cavity, since there is a relatively unrestricted path for moisture movement from the studs to outdoors. In this case, moisture is transported by a combination of diffusion and convective motion of the air between the cavity and outdoors.

The temperature corrected moisture contents of the top and bottom plates in panel 2 over the test period, are shown in Fig.8. Temperatures were measured at the location of these moisture pins, except for the top plate in panel N2; temperature at the top plate location was estimated using the bottom plate temperature. In both the north and south panels, the top plate dried at comparable rates to the studs. However, the bottom plates showed a prolonged period where the wood was at or near fiber saturation. This may have been caused by gravity drainage of excess water that was initially in the storage bag. When the panel was placed in position, all the free water collected at the bottom; thus, the bottom plate had free water that had to evaporate before the wood began to dry. This would explain the prolonged period of constant (or increasing moisture content, seen in panel S2). To a certain extent, this was an artifact of the test procedure, although this sort of pre-wetting of wall assemblies may occur during actual construction when water collects at the bottom of wall cavities during rainy periods.

3.2 Cavity Vapour Pressure

In all panels, surface relative humidities were measured at the top and bottom of the studs and at mid-height of the exterior sheathing. After installing the panels, two relative humidity sensors (bottom sensors in panels S3 and N5) were found to be inoperative. In order to condense the data somewhat, differences between cavity and ambient vapour pressures are presented in Figs.9a through 9f. This is a convenient form of presentation of this data since the vapour pressure difference represents the driving potential for diffusion of moisture from the cavity. Vapour pressures were calculated at each location from measured relative humidities and temperatures. Weekly averaged temperatures measured within each wall cavity are shown in Figs.10a through 10f. Ambient vapour pressures were calculated from ambient relative humidity and temperature, shown in Fig.11.

Although there is some scatter in the data, certain trends can be seen in the results. First, for most of the panels, there was a positive vapour pressure difference for a large fraction of the test period. Thus, moisture diffusion was from the wall cavity to outdoors, which resulted in drying of the studs throughout most of the test period. During winter months, when cold temperatures reduced the partial pressure of moisture in air, vapour pressure differences for each panel decreased somewhat, as can be seen in Figs.9c and 9d, for example; however, even during winter, vapour pressure differences remained positive for these cavities.

Second, the effect of mean cavity temperature on vapour pressure differences are significant. During winter months, panels with non-insulating exterior sheathing had temperatures that averaged approximately 0°C. Panels with insulating exterior sheathing (Figs.10a and 10b) had mean temperatures that were almost 10 C° higher than the other panels, during winter. For panel 2, this meant a higher mean cavity vapour pressure difference during winter compared to the other panels with non-insulating sheathing (approximately, 750 Pa in panel 2 versus 200 Pa in panel 3). Although the exterior sheathing of panel 2 (expanded polystyrene foam) had a lower permeance than the other panels, this was offset to some degree by a larger driving potential for moisture diffusion.

3.3 Wall Heat Flux

Wall heat fluxes were measured at mid-height through the central cavity of each wall panel. The data show that heat fluxes gradually increased as colder weather approached. Although variations in heat flux are interesting, a more convenient way to present these data are by calculating an effective thermal resistance of the wall as the ratio of measured heat flux divided by the indoor-outdoor temperature difference. This yields the total thermal resistance, which includes surface film resistance on the inside and outside of the wall. The calculation was carried out only for the north facing wall panels. Direct solar gain on the south facing panels would require more detailed measurements and analysis to estimate the effective thermal resistance. Calculated thermal resistances for the north panels, averaged over one week intervals, are shown in Figs.12a through

12f. The thermal resistances for each panel remained relatively constant throughout the test period, ranging in value from 3.5 RSI (R20) for panel 6 to 4.2 RSI (R24) for panel 1. These values agree with the estimated thermal resistance based on the sum of resistances for individual components in the wall assembly. Assuming exterior and interior film resistances of 0.03 and 0.1 RSI (R 0.07 and 0.57), the estimated thermal resistances of panels 1, 2, 3, and 4 are 3.60 RSI (R20.5), 3.74 RSI (21.2), 3.71 RSI (R21.1), and 3.63 RSI (R20.6), respectively; panel 6 has an identical resistance as panel 4 and an estimate for panel 5 was not given due to the vented air gap.

It is interesting to compare the wall resistances of panels 4 and 5. The only difference between these two walls is the 38 mm (1 1/2") vented air gap between the insulation and the exterior sheathing in panel 5. The wall resistance of panel 5 was approximately 4% higher than panel 4 throughout the winter period. Thus, venting of this air gap at the top and bottom of the cavity did not result in any loss of insulating value. Since the heat flux measurements were made at cavity mid-height, well removed from the vent openings, it is not known whether there was a significant loss in thermal resistance near the vent openings. However, had there been a loss in resistance, temperatures near the vent openings would have been lower than the corresponding temperatures in panel 4. A comparison of the stud temperatures shown in Figs. 10d and 10e shows that, in fact, average stud temperatures on the exterior sheathing side, at both the top and bottom of the cavity were higher (by some 3 C°) in panel 5 than in 4. This was true for both the north and south facing panels. These data would suggest that the air gap tends to keep the studs insulated from ambient conditions and that resultant loss in thermal resistance (if any) is probably small or restricted to a very small area around the vents. More detailed measurements would be needed to confirm this.

3.4 Wall Panel Leakage Tests

Results of the wall pressurization tests are shown in Figs.13a through 13f. The results are presented in log-log form in order to highlight the power law relation between flowrate and pressure difference. A minimum of six pressure differences were used ranging from less than 1 Pa up to 15 Pa. For panel 5, the maximum pressure difference was approximately 3 Pa; since this panel has a large leakage area (vented cavity), the maximum pressure difference was limited by the capacity of the blower. For each set of results, a least squares linear fit to the data is shown together with the power law relation between flowrate and pressure difference and the leakage area at 4 Pa pressure difference. A 4 Pa pressure difference was used to calculate the equivalent leakage area because this is a typical average pressure difference that a building envelope would experience; the leakage area at 4 Pa can be converted to other pressure differences using

$$A_{\Delta P} = \left(\frac{\Delta P}{4}\right)^{n-0.5} A_4$$

where $A_{\Delta P}$ and A_4 are the leakage areas at a pressure difference ΔP and 4 Pa, respectively, and n is the flow exponent. A summary of the flow coefficients, C, power law exponent, n, and leakage area, A_4 and correlation coefficients is given in Table 2.

The leakage areas for the panels show no definite relation to the type of exterior wall assembly, except for panel 5 which has vents at the top and bottom of the cavity. The leakage areas for panel 5 were 59.5 (north) and 74.7 (south) cm^2 which are, at least an order of magnitude larger than the other panels. The correlation coefficients for panels N5 and S5 were much smaller than the other panels. The relatively low coefficients were due to limitations of the cavity pressurization tests. As mentioned previously, cavity pressures in panel 5 were limited to a maximum of 3 Pa. At these small pressure differences, the effect of wind on flowrate measurements was still large, despite the fact that the pressurization tests were carried out at windspeeds less than 1.5 m/sec (3.4 mph). Testing at higher pressure differences would have reduced scatter in these data sets.

The exponents of the power law relation are in the anticipated range of 0.5 (fully turbulent flow) and 1.0 (laminar flow). Panel 5 had exponents that were close to 0.5 since the flow through the vent openings behaved as orifices so that flowrate varies with square root of pressure difference. At the other end of the spectrum, it is anticipated that panel 1 would have flowrate depend directly on pressure difference (exponent of 1.0). For this panel, most of the flow resistance occurs across the Facing of the semi-rigid glass fiber exterior sheathing. At the pressure differences existing in walls, flowrate through porous media varies linearly with pressure difference. This was more or less confirmed for panels N1 and S1 which had exponents of 1.0 and 0.87, respectively. The remaining panels had flow exponents between 0.5 and 1.0 with no obvious correlation between exponent and type of exterior assembly. In most walls, flow through tiny cracks is never fully developed, since the flow paths are generally quite tortuous. This leads to flow exponents that fall between fully developed turbulent and laminar flows.

Panel N1 was tested by pressurizing all three wall cavities to the same pressure difference and monitoring flow through the central cavity. This procedure minimized flow between wall cavities. Results for this test are shown in Fig.14. If all six data points are used to fit a straight line through the data then the flow exponent is 1.21, which is physically impossible, since flow exponents must fall within the range of 0.5 (orifice

Table 2. Summary of Flow Characteristics and Leakage Areas for Test Panels

PANEL	C $*10^{-4}$	n	A_4 (cm^2)	Correlation Coefficient R^2
N1	1.52	1.0	4.03	0.9981
N2	0.61	0.96	1.48	0.9945
N3	3.64	0.88	8.00	0.9274
N4	0.49	0.96	1.20	0.9986
N5	46.5	0.50	59.5	0.8695
N6	0.63	0.93	1.48	0.9966
S1	2.01	0.87	4.37	0.9748
S2	4.16	0.76	7.75	0.9736
S3	2.53	0.896	5.65	0.9573
S4	1.19	0.79	2.28	0.9758
S5	57.0	0.51	74.7	0.6799
S6	0.27	0.90	0.62	0.9966

flow) and 1.0 (laminar flow). The straight line shown in Fig.14 was based on the results for the three lowest pressure differences, which gave an exponent of 0.97 and a leakage area of 2.92 cm^2 compared to 4.03 cm^2 for the single cavity pressurization tests. With this balanced cavity test, one would expect some reduction in leakage area, the effect being largest for panel 1 with the semi-rigid glass fiber sheathing. For the other panels with rigid foam or waferboard sheathing, the leakage area reduction is expected to be smaller than that of panel 1, although there may be significant leakage area between cavities, even for these panels. The difficulties in maintaining a continuous balance between all three cavities throughout the tests probably explains why the data does not fit a straight line over the entire pressure range and precludes its use as a viable test procedure.

Wall cavity pressure difference was monitored in one of the test panels (panel S1) for a short period near the beginning of the test. Wall cavity-indoor pressure differences are shown in Fig.15 for a two day period between Oct.2 and Oct 4, 1989. Generally, cavity pressure was greater than the indoor pressure. However, during periods with light winds, pressure differences were quite low (1 or 2 Pa). As wind speeds increased, average cavity-indoor pressure differences increased, but this was accompanied by large pressure fluctuations. For example, during period AB, average pressure differences were on the order of 15 Pa with fluctuating pressures that were of similar magnitude. These pressure fluctuations are a direct result of turbulence in air flow near ground level. It is anticipated that wall cavity pressure fluctuations will depend on the amount of leakage area in the exterior sheathing. Thus, panel S5, with vent openings top and bottom is expected to have the largest pressure fluctuations and panel S6, the smallest fluctuations, although these measurements were not carried out.

3.5 Microbiological Tests

Microbiological analysis of cavity air samples and wood samples from wall cavities (collected near the end of the test period) were carried out by Agriculture Canada and Forintek Canada Corp., respectively. None of the air samples were found to contain any bacteria or fungi. However, at the end of the test period when wall cavities were exposed, there was evidence of microbiological activity. Wood samples were taken by Lynne Sigler (University of Alberta, Devonian Foundation) and sent to Forintek Canada for analysis. Forintek's report is included as Appendix B.

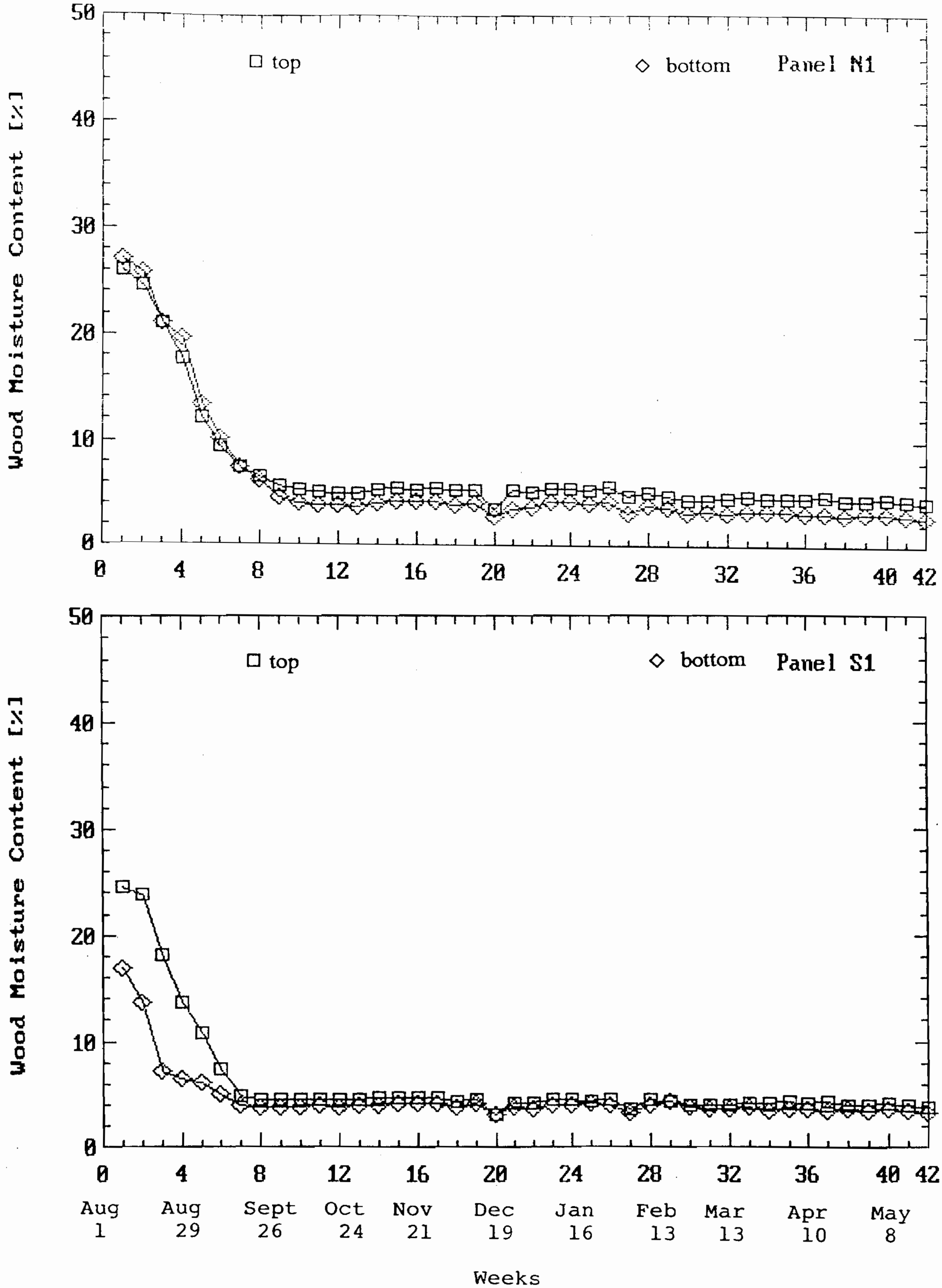


Fig.5a. Weekly averaged wood moisture contents versus time for panel N1 an S1

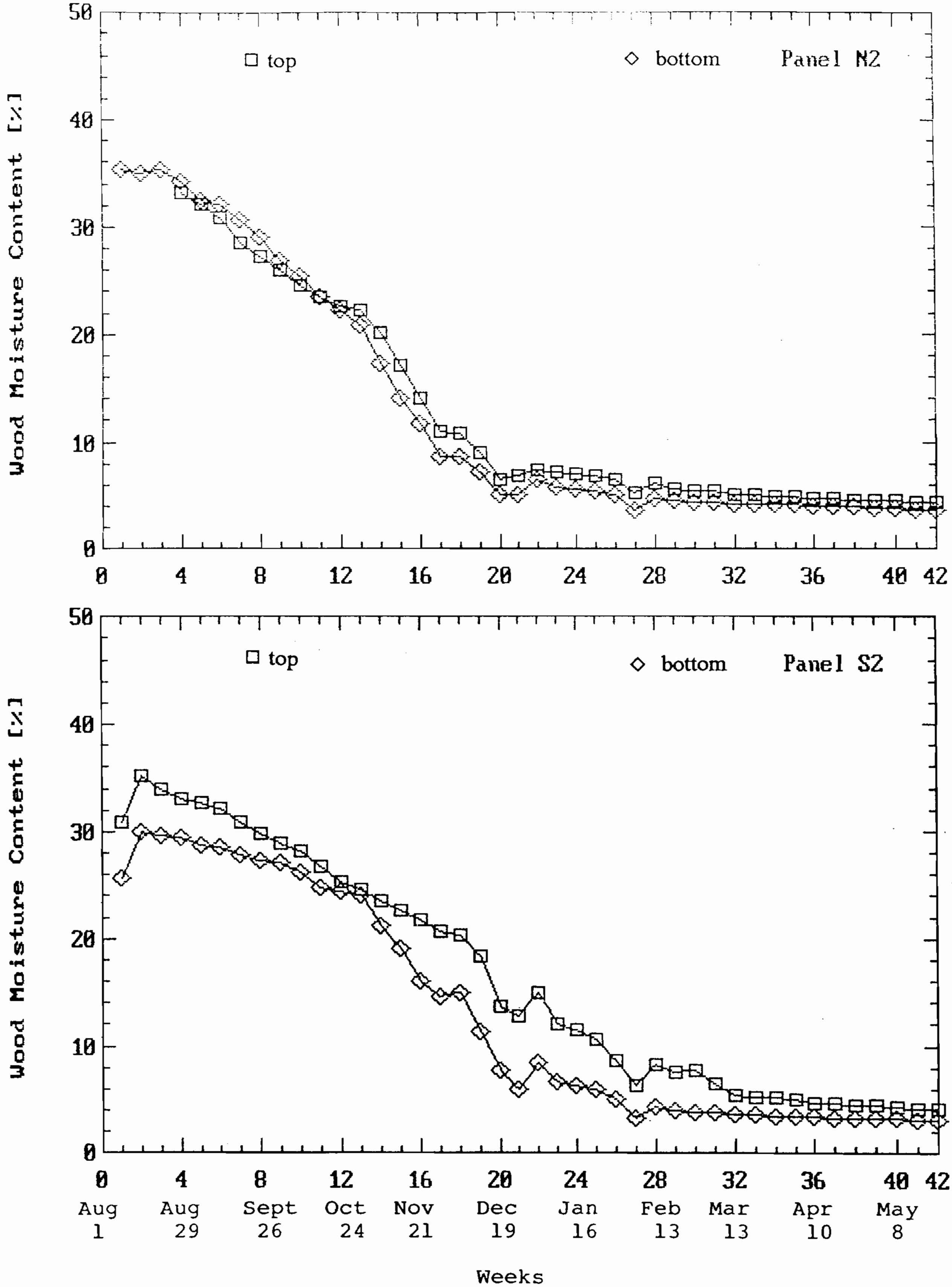


Fig.5b. Weekly averaged wood moisture contents versus time for panel N2 and S2

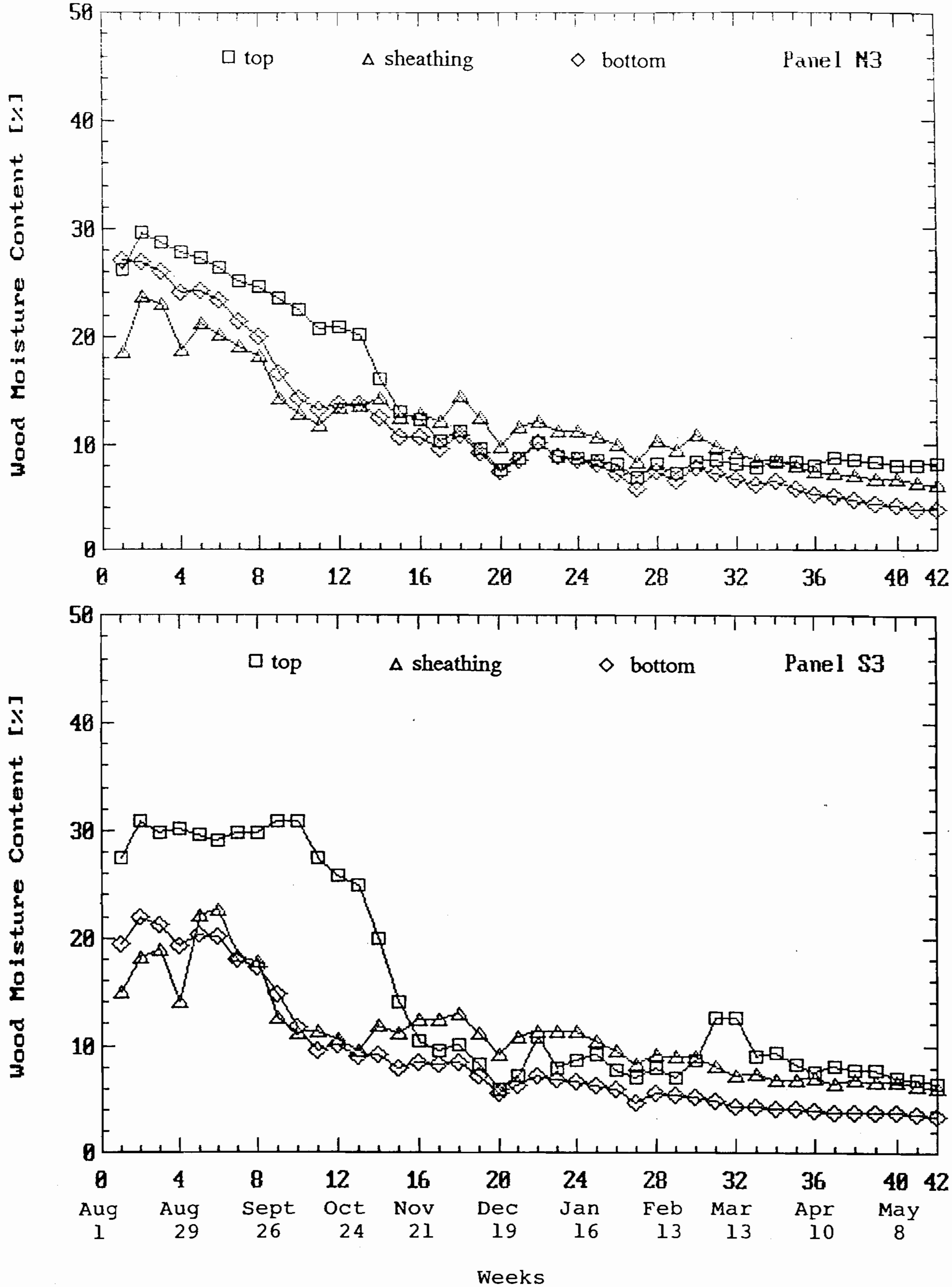


Fig.5c. Weekly averaged wood moisture contents versus time for panel N3 and S3

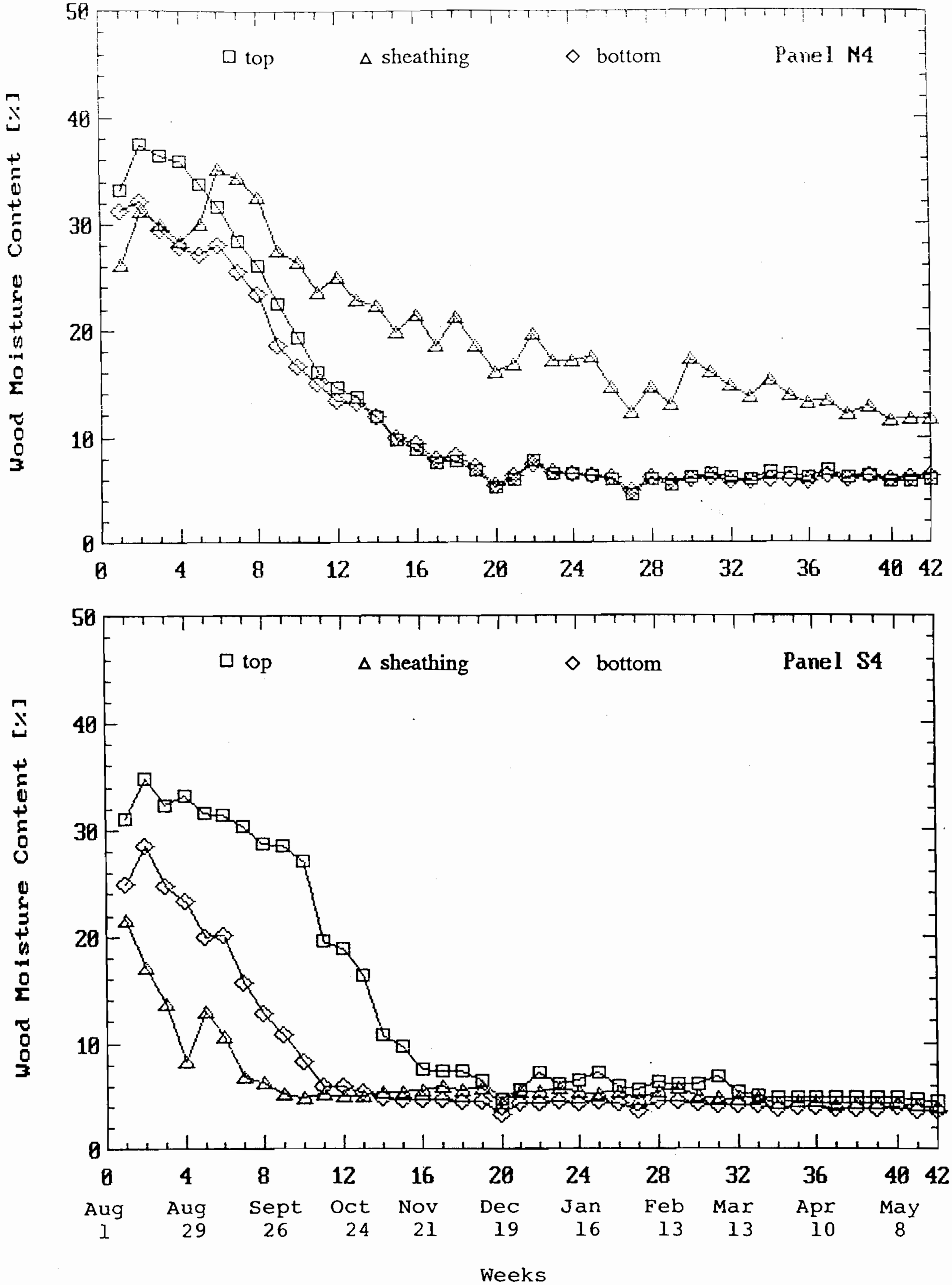


Fig.5d. Weekly averaged wood moisture contents versus time for panel N4 and S4

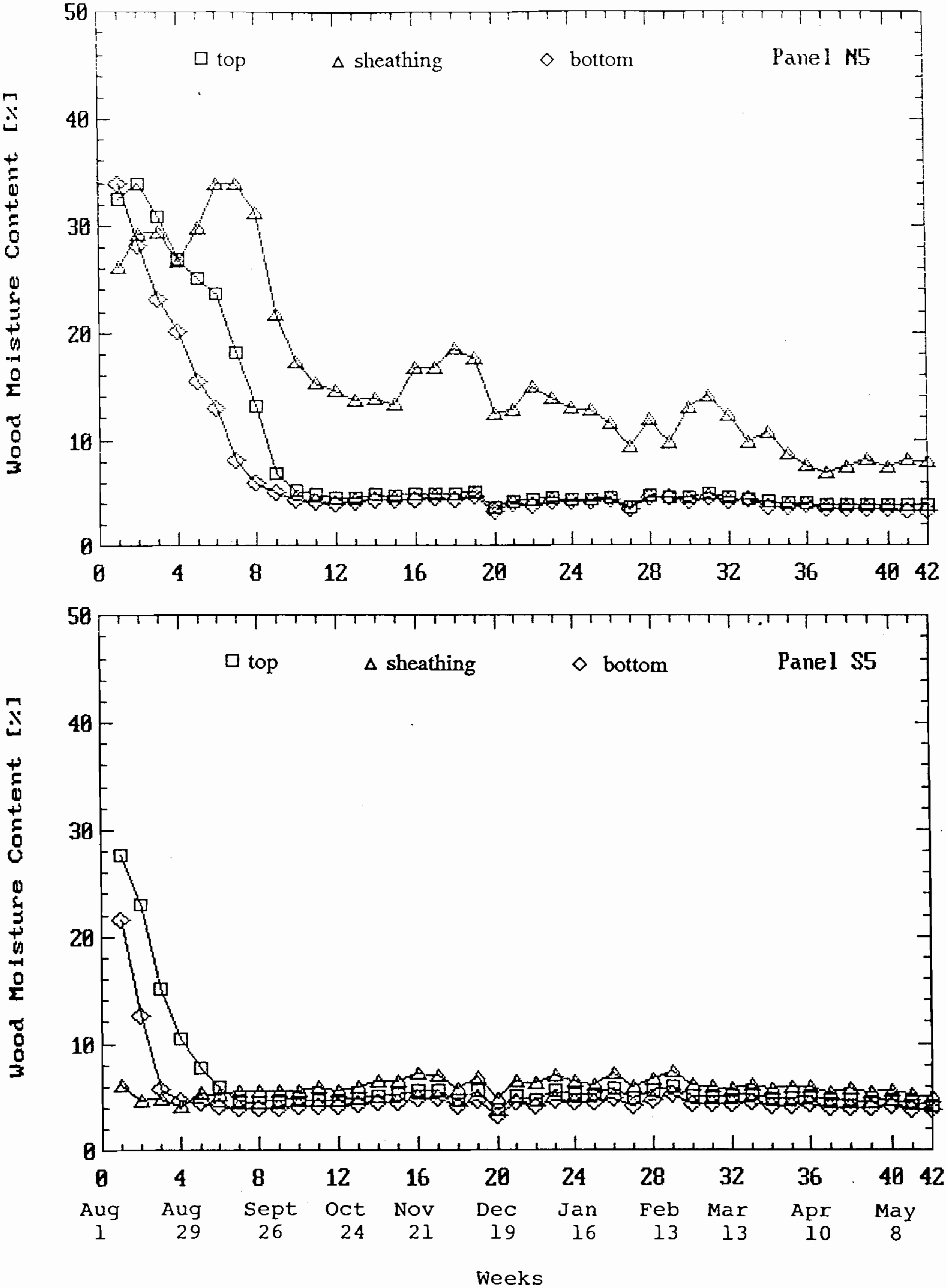


Fig.5e. Weekly averaged wood moisture contents versus time for panel N5 and S5

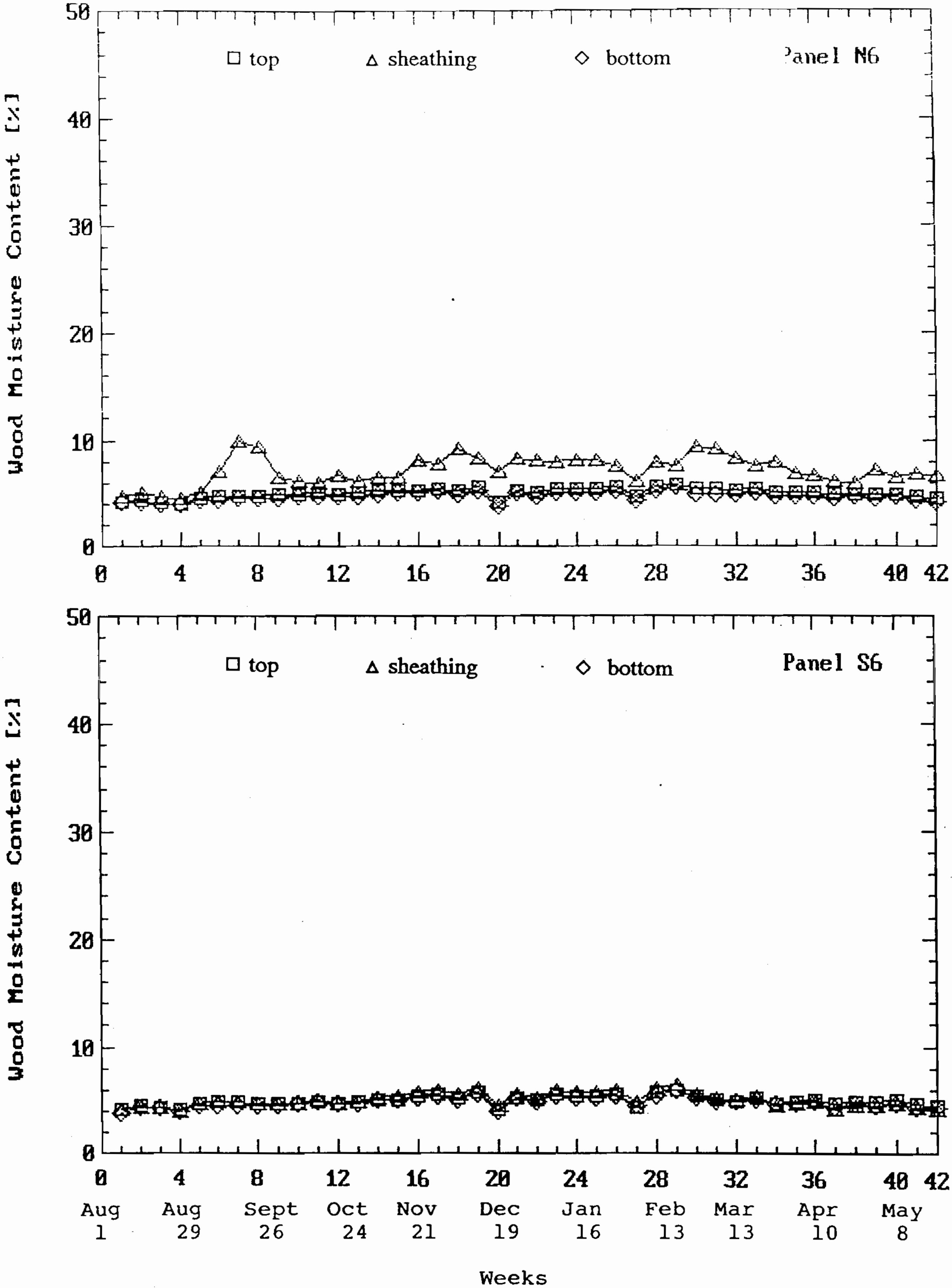


Fig.5f. Weekly averaged wood moisture contents versus time for panel N6 and S5

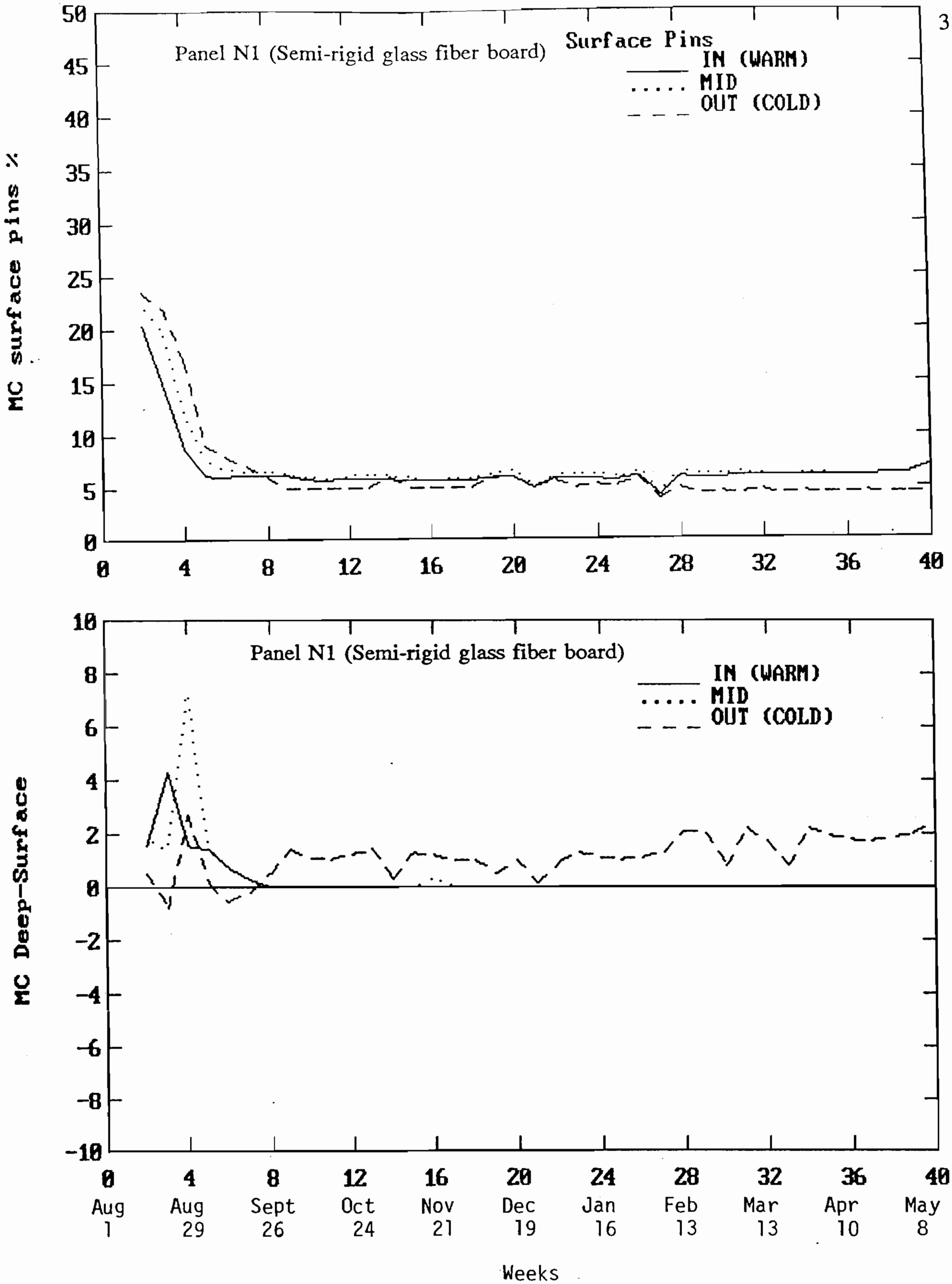


Fig.6a. Weekly averaged moisture contents for panel N1.
Upper plot is moisture content at the surface.
Lower plot is difference between mid-depth and surface moisture contents

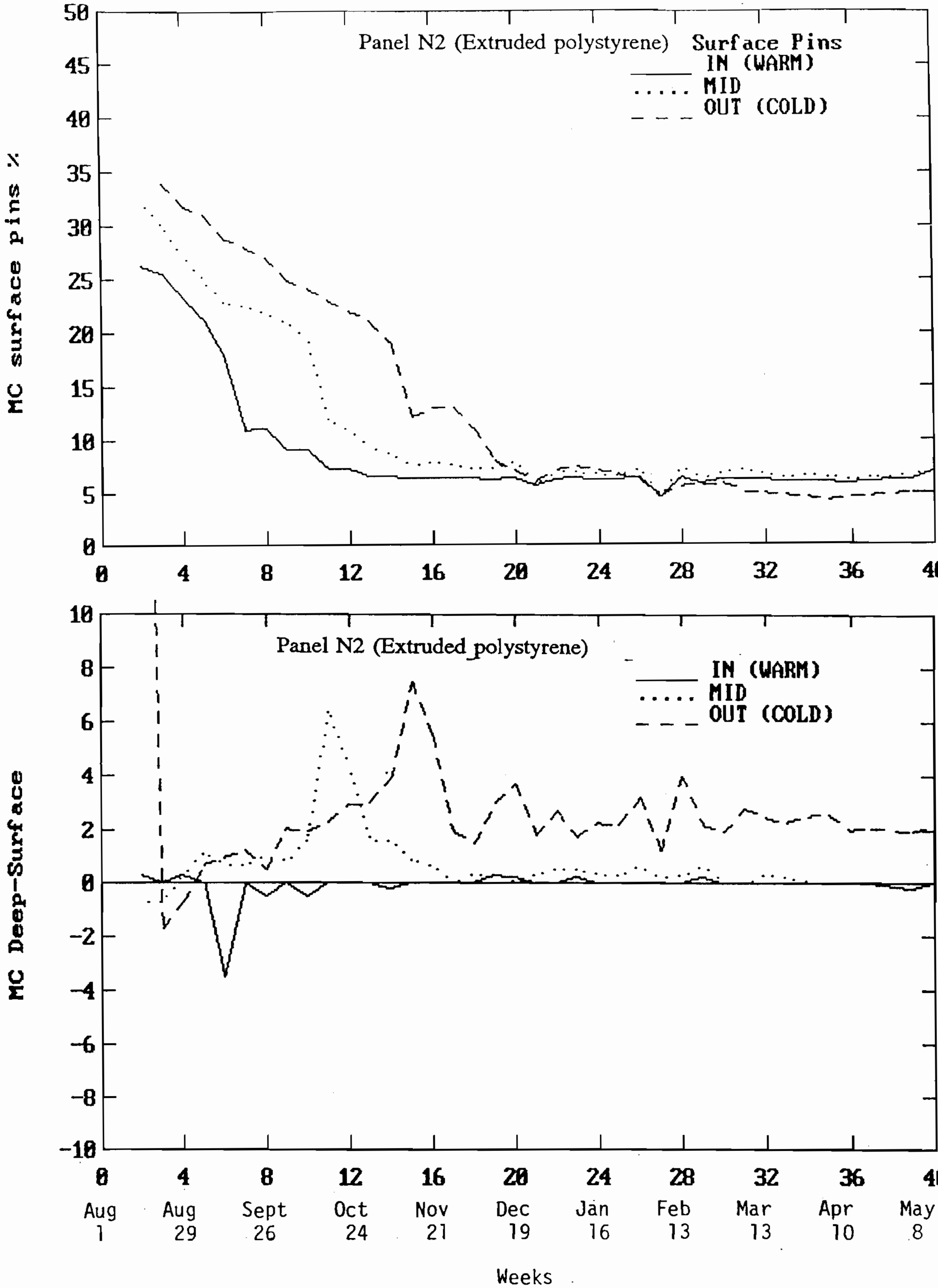


Fig.6b. Weekly averaged moisture contents for panel N2.
Upper plot is moisture content at the surface.
Lower plot is difference between mid-depth and surface moisture contents

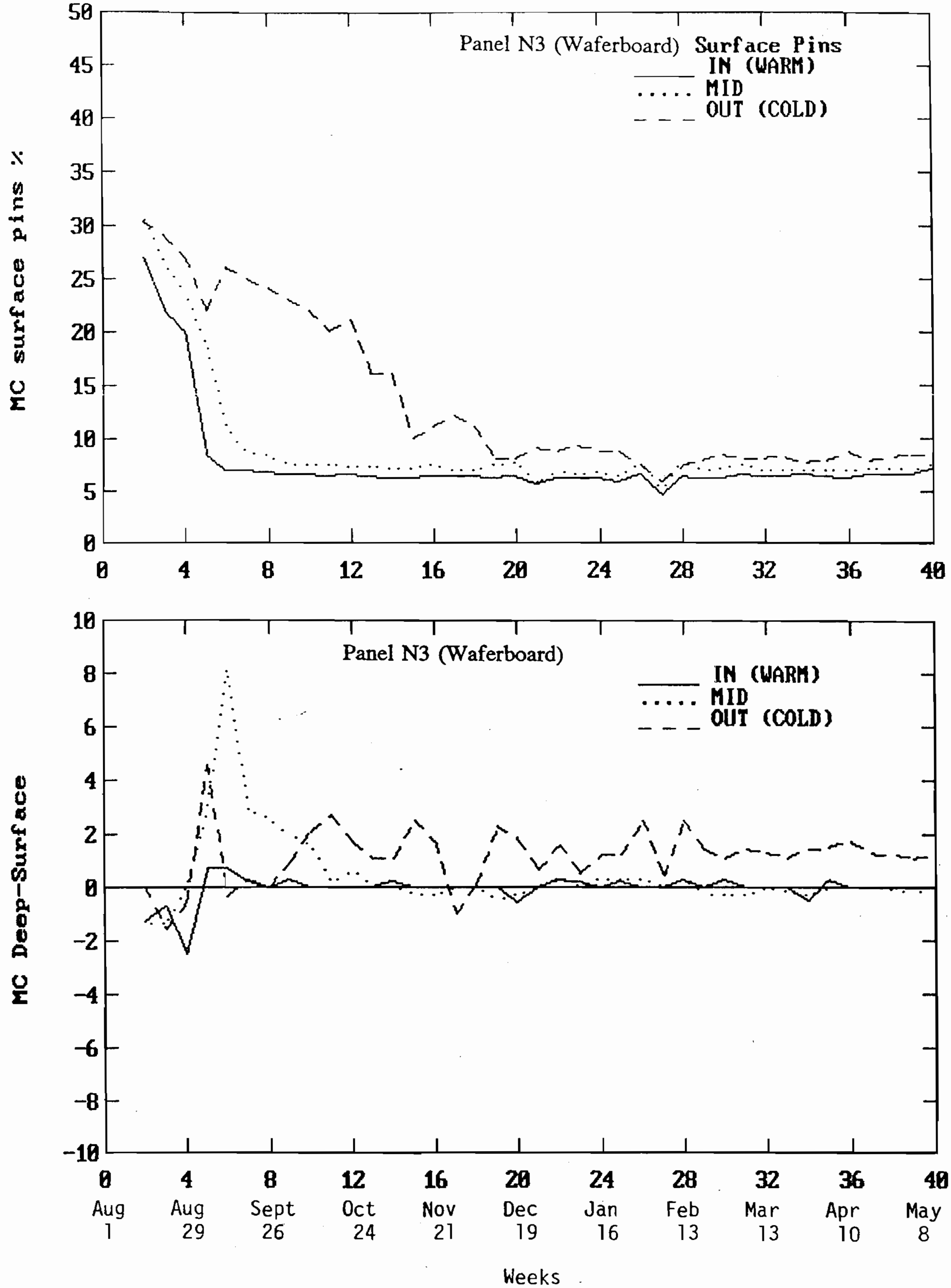
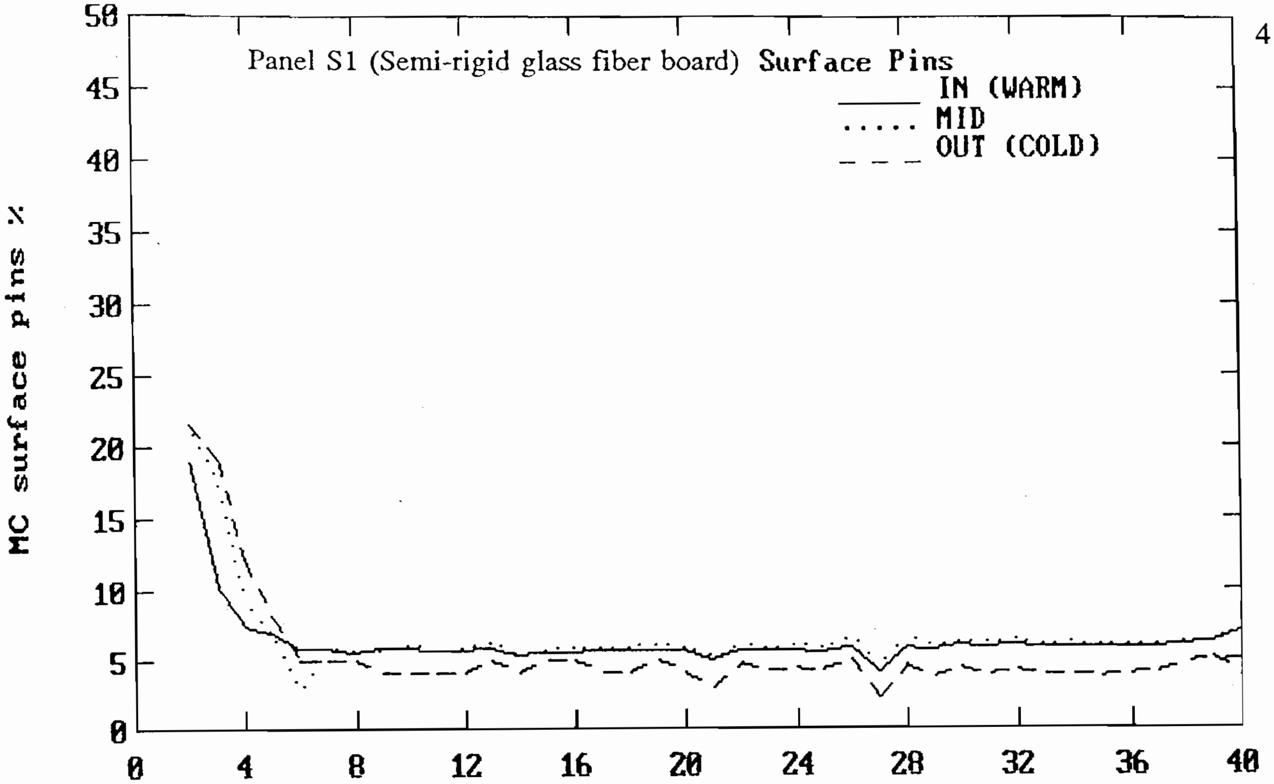


Fig.6c. Weekly averaged moisture contents for panel N3.
Upper plot is moisture content at the surface.
Lower plot is difference between mid-depth and surface moisture contents



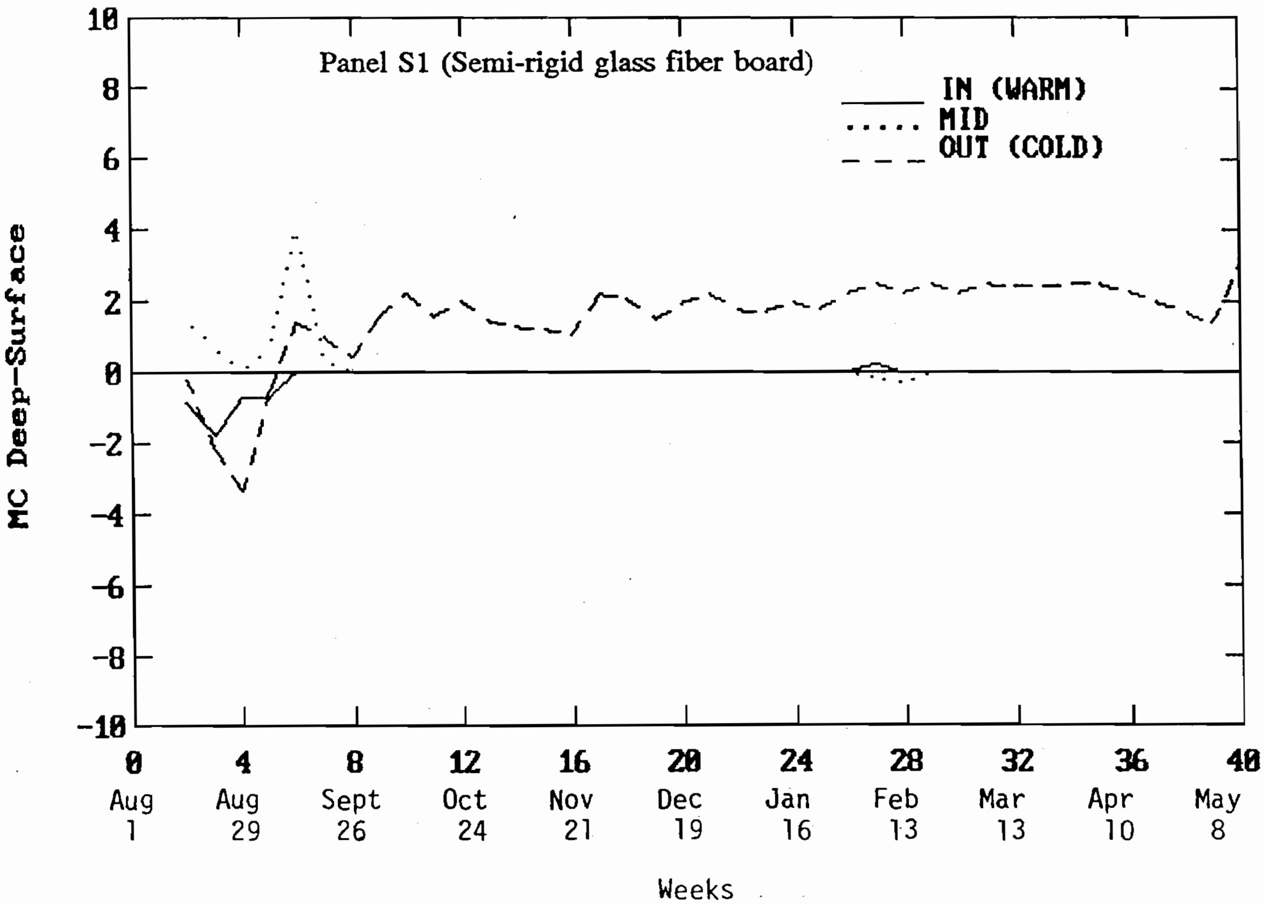


Fig.7a. Weekly averaged moisture contents for panel S1.
Upper plot is moisture content at the surface.
Lower plot is difference between mid-depth and surface moisture contents

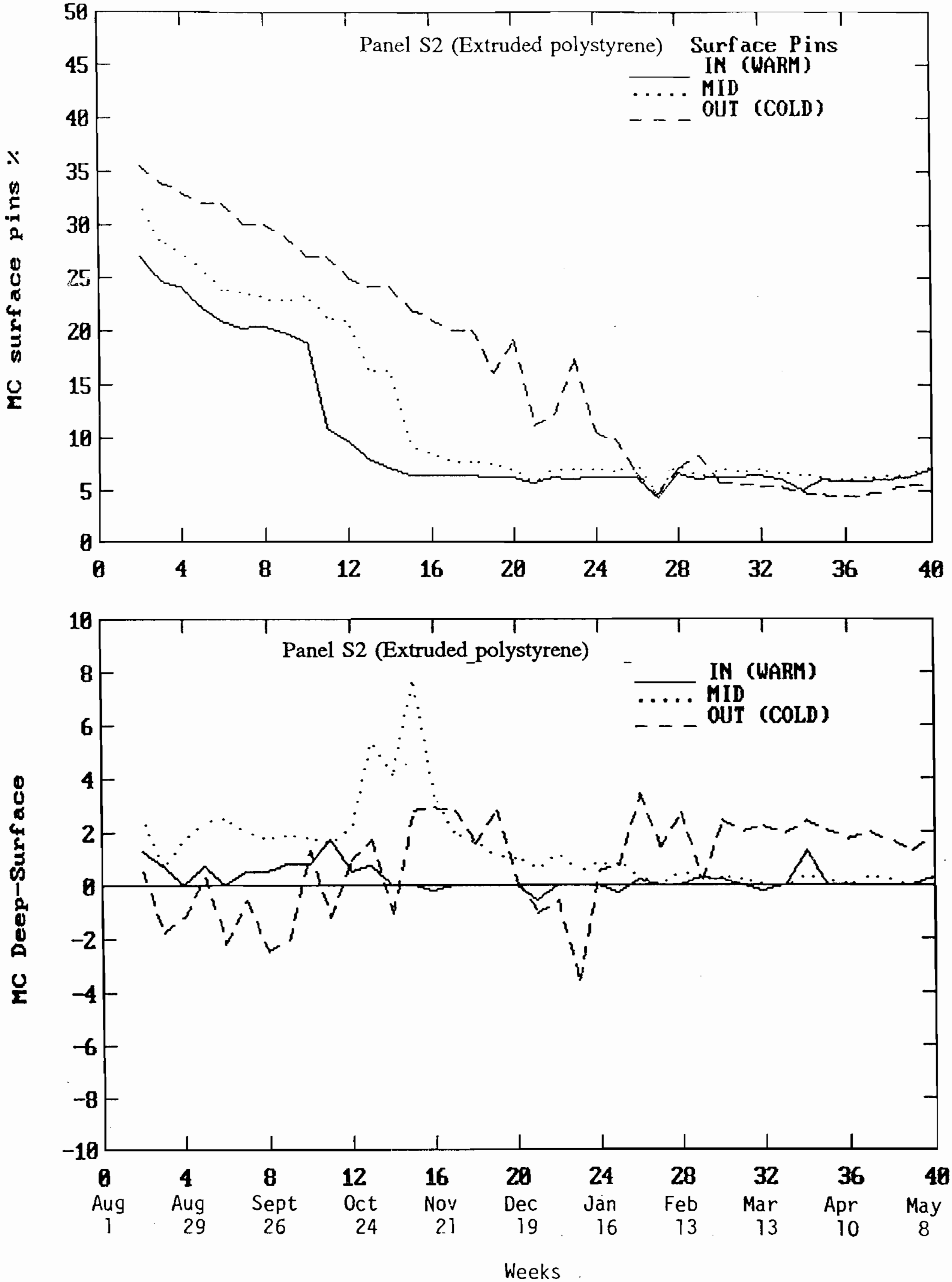


Fig.7b. Weekly averaged moisture contents for panel S2. Upper plot is moisture content at the surface. Lower plot is difference between mid-depth and surface moisture contents

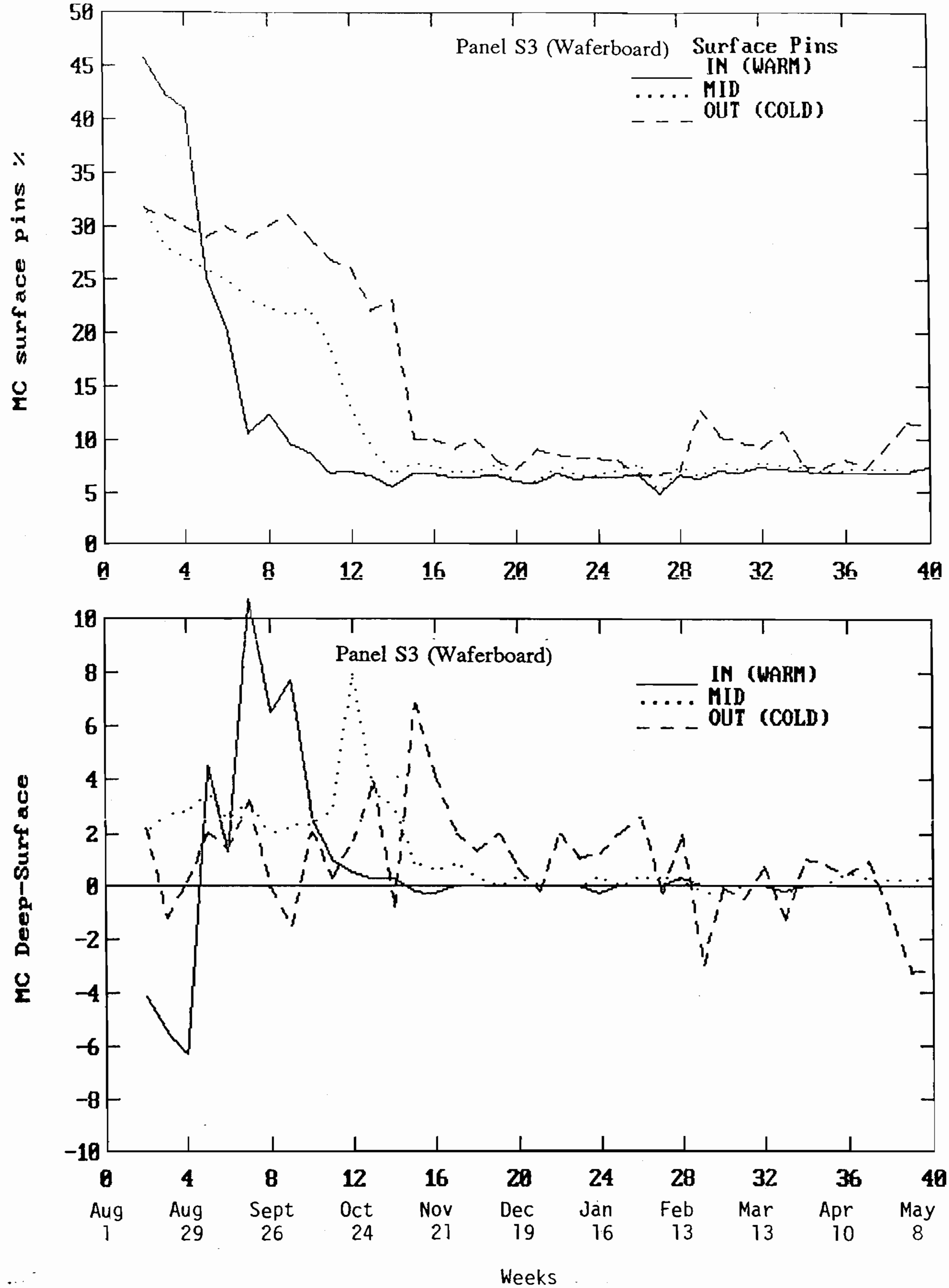


Fig.7c. Weekly averaged moisture contents for panel S3.
Upper plot is moisture content at the surface.
Lower plot is difference between mid-depth and surface moisture contents

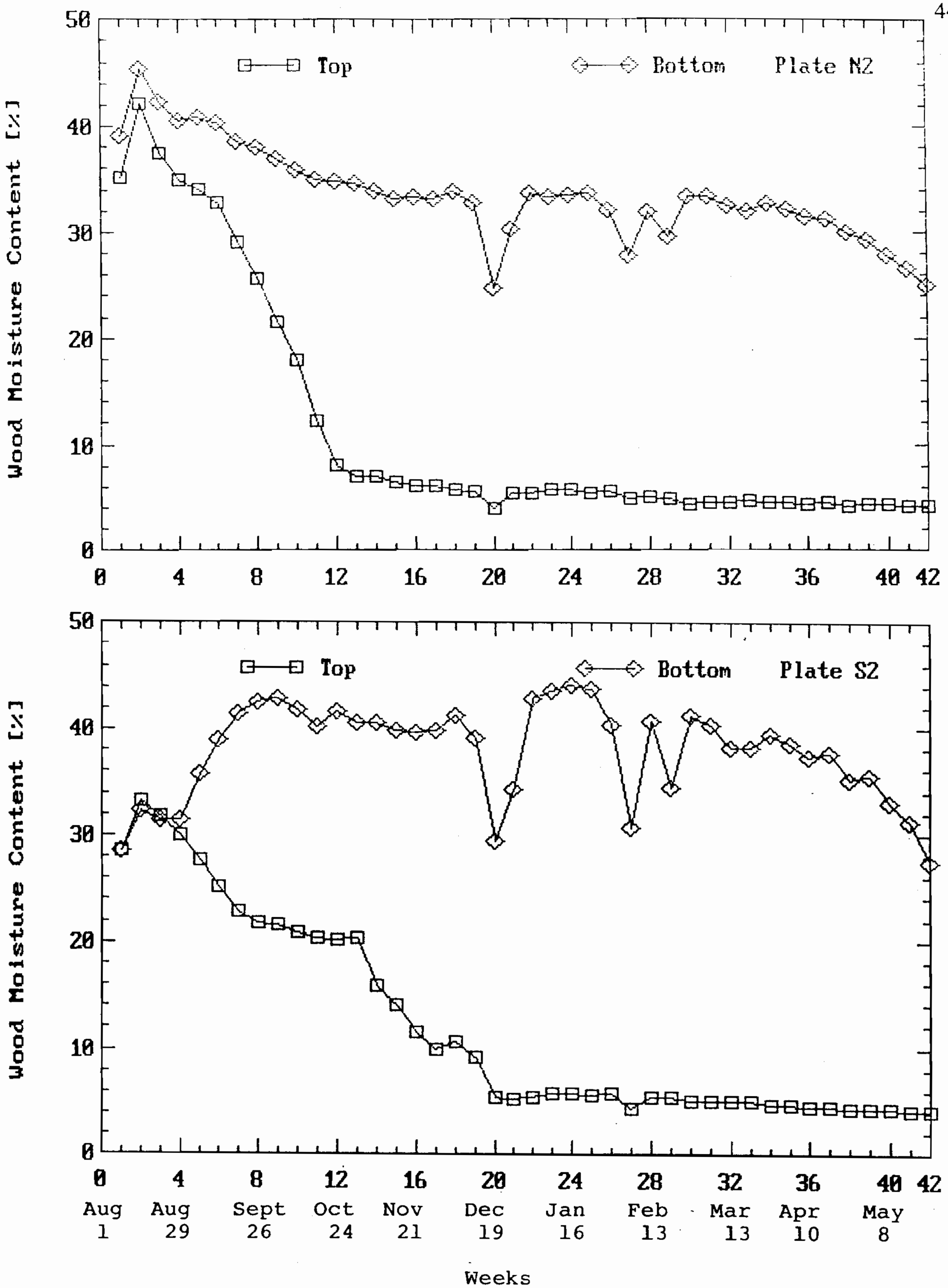


Fig.8. Weekly averaged moisture contents in the top and bottom plates of panel 2

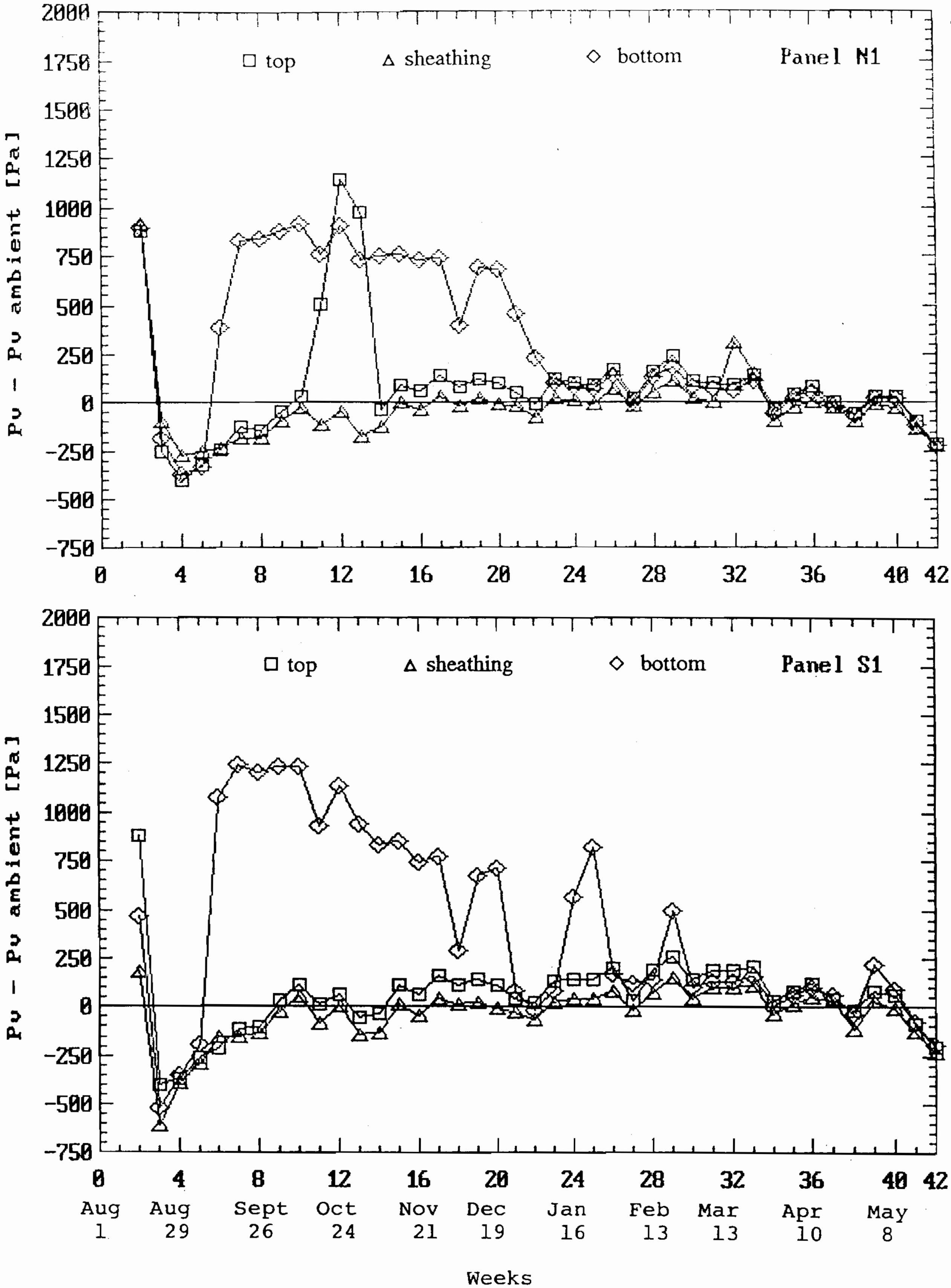
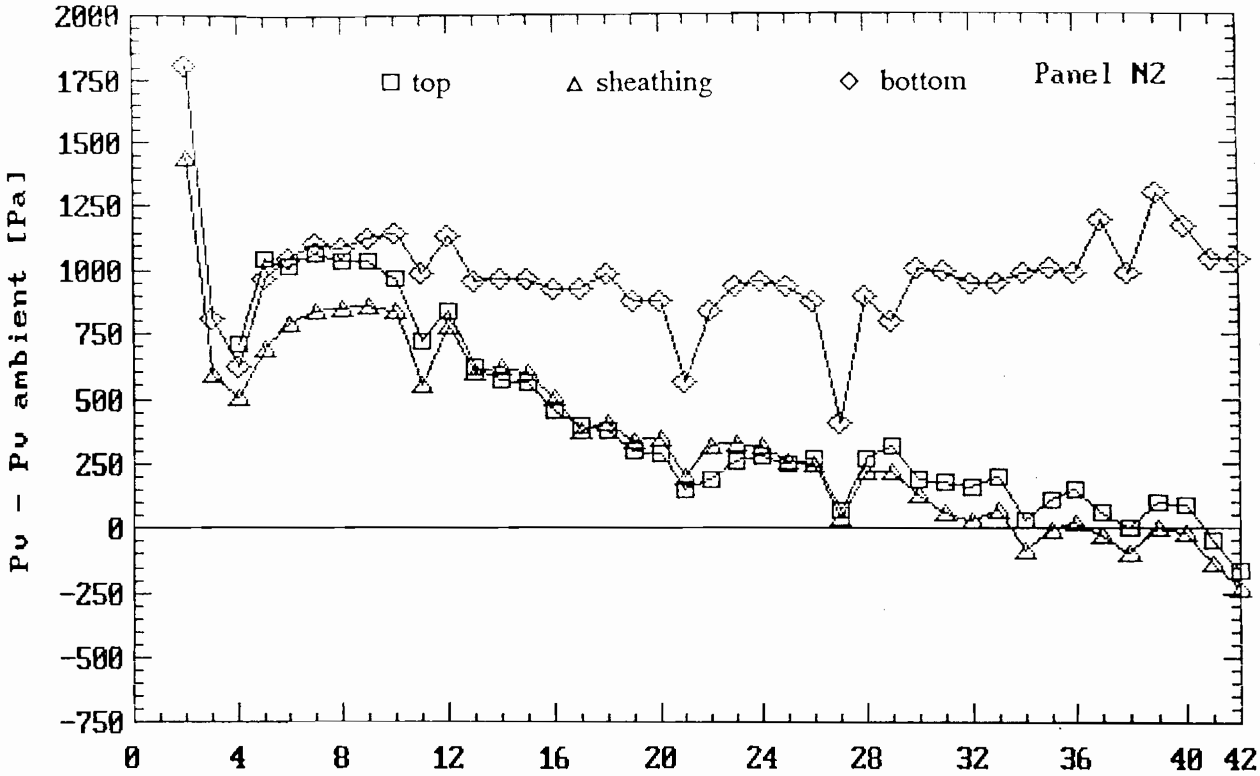


Fig.9a. Weekly averaged vapour pressure differences between wall cavity and ambient for panel 1



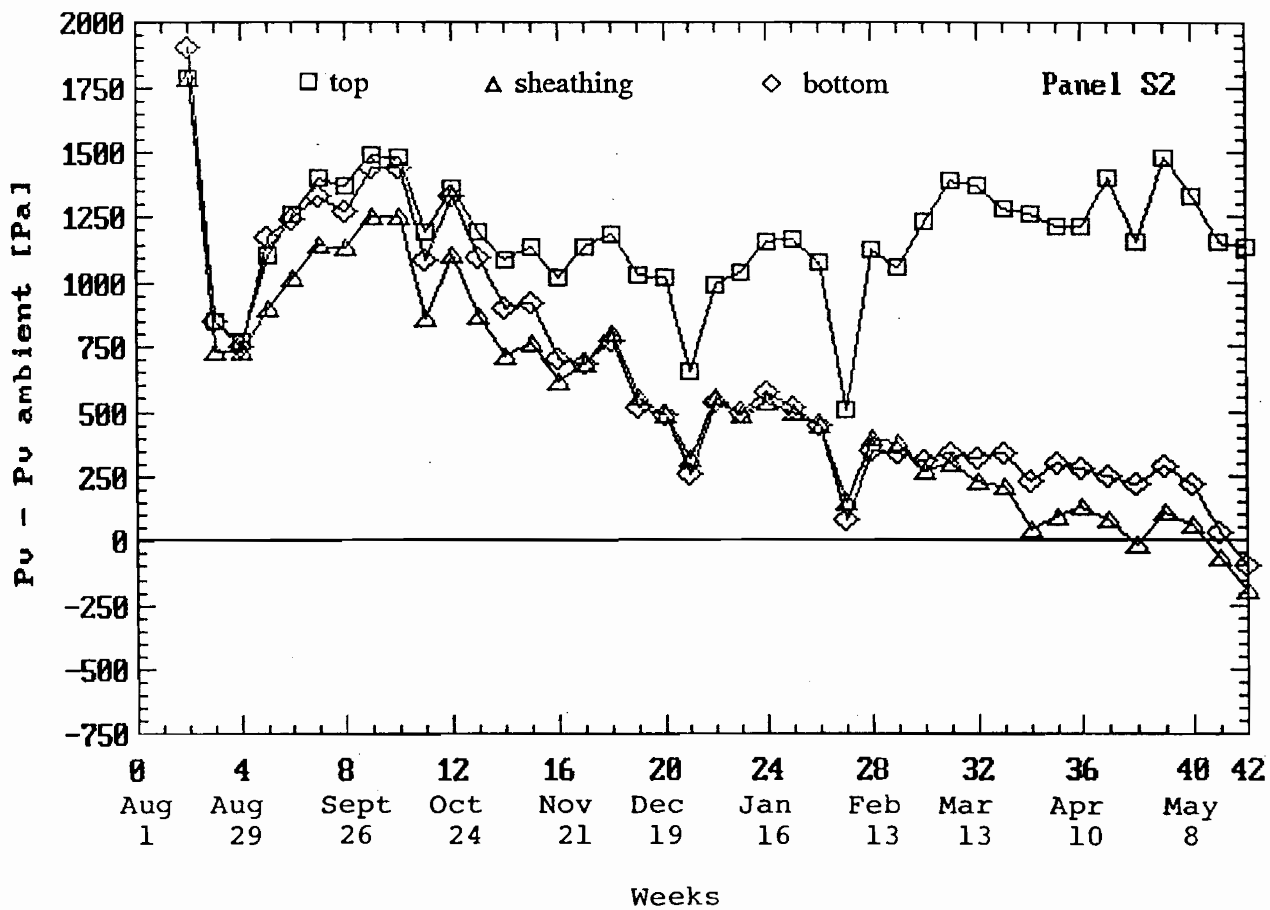


Fig.9b. Weekly averaged vapour pressure differences between wall cavity and ambient for panel 2

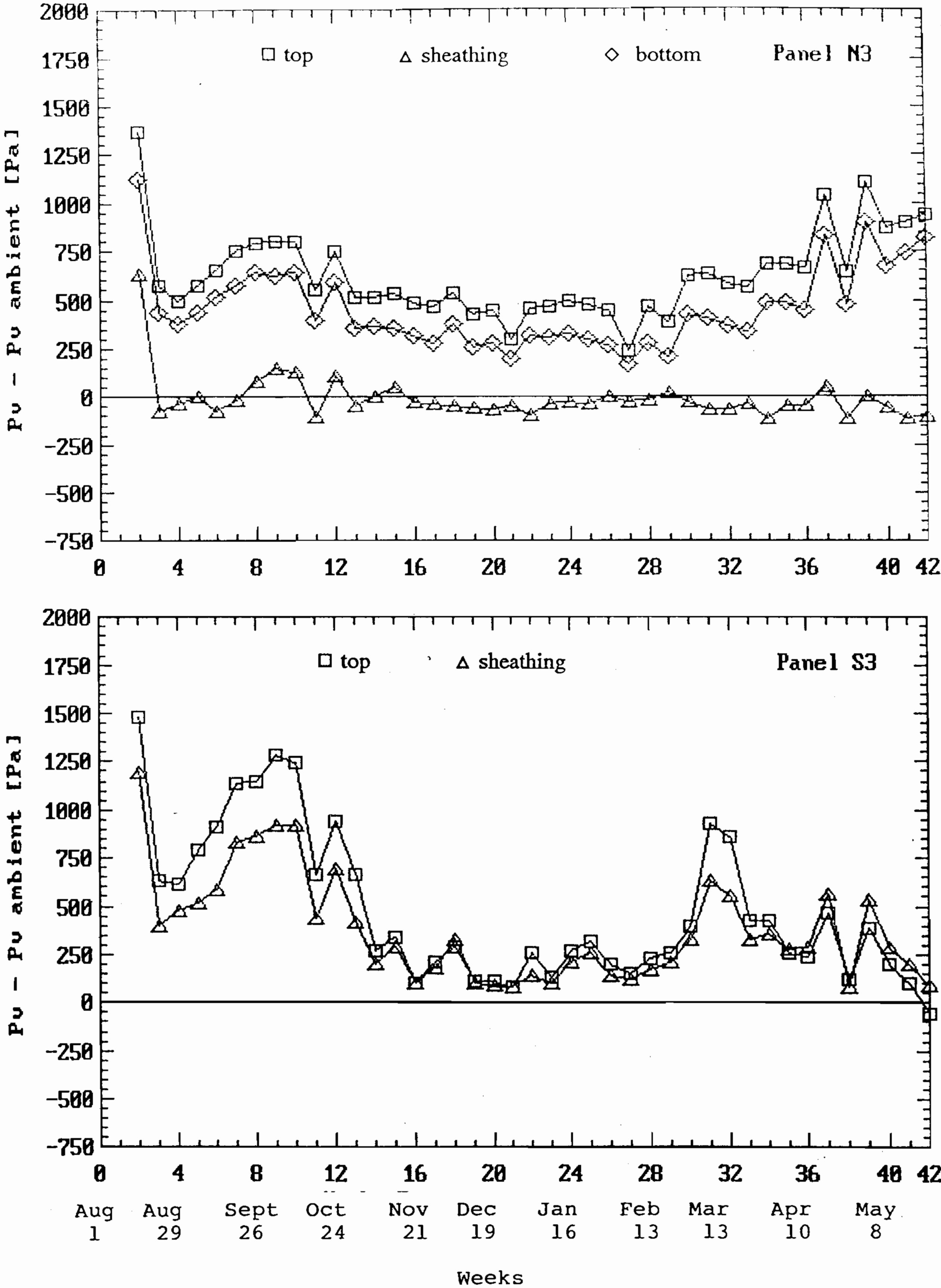


Fig.9c. Weekly averaged vapour pressure differences between wall cavity and ambient for panel 3

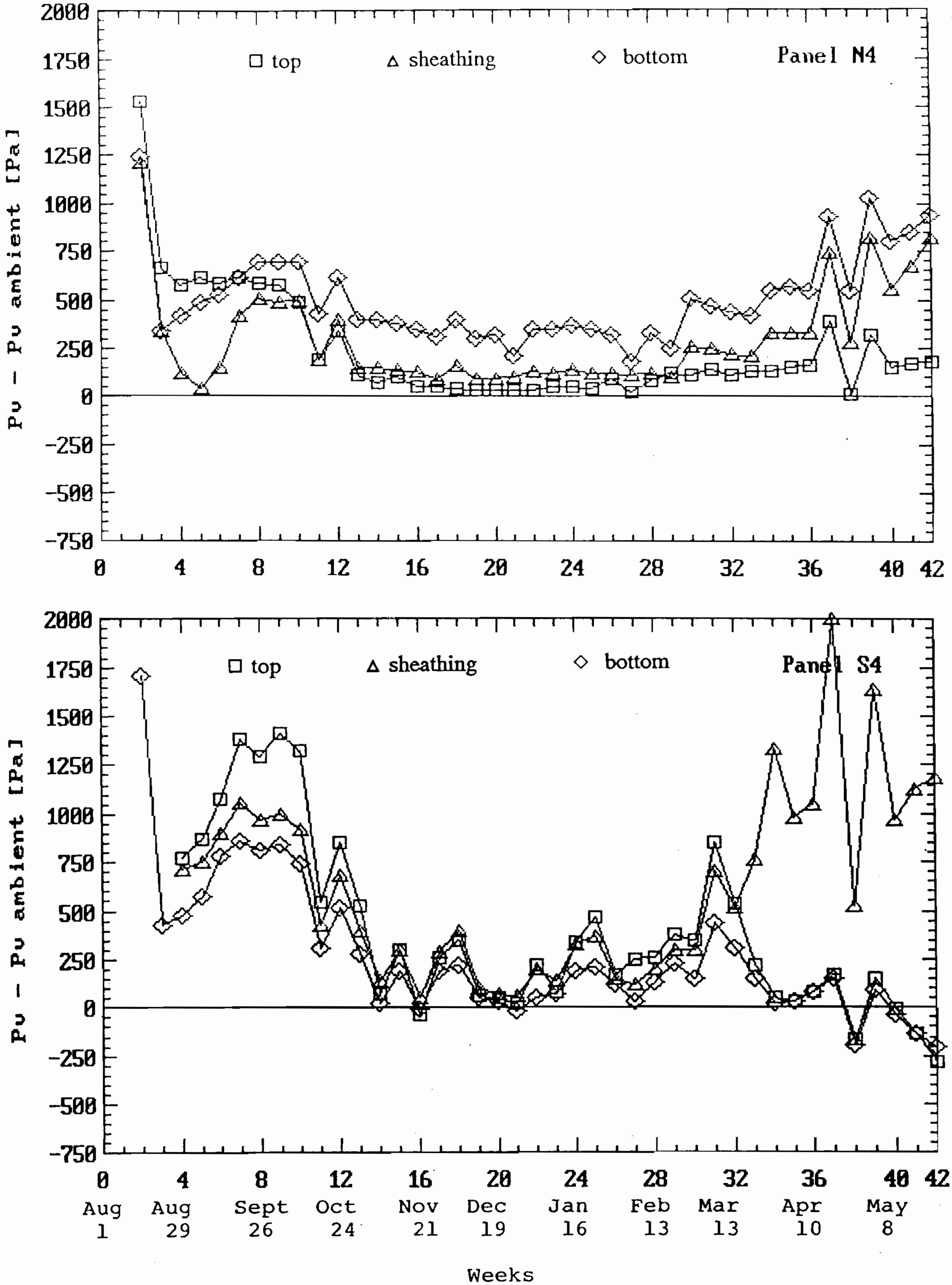


Fig.9d. Weekly averaged vapour pressure differences between wall cavity and ambient for panel 4

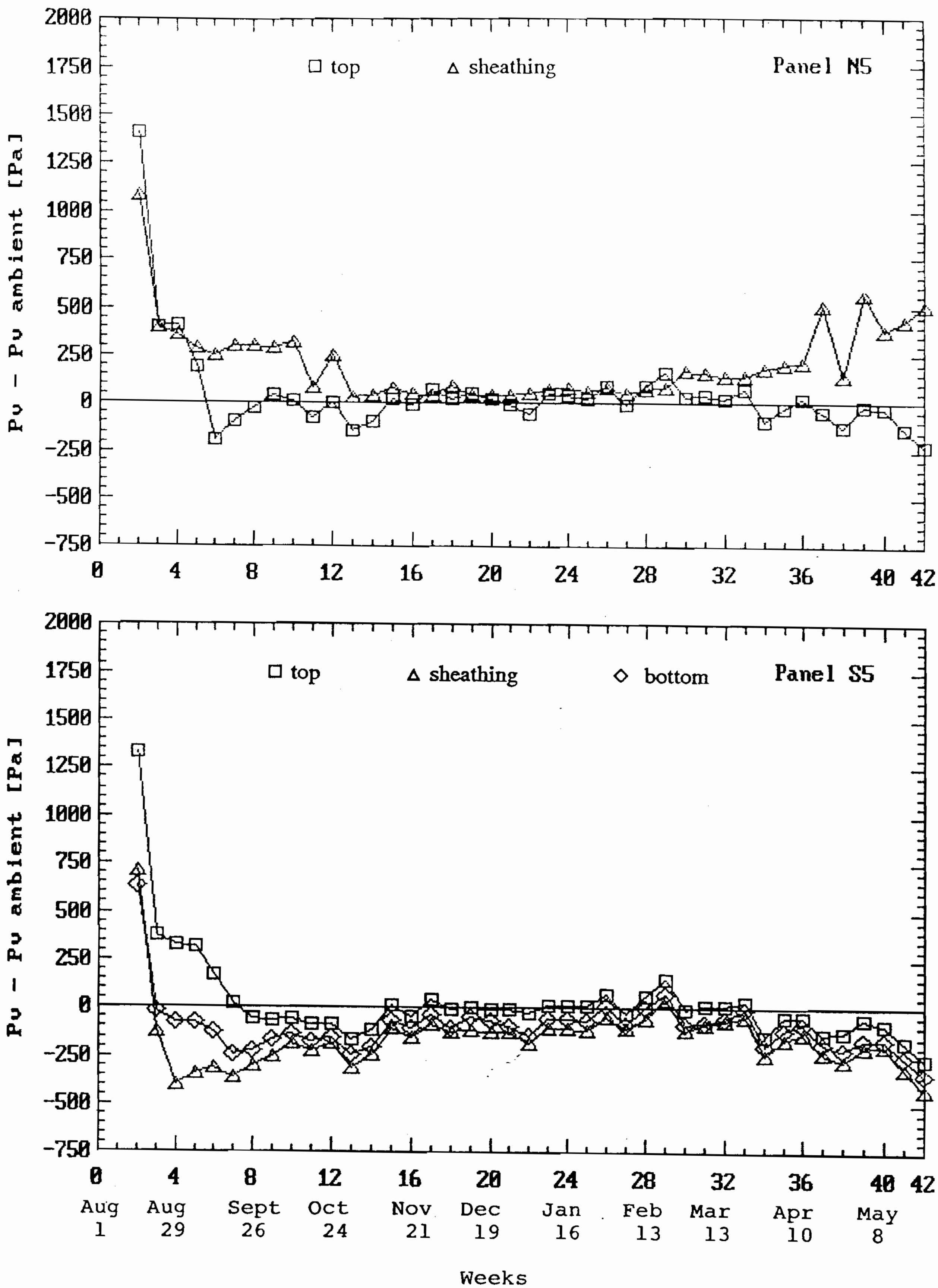


Fig.9e. Weekly averaged vapour pressure differences between wall cavity and ambient for panel 5

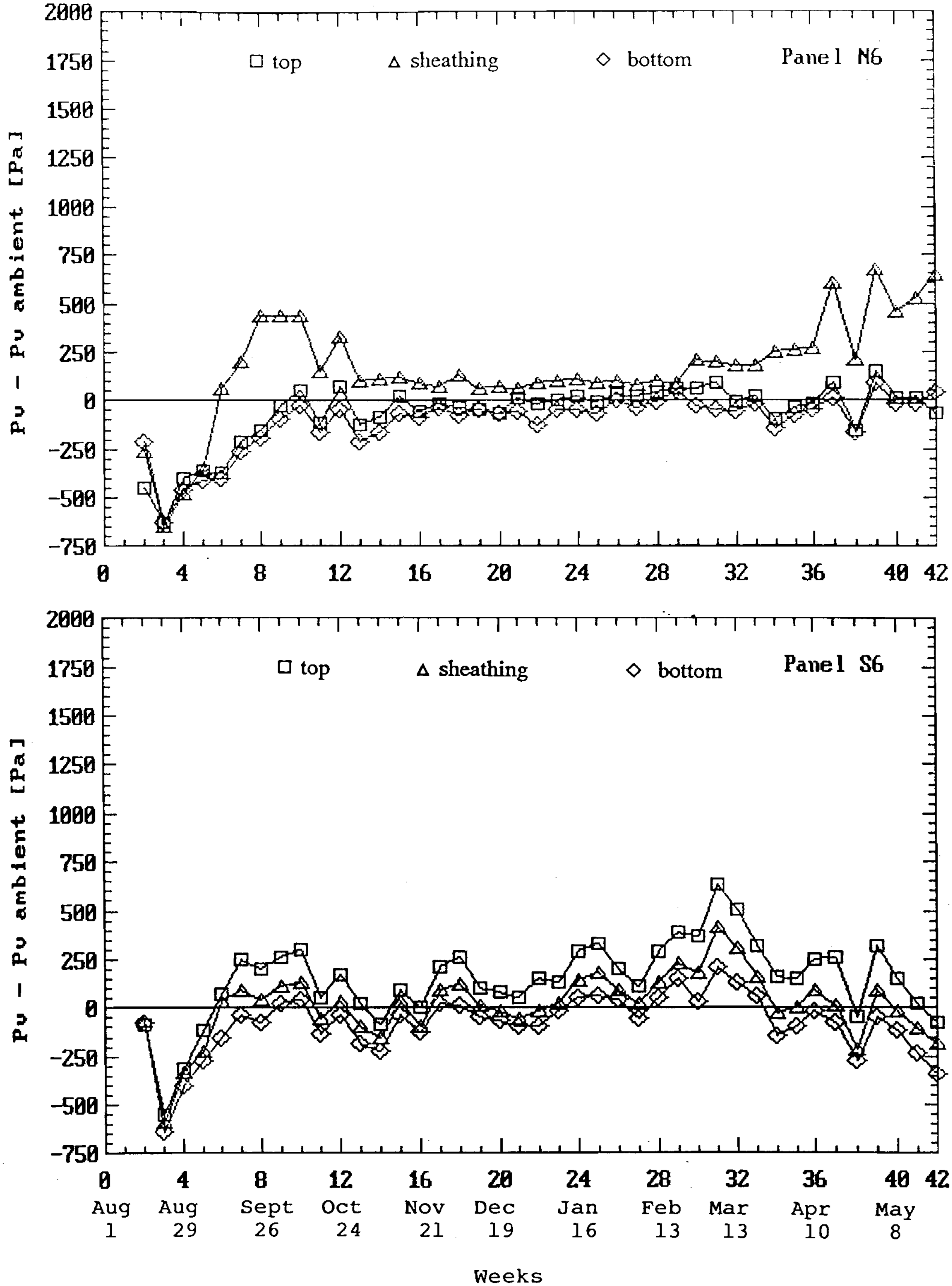
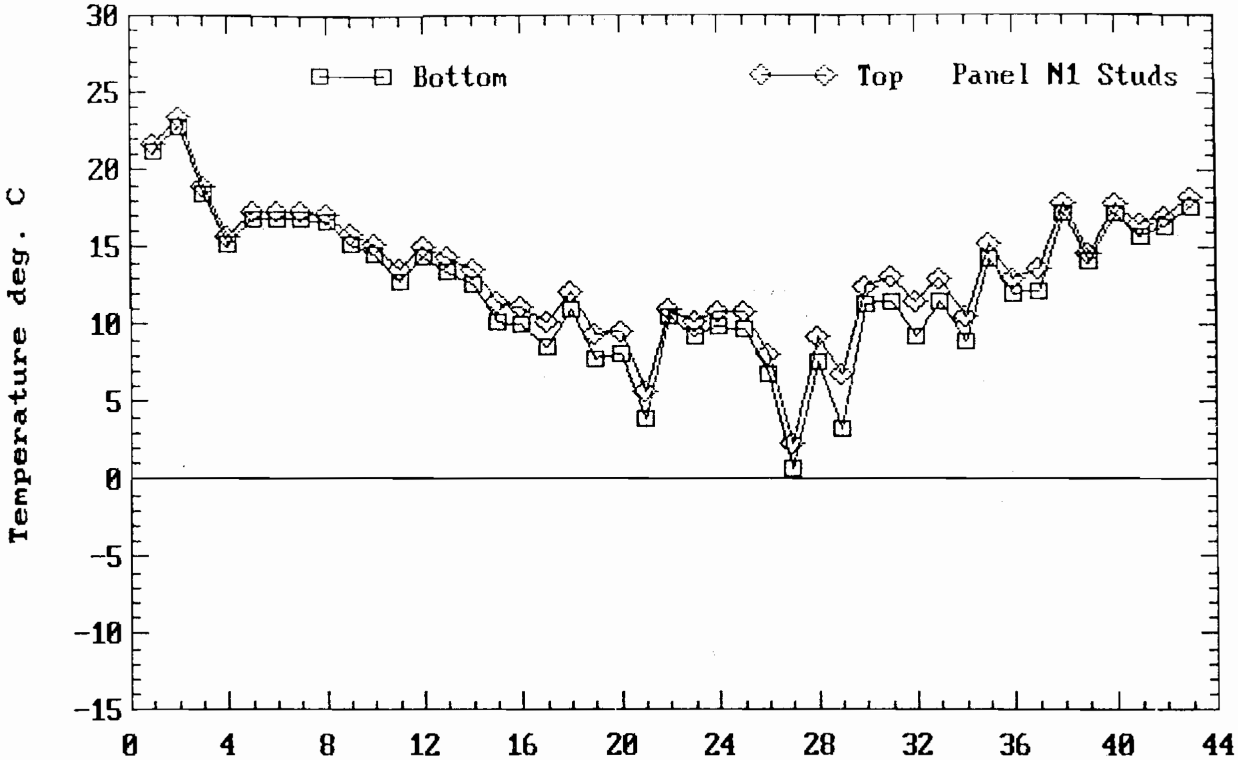


Fig.9f. Weekly averaged vapour pressure differences between wall cavity and ambient for panel 6 -



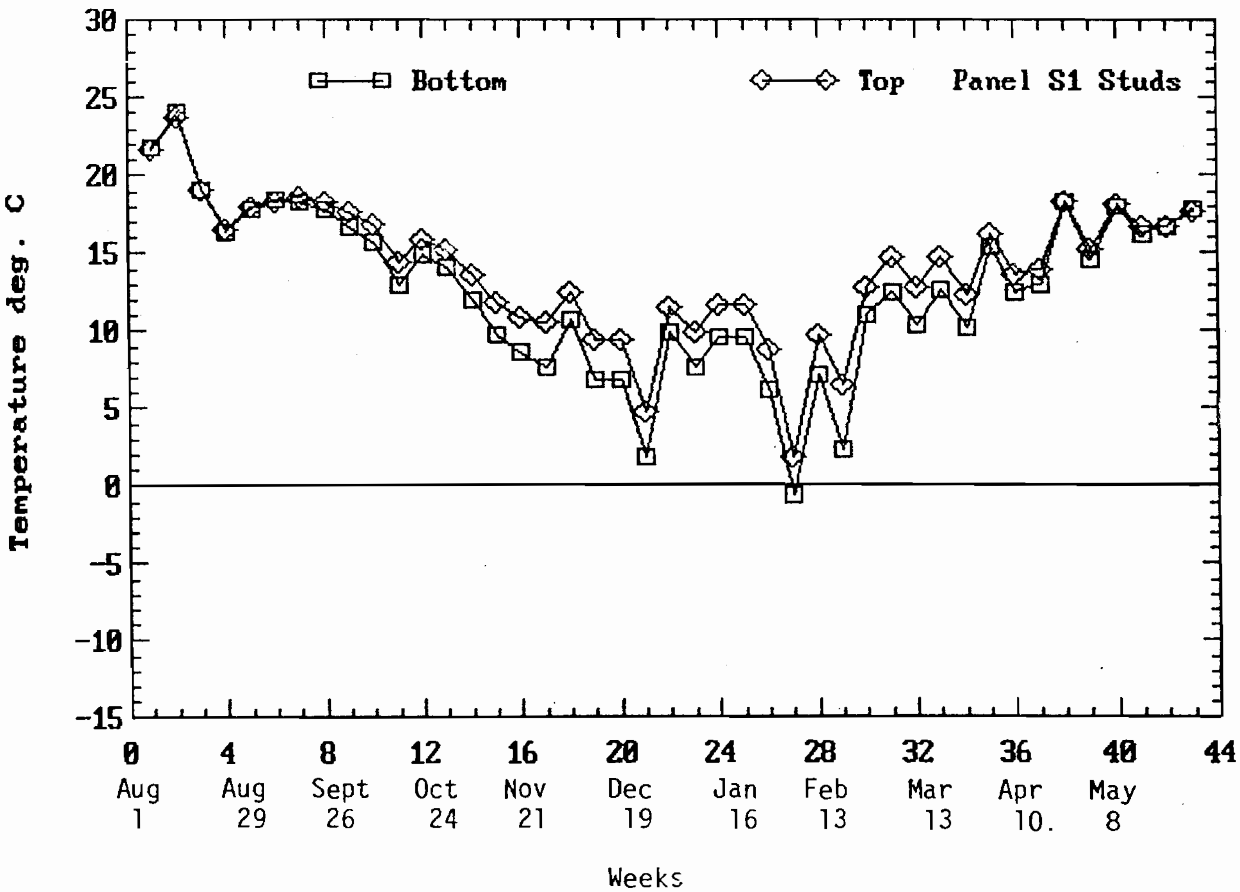


Fig.10a. Weekly averaged stud and sheathing temperatures for panel 1

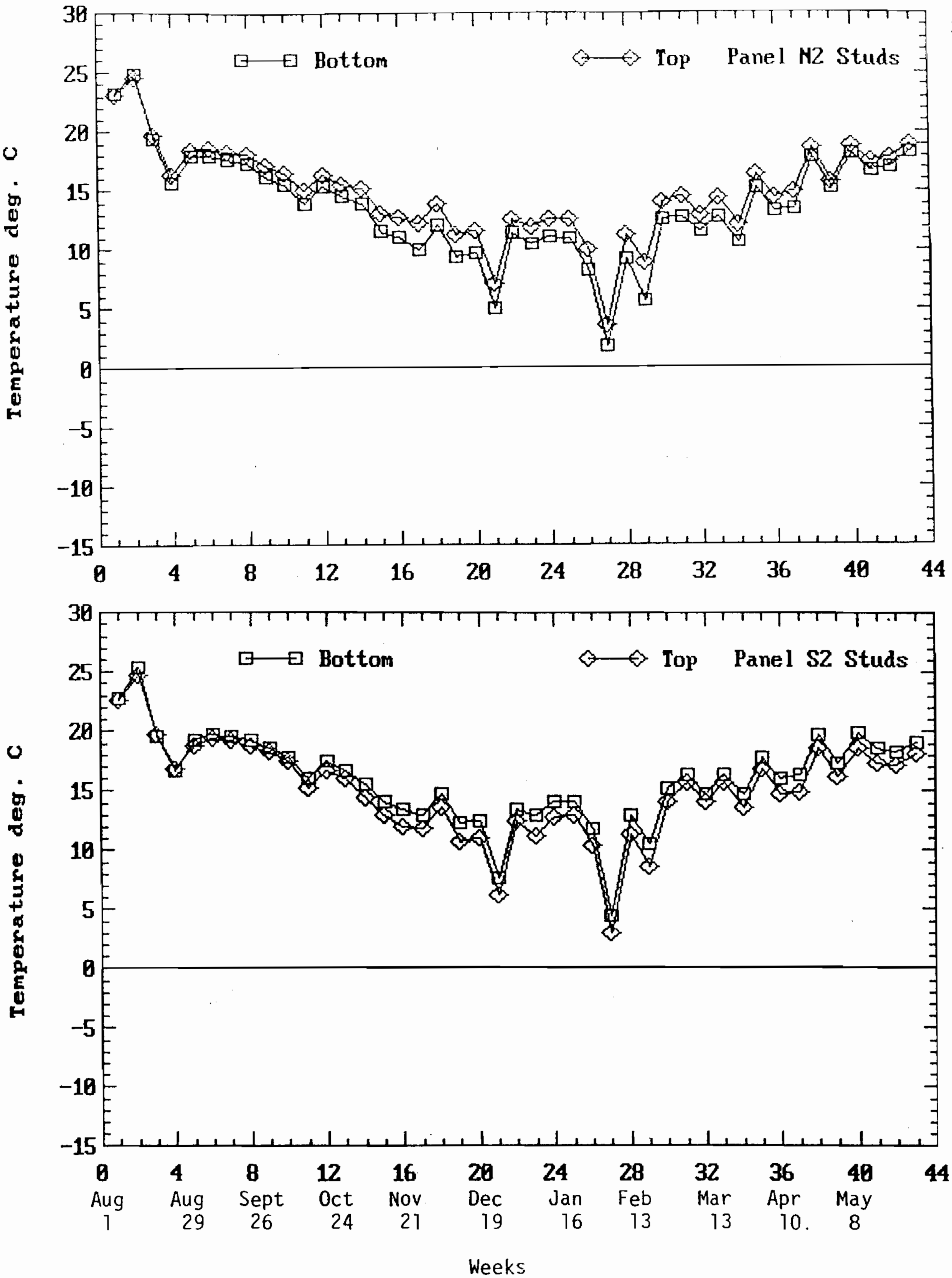


Fig.10b. Weekly averaged stud and sheathing temperatures for panel 2

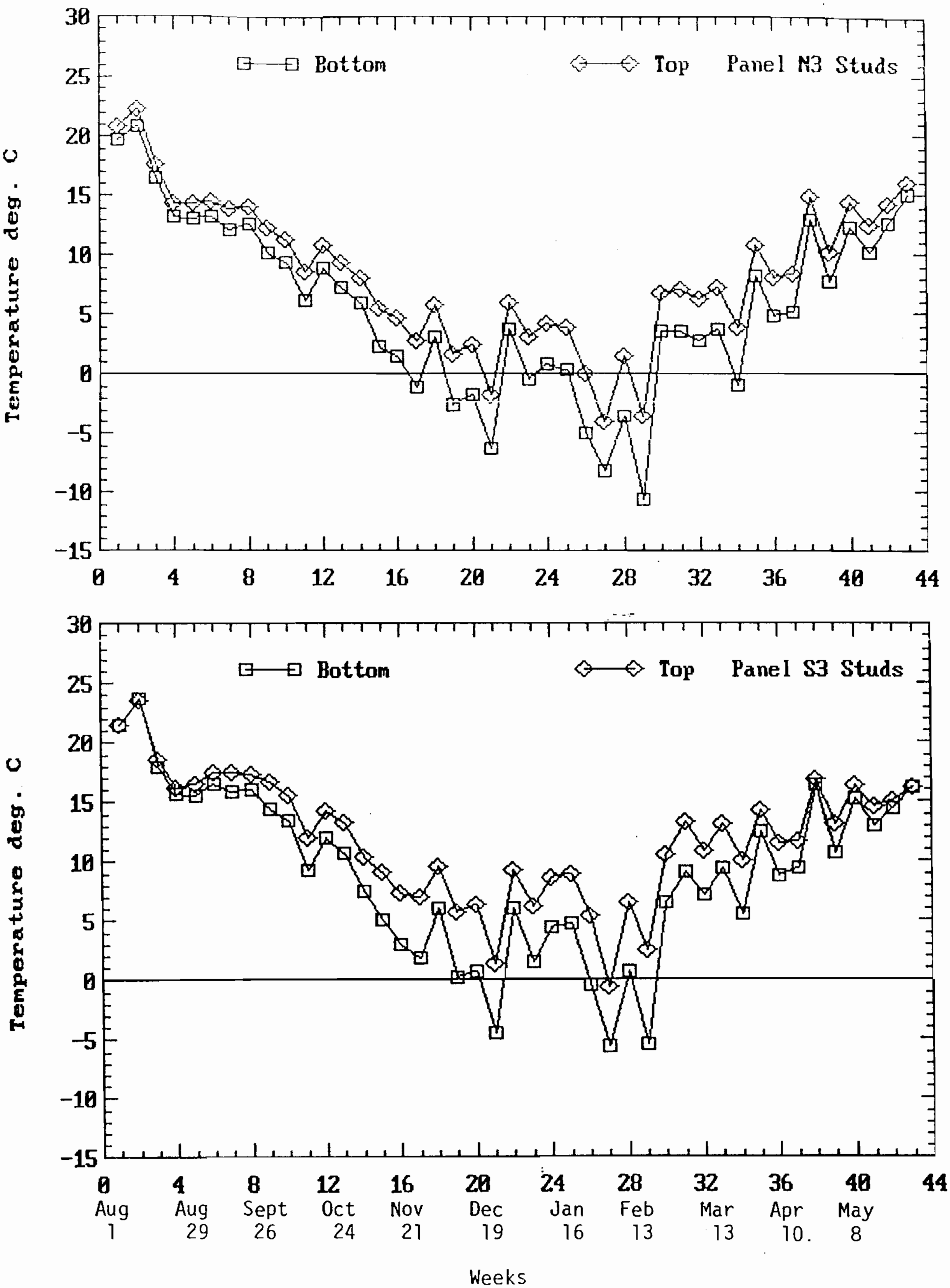


Fig.10c. Weekly averaged stud and sheathing temperatures for panel 3.

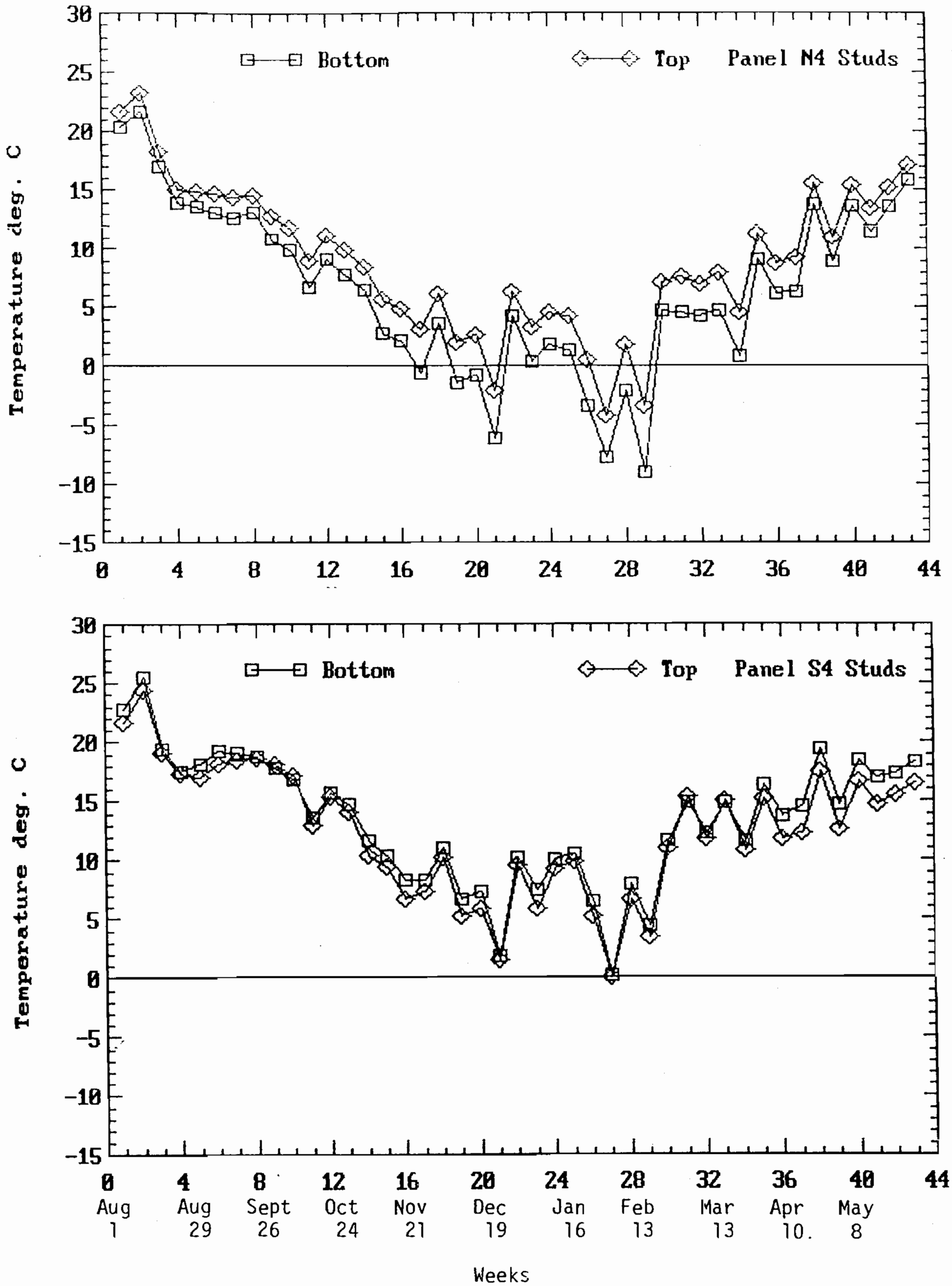


Fig.10d. Weekly averaged stud and sheathing temperatures for panel 4.

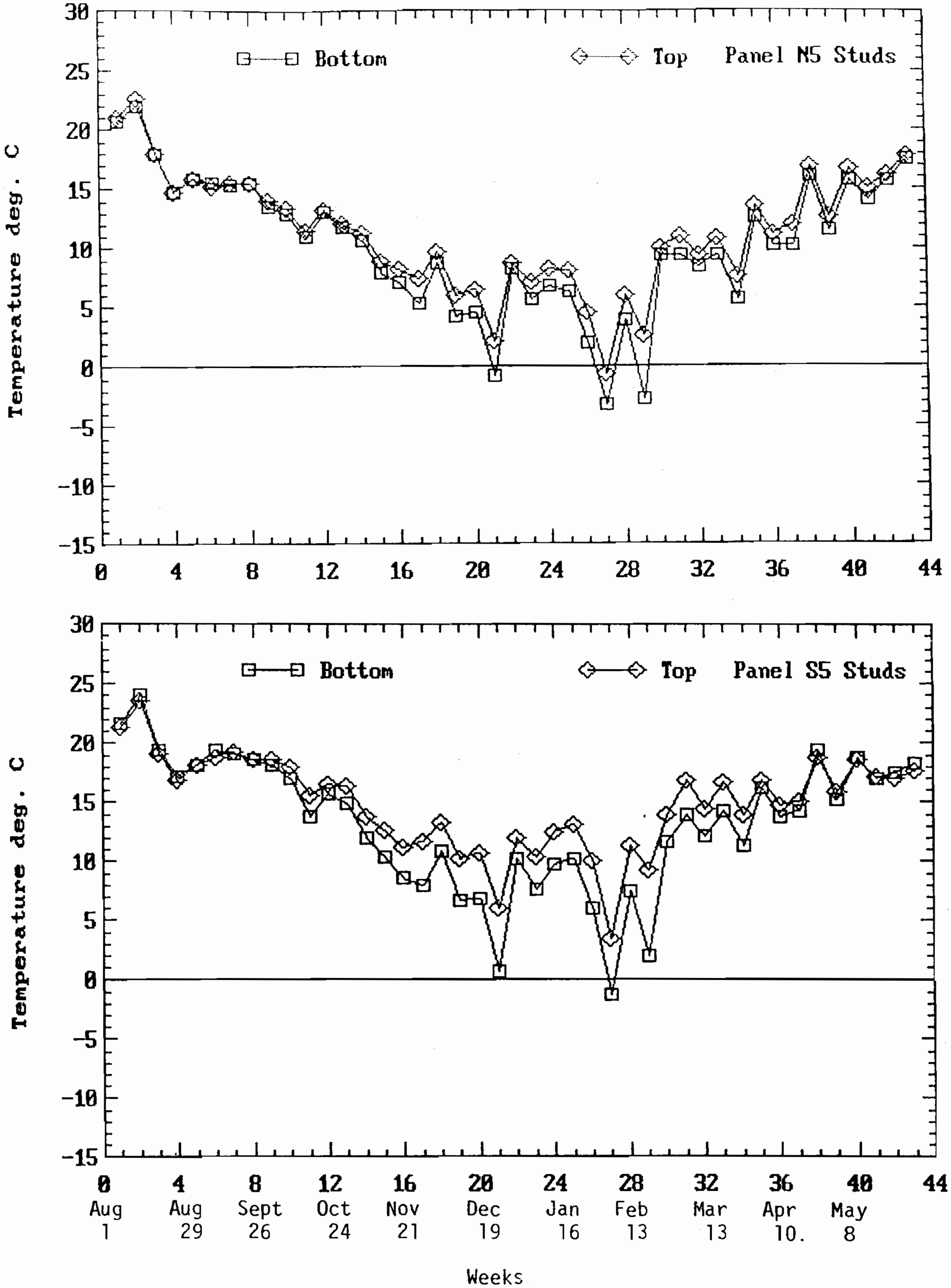


Fig.10e. Weekly averaged stud and sheathing temperatures for panel 5

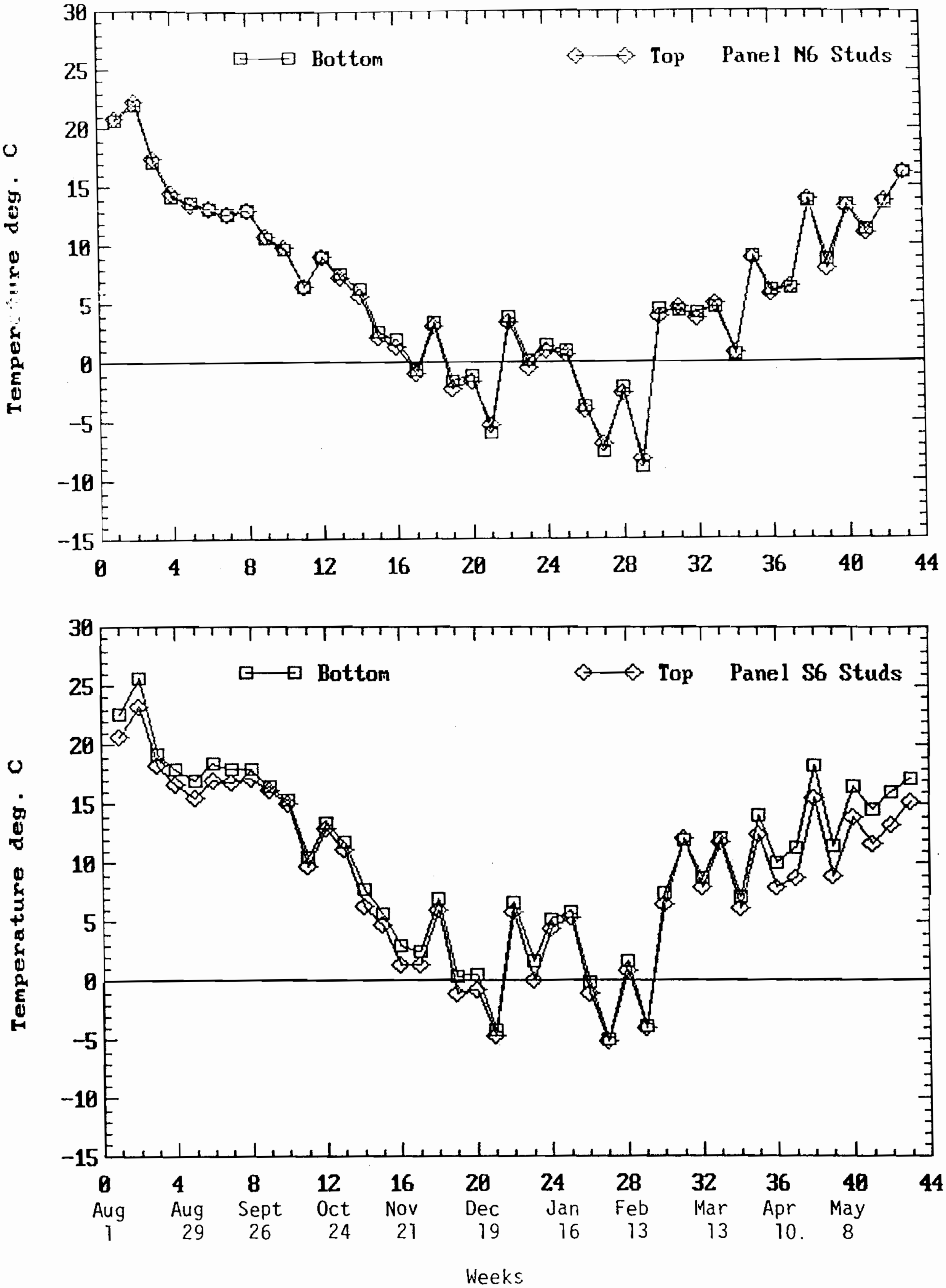


Fig.10f. Weekly averaged stud and sheathing temperatures for panel 6

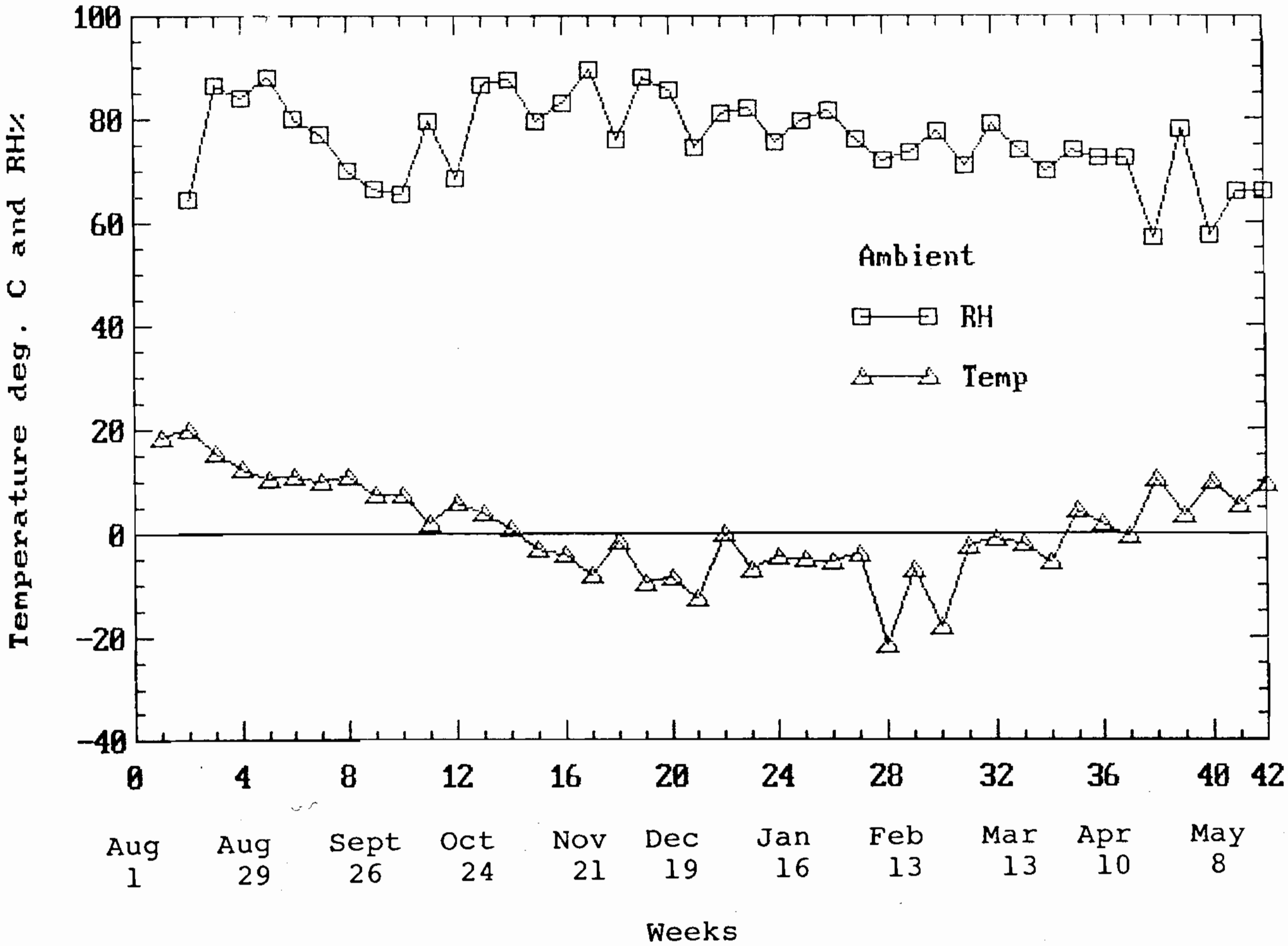


Fig.11. Weekly averaged ambient relative humidity and temperature

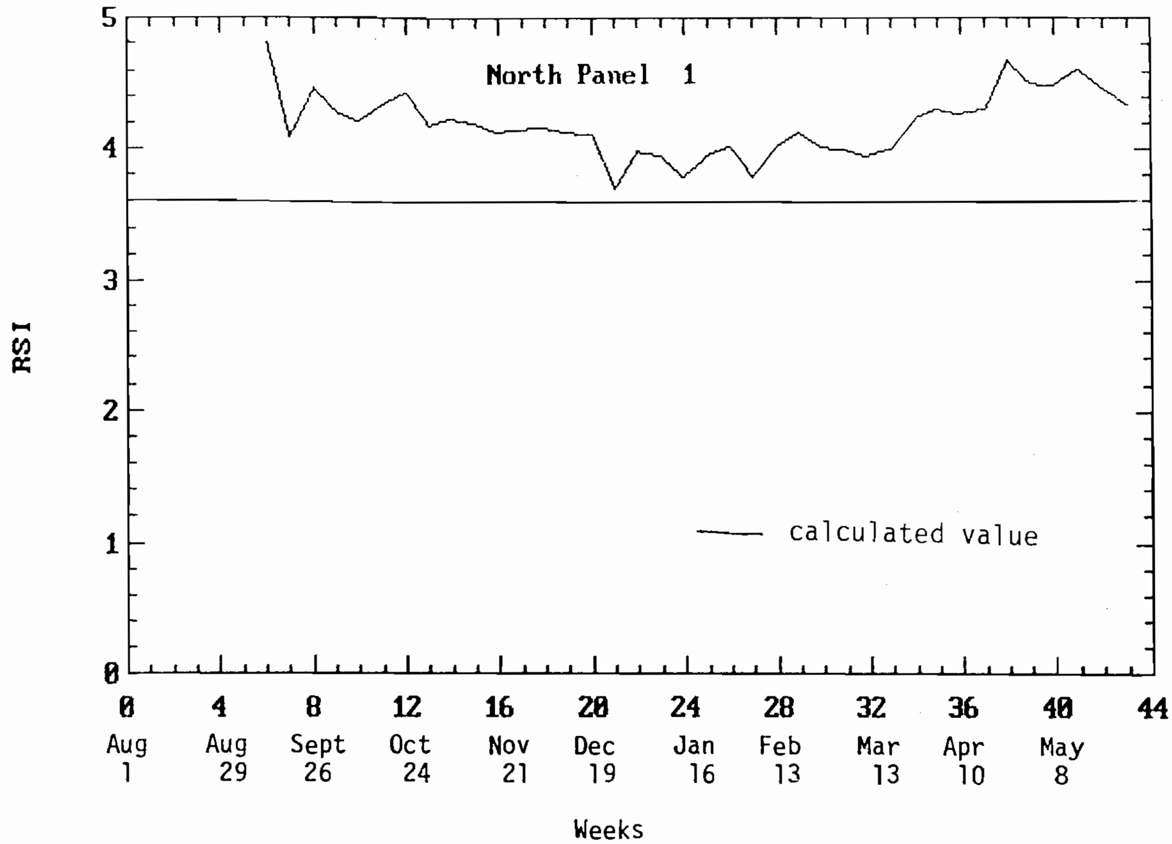


Fig.12a. Effective wall thermal resistance versus time for panel 1

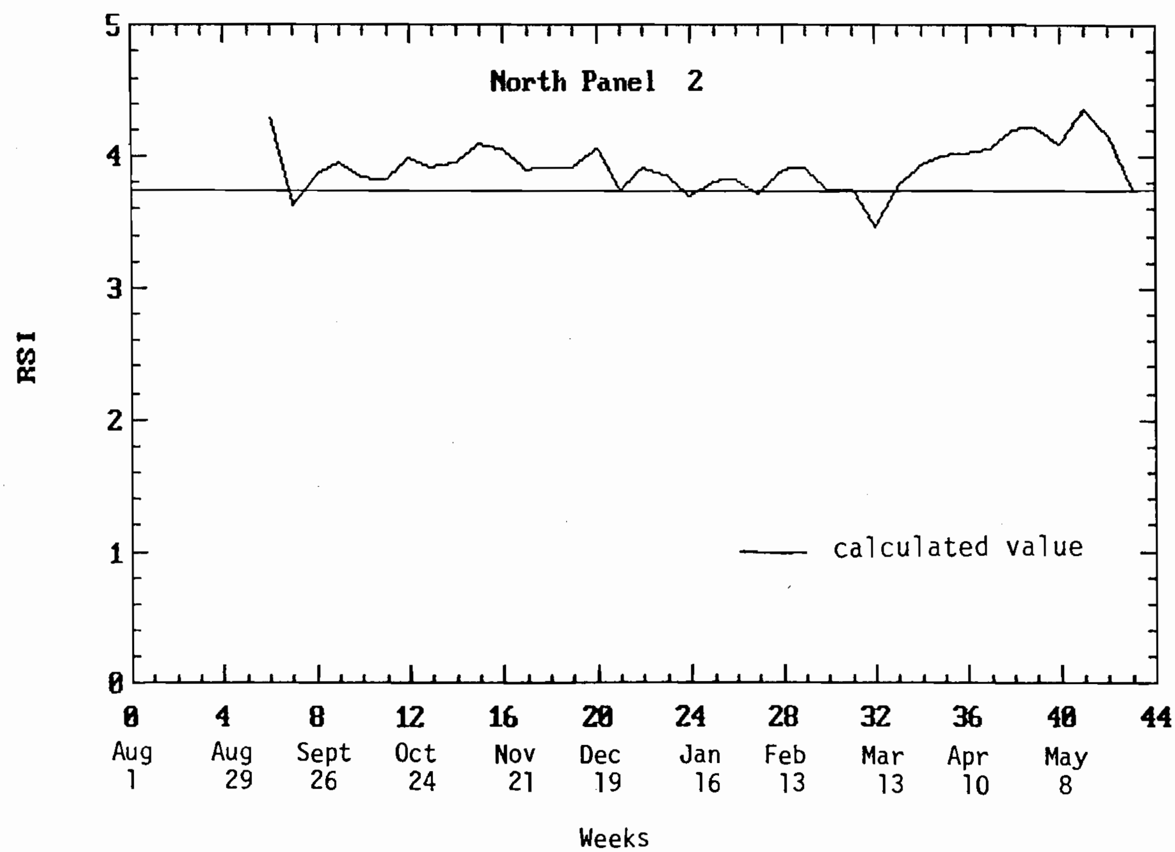


Fig.12b. Effective wall thermal resistance versus time for panel 2

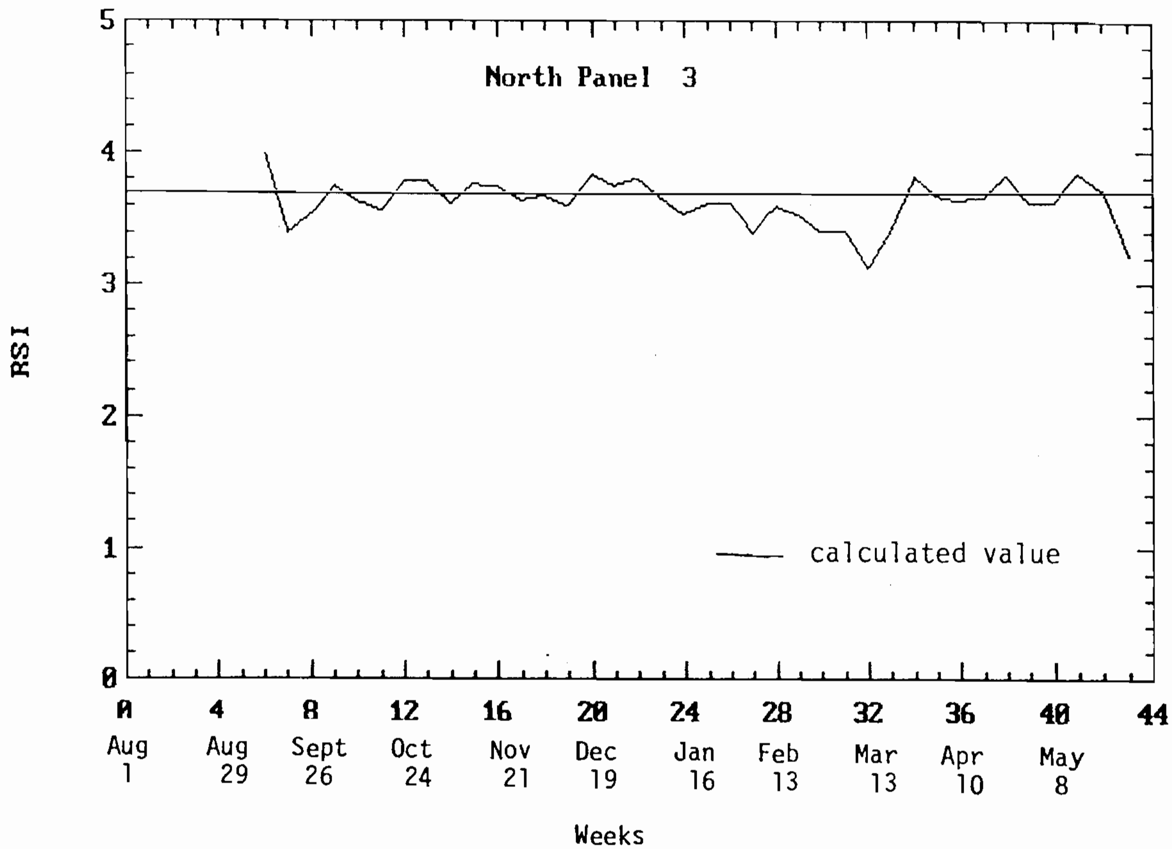


Fig.12c. Effective wall thermal resistance versus time for panel 3

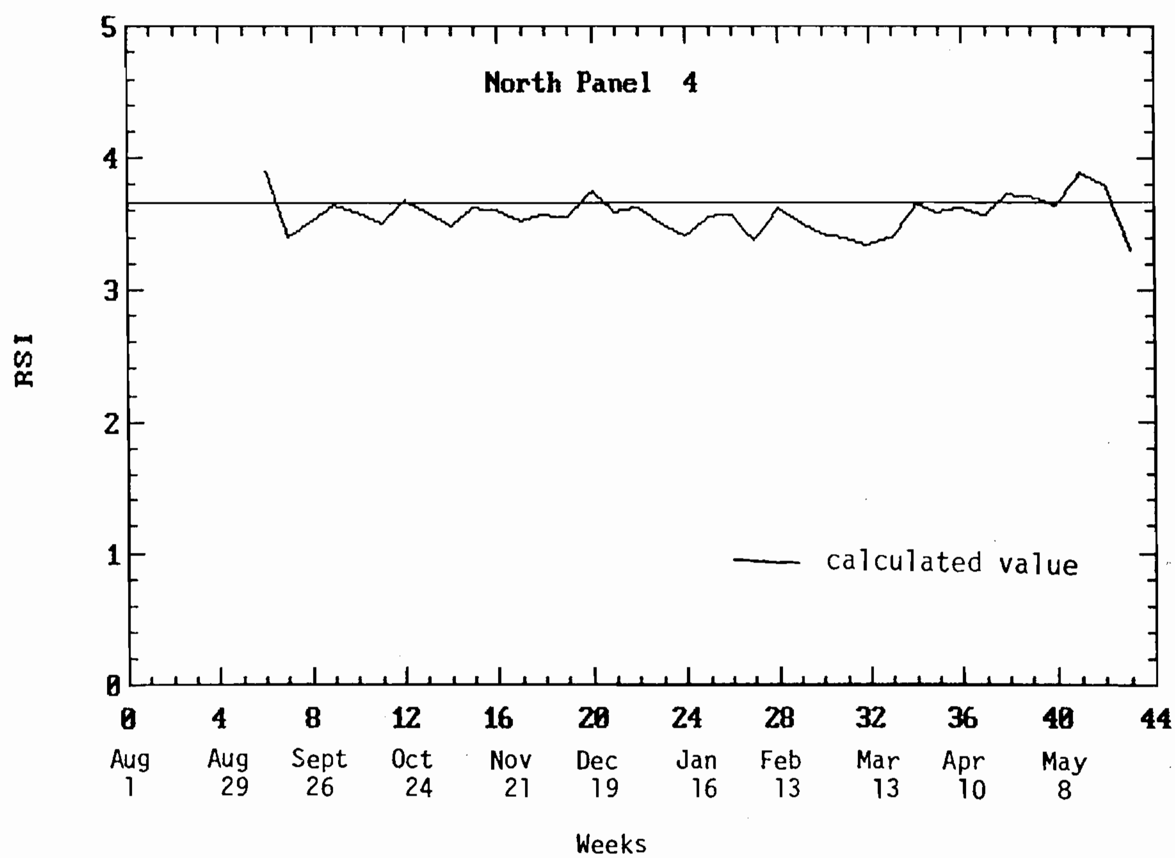


Fig.12d. Effective wall thermal resistance versus time for panel 4

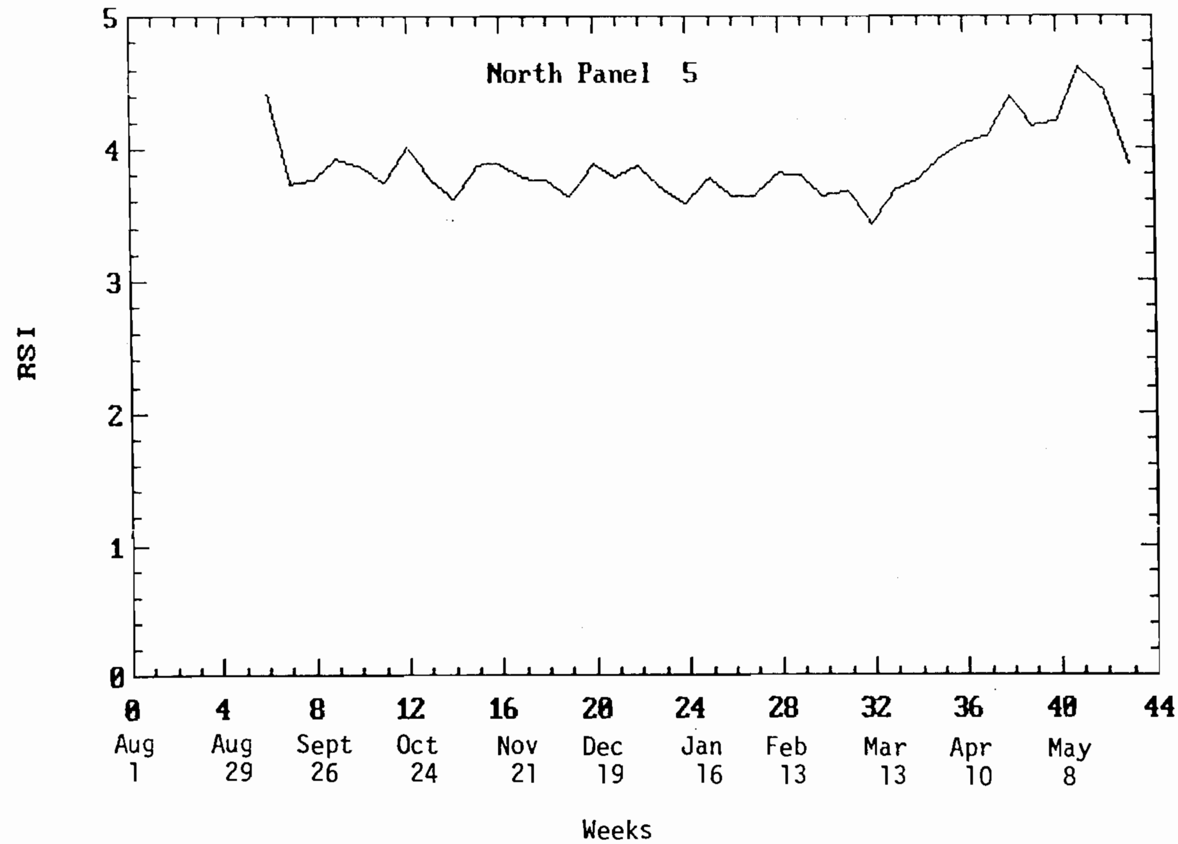


Fig.12e. Effective wall thermal resistance versus time for panel 5

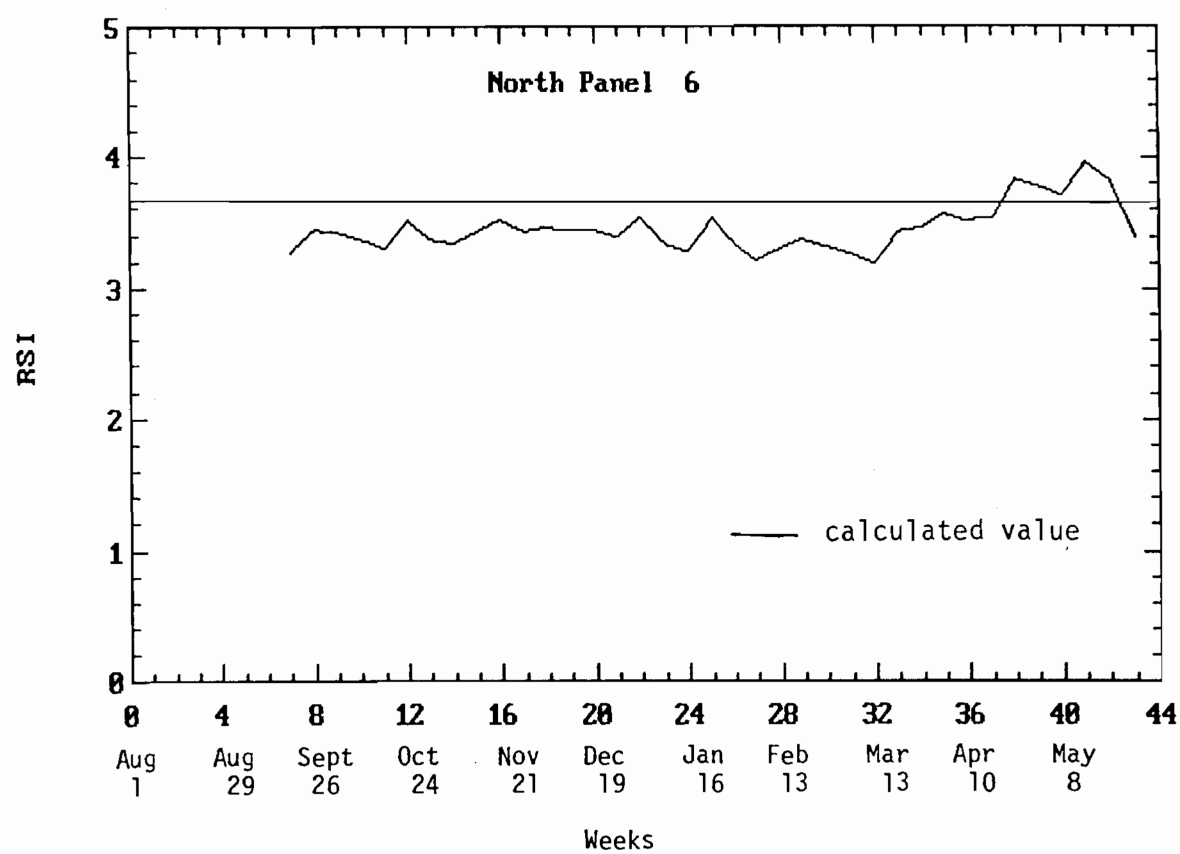
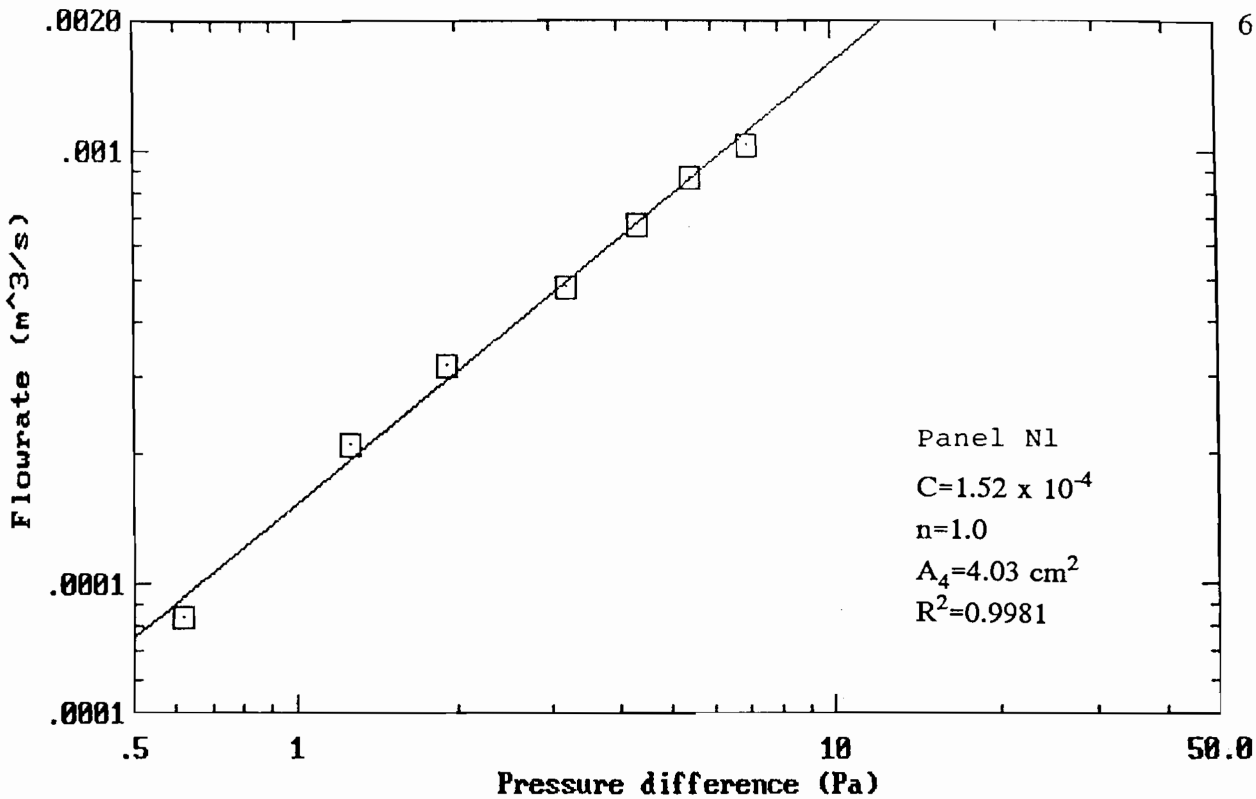


Fig.12f. Effective wall thermal resistance versus time for panel 6.



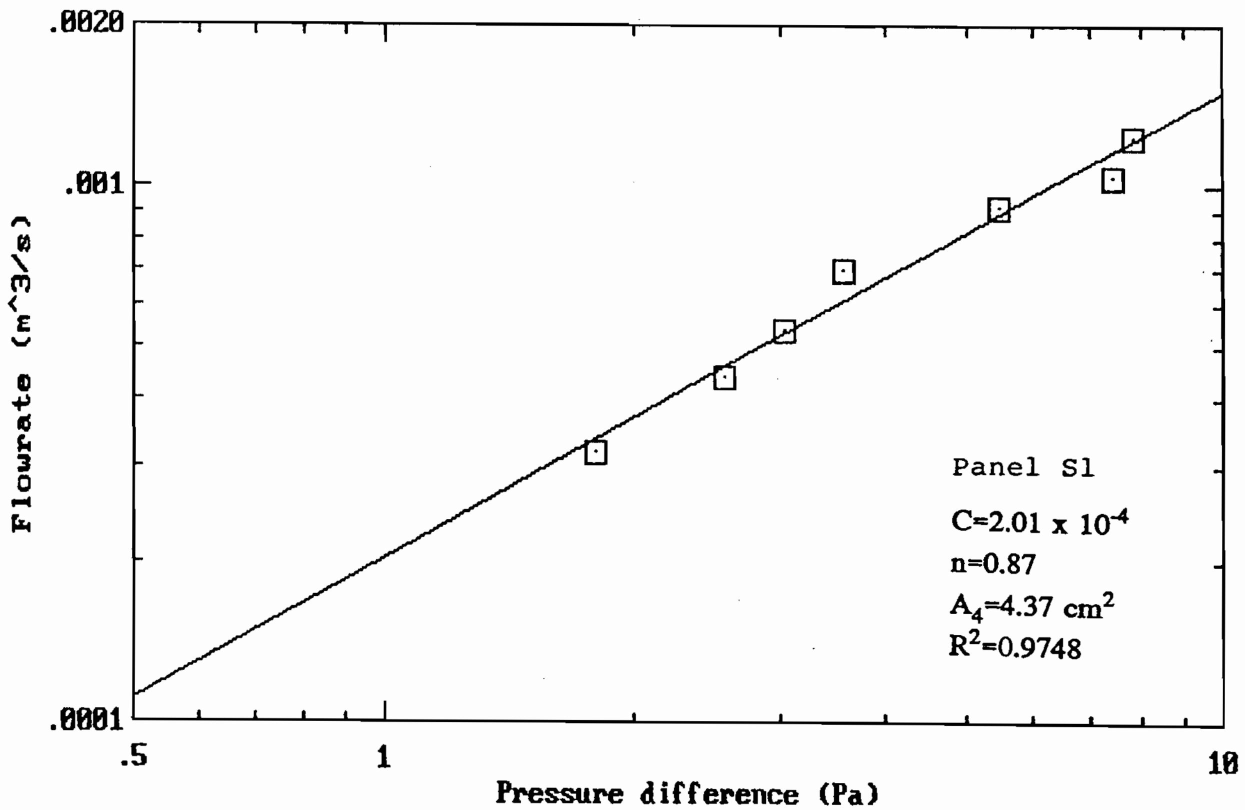
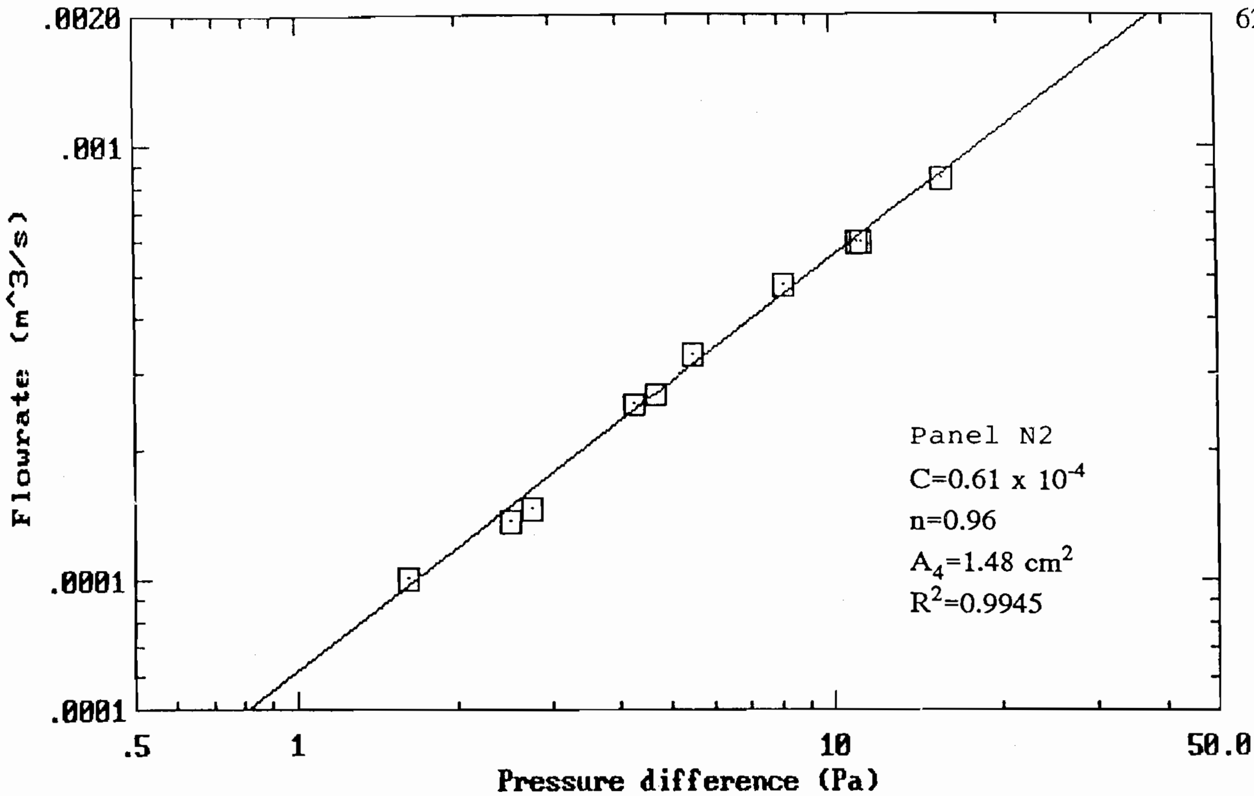


Fig.13a. Air flowrate versus wall cavity-outdoor pressure difference for panel 1



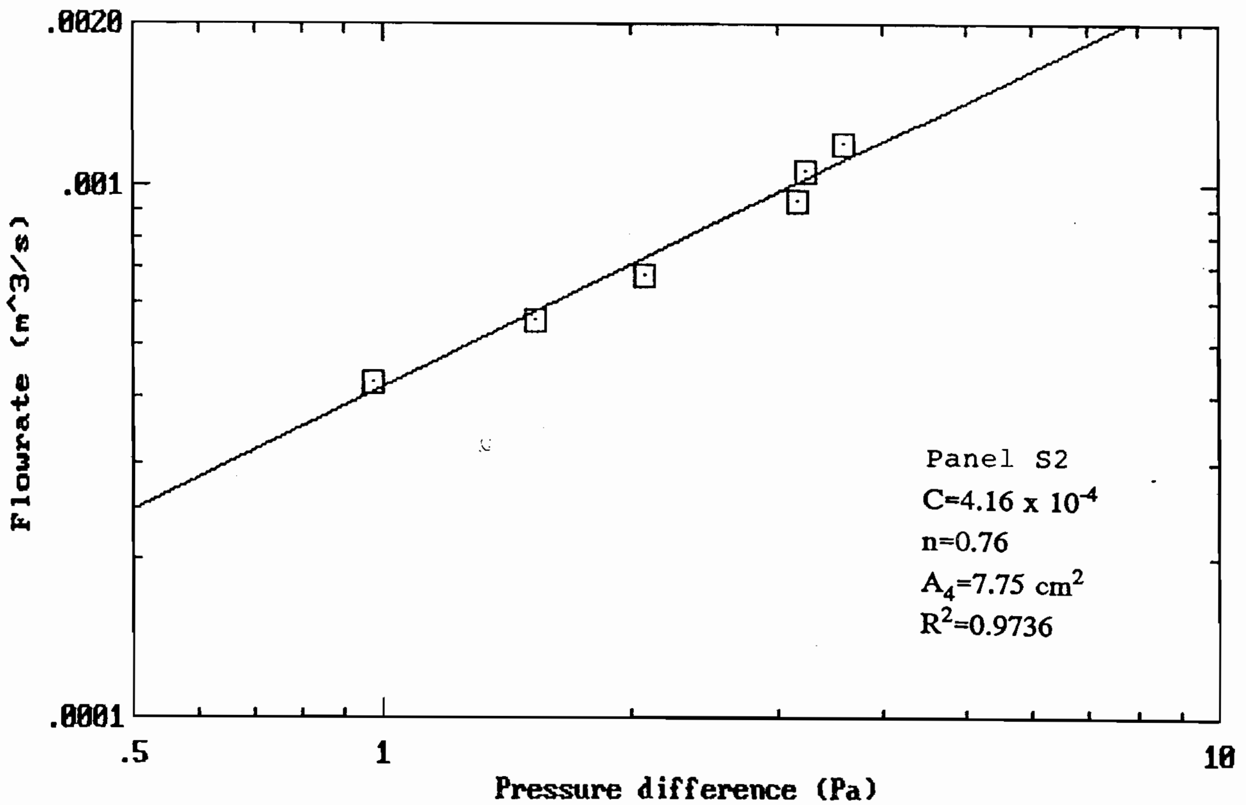
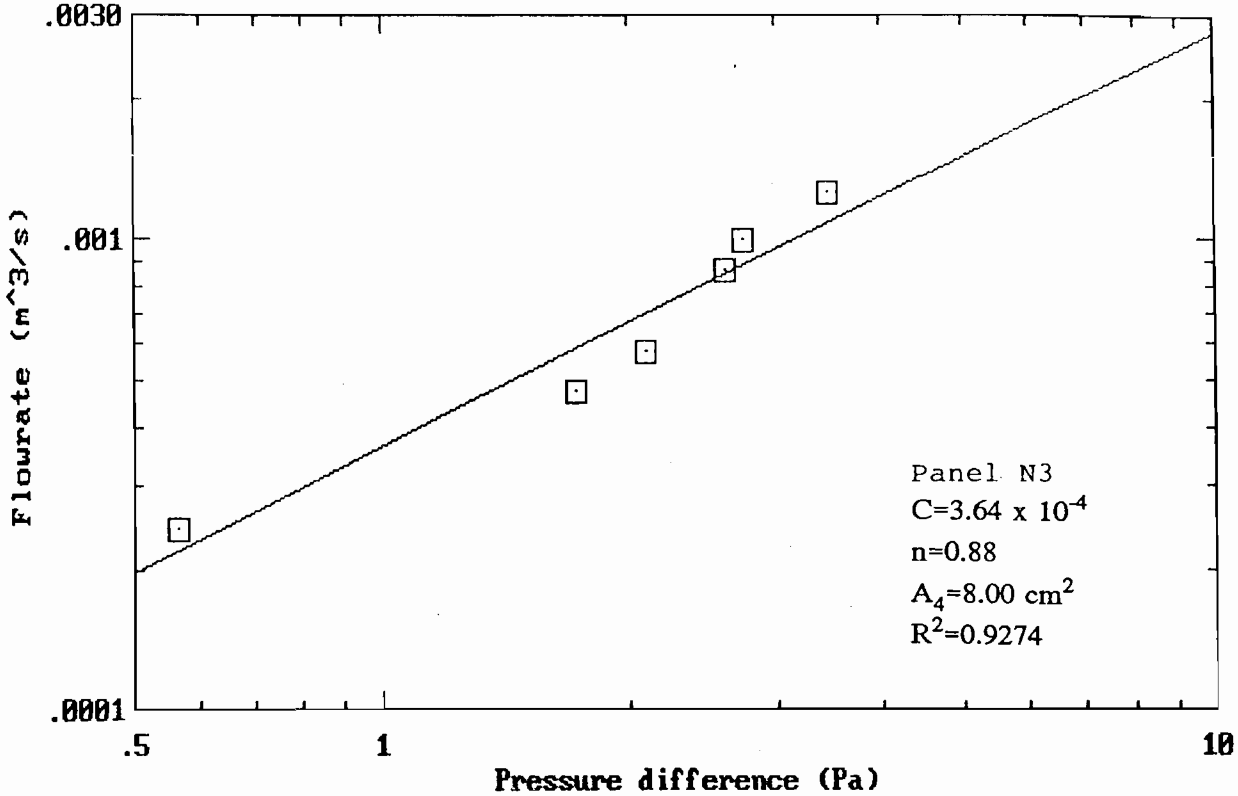


Fig.13b. Air flowrate versus wall cavity-outdoor pressure difference for panel 2



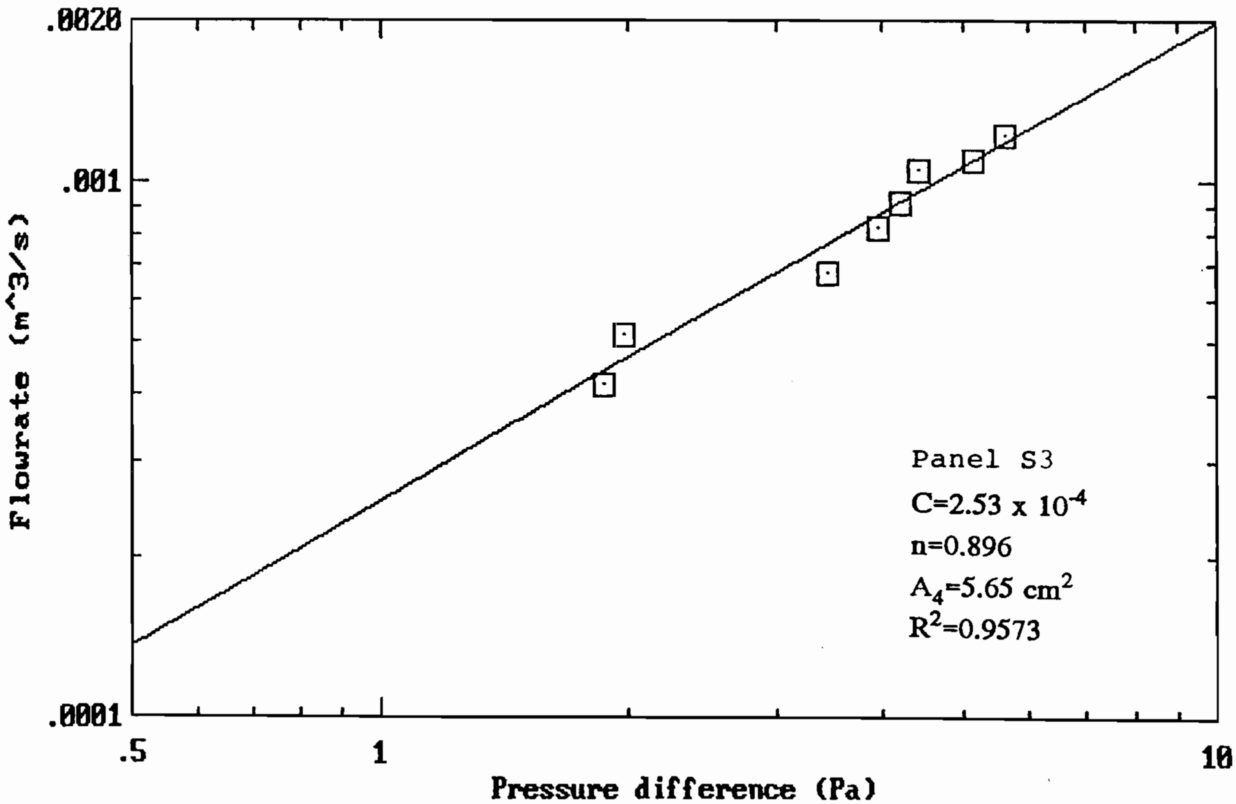


Fig.13c. Air flowrate versus wall cavity-outdoor pressure difference for panel 3

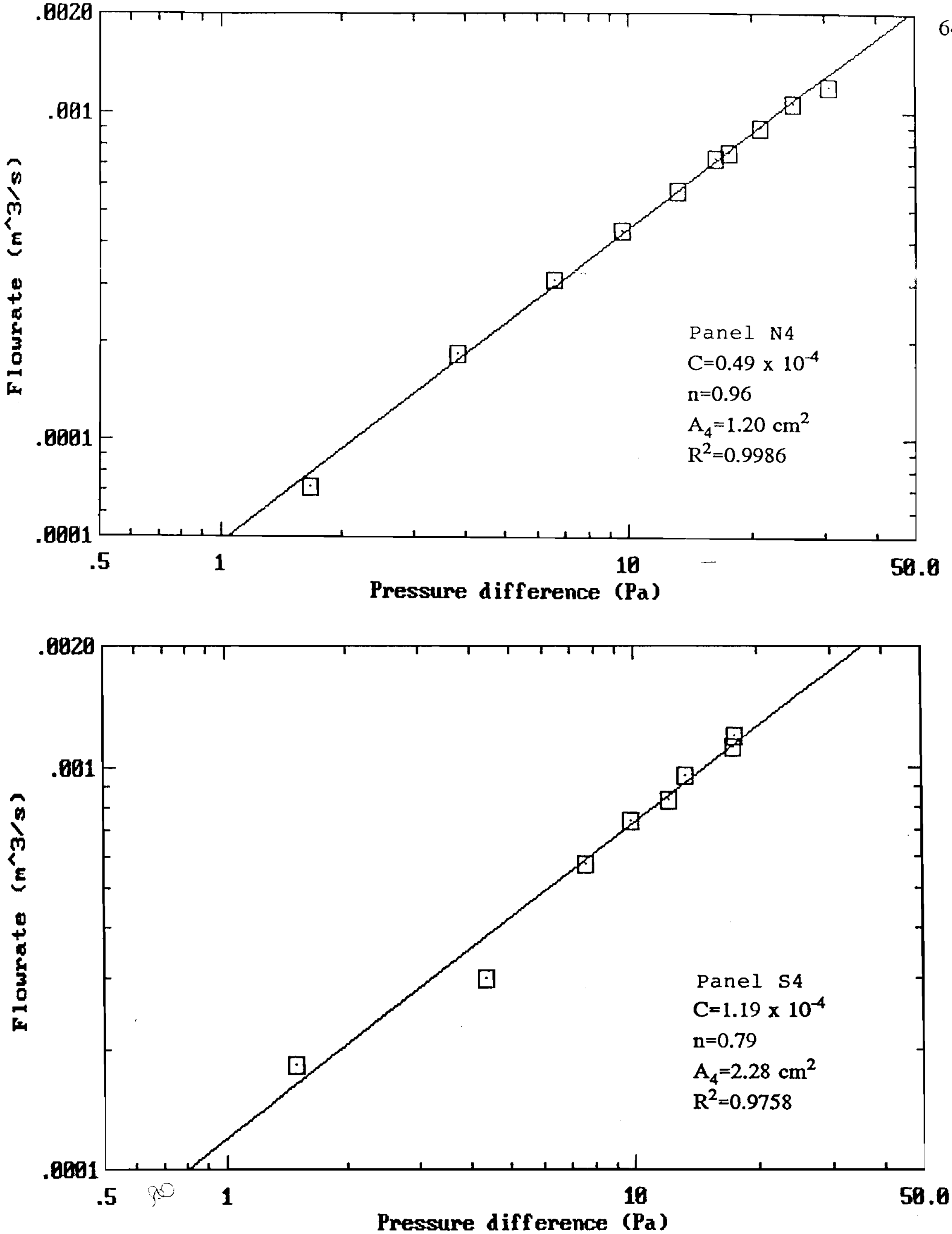


Fig.13d. Air flowrate versus wall cavity-outdoor pressure difference for panel 4

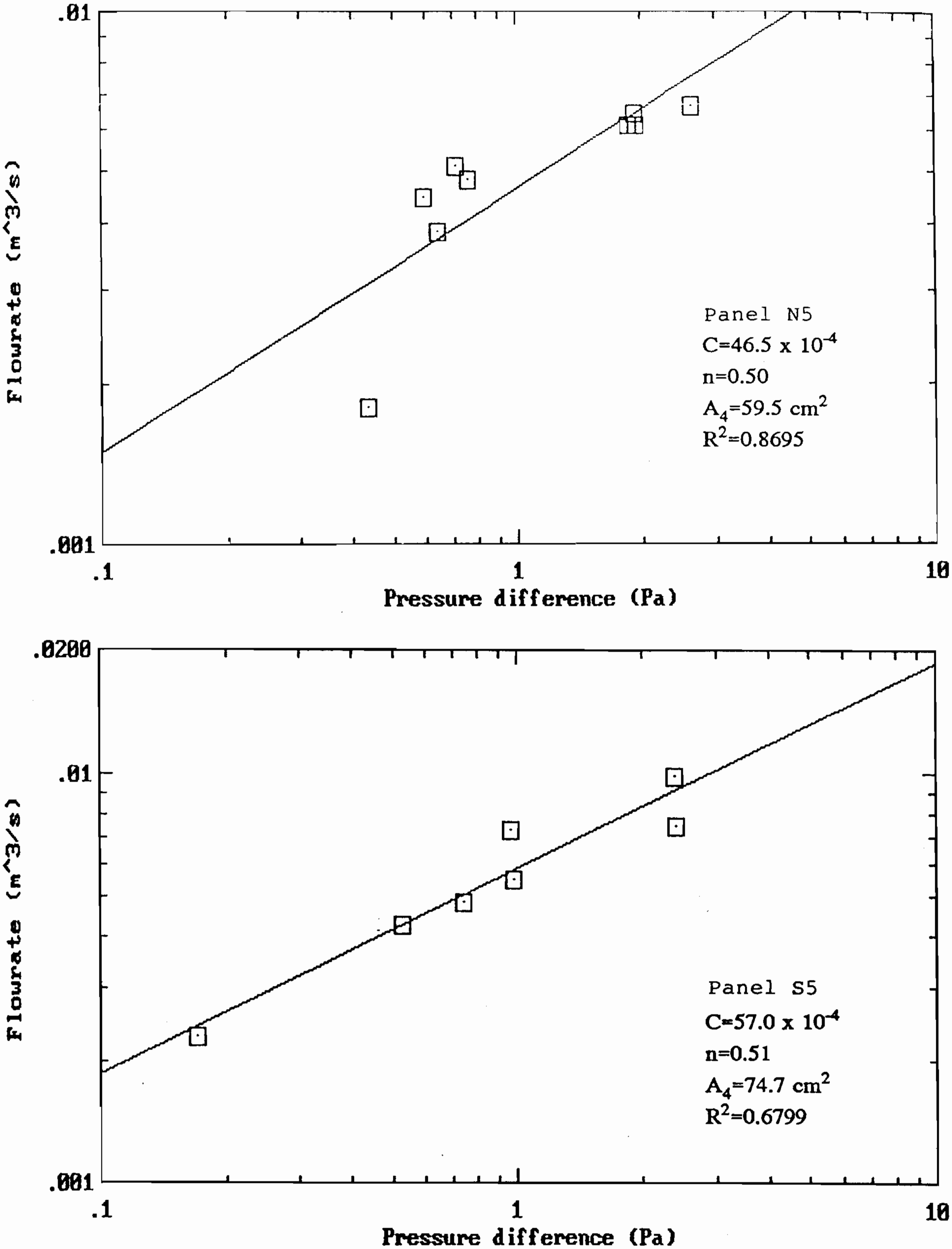
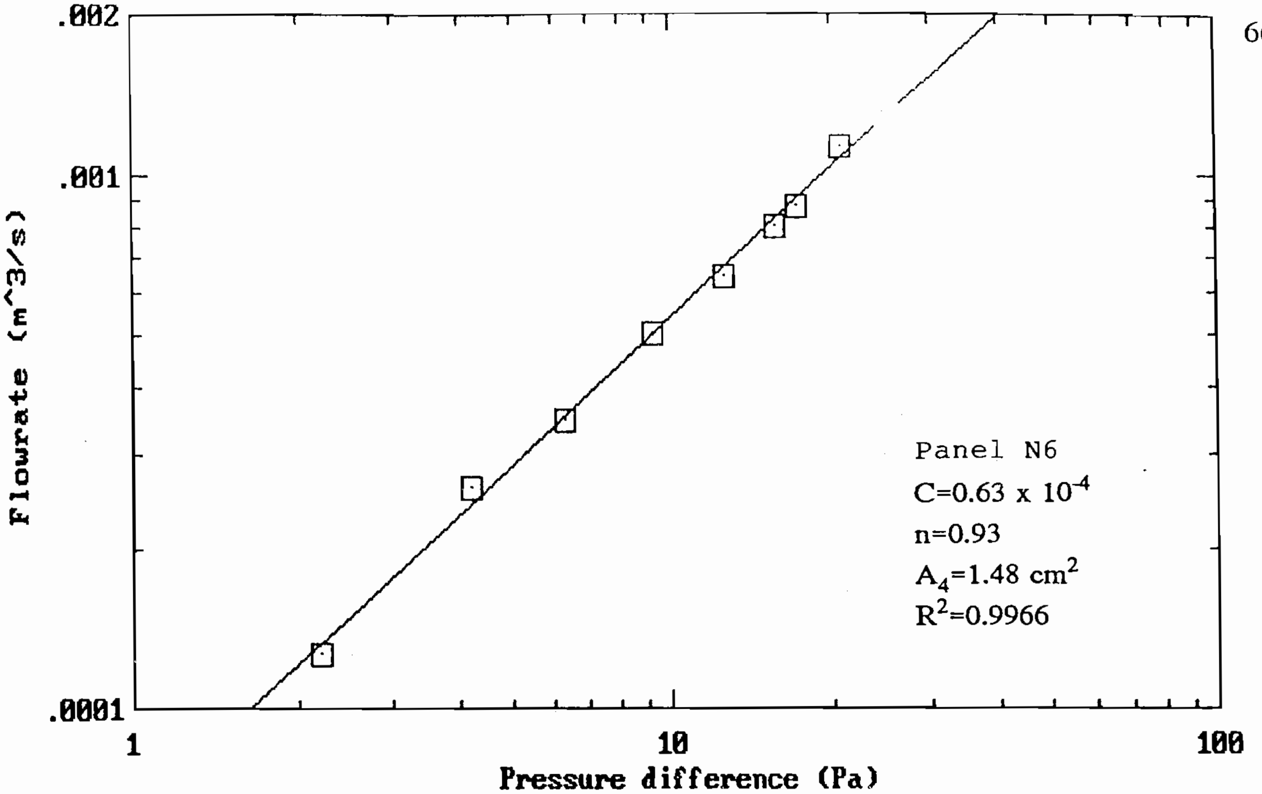


Fig.13e. Air flowrate versus wall cavity-outdoor pressure difference for panel 5



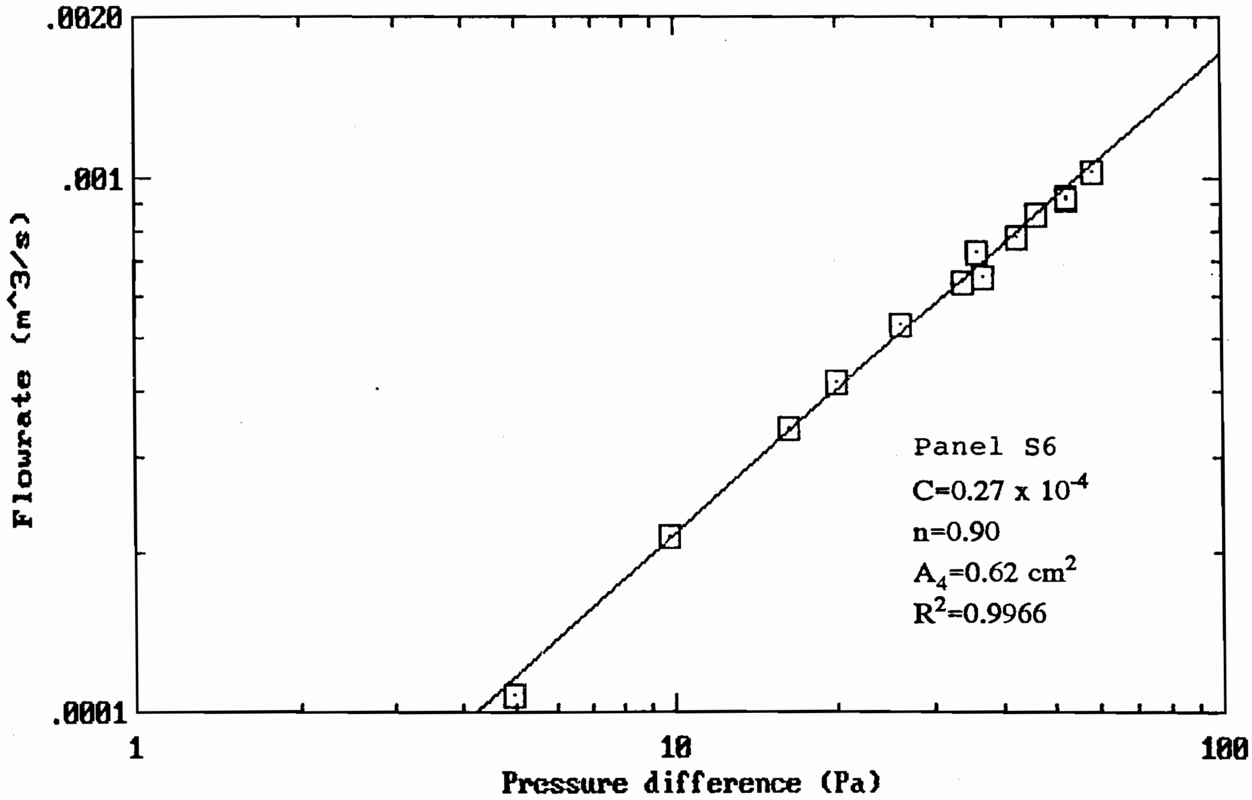


Fig.13f. Air flowrate versus wall cavity-outdoor pressure difference for panel 6

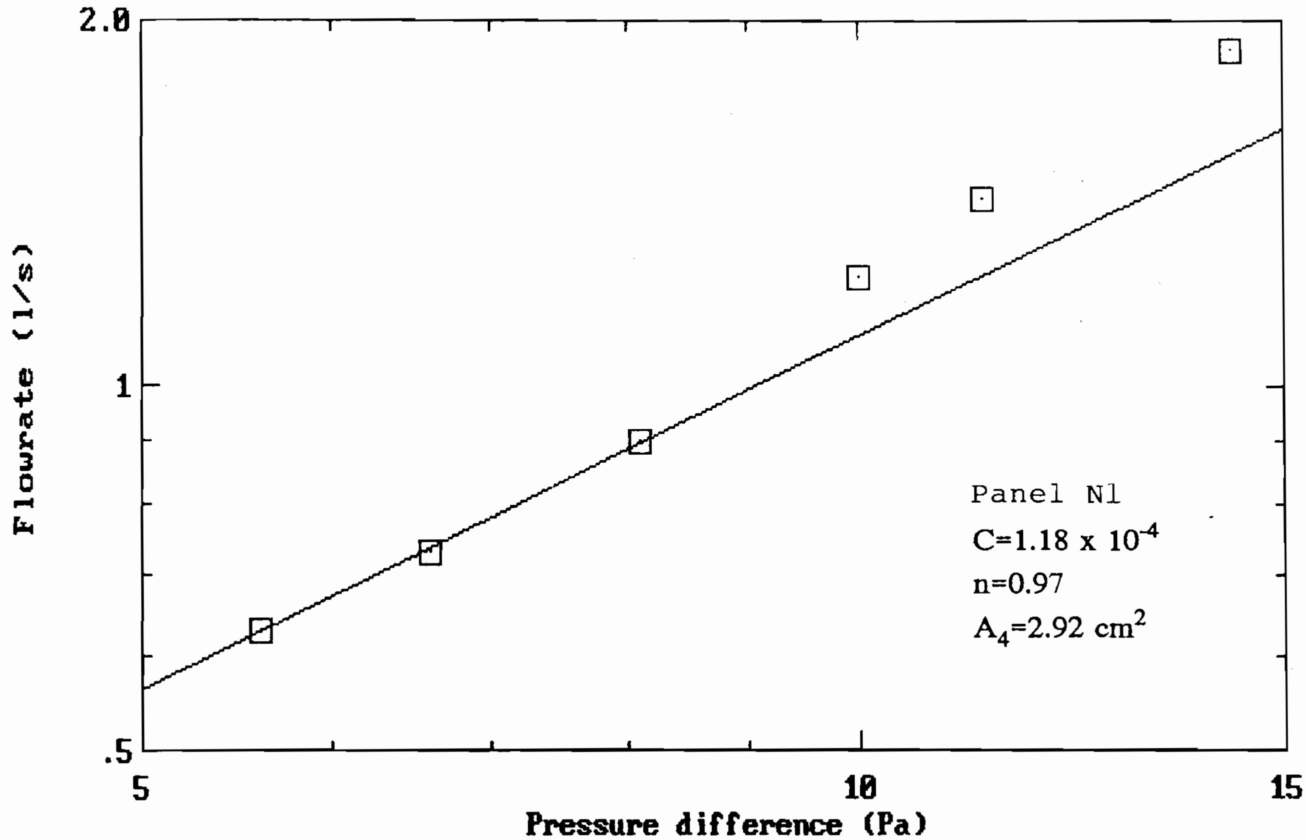


Fig.14. Air flowrate versus wall cavity-outdoor pressure difference for panel N1, when all three cavities are held at the same pressure difference

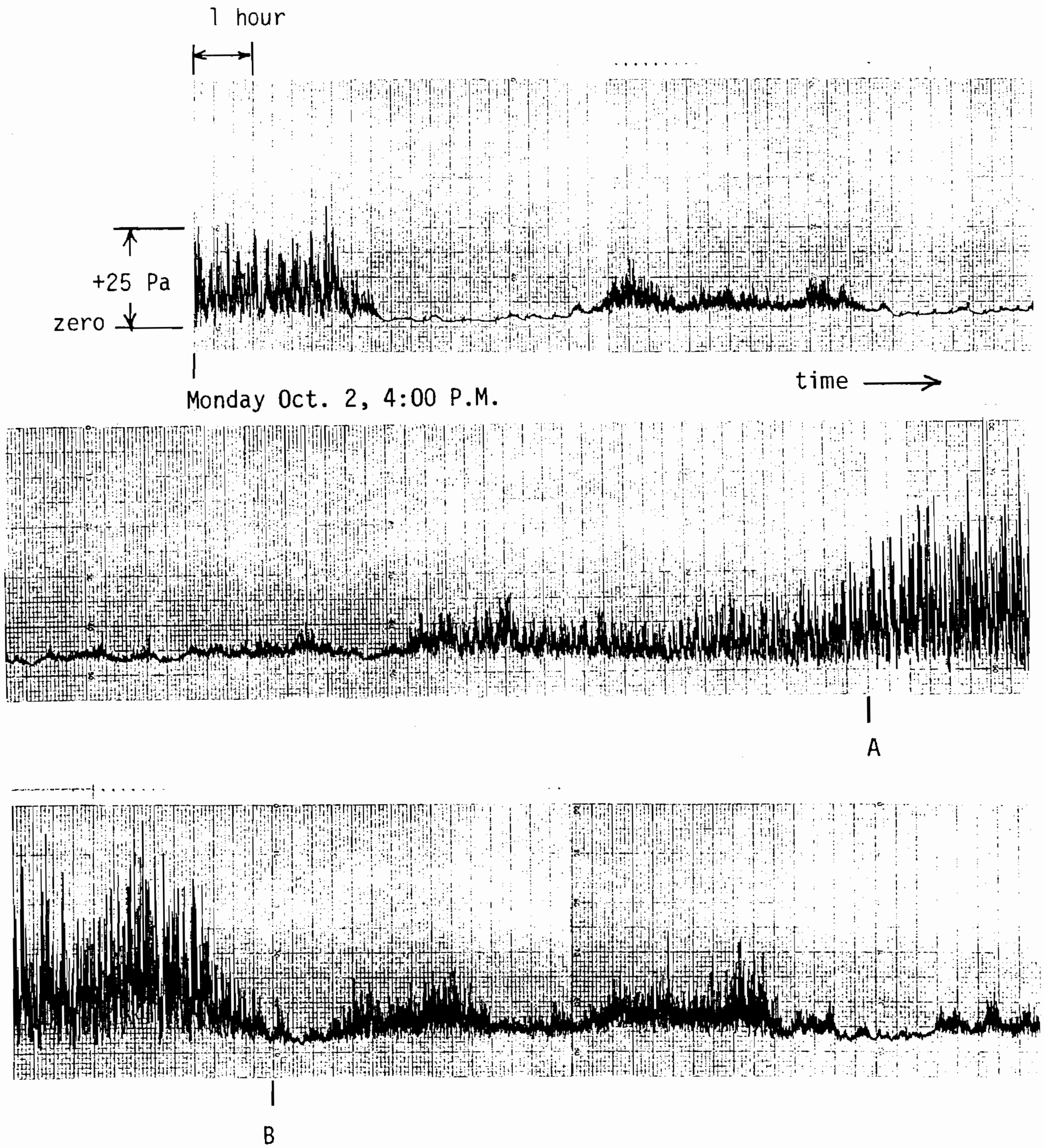


Fig.15. Pressure difference between the wall cavity and indoors in panel S1 versus time between Monday, October 2 and Wednesday, October 4

4.0 DISCUSSION OF RESULTS

4.1 Drying Performance

One of the original objectives of this study was to compare the effect of different exterior sheathings on the drying performance of wet walls. Table 1 summarizes the estimated moisture loss rates from the different wall panels and shows some expected trends. For example, panel 5, with the vented cavity had the highest moisture loss rate of any panels tested. This was followed by panel 1 with the semi-rigid glass fiber insulating sheathing, which is designed to be permeable to moisture. The lowest moisture loss rates occurred from cavities that were well sealed (panels 2 and 3). However, a comparison of panels, based solely on moisture loss rates does not take into account the different cavity-outdoor vapour pressure that existed in the panels. If the dominant moisture transport mechanism is diffusion then the relationship between these two quantities is [6]

$$\dot{m}_w = MA\,\Delta P_v$$

where A is the exterior sheathing area across which moisture is diffusing, M is the permeance, and ΔP_v is the cavity-outdoor vapour pressure difference. From the data presented in Table 1 and vapour pressure differences shown in Figs.9a through 9f, "effective" sheathing permeances were calculated based on a sheathing area of 0.93 m^2 (10 ft^2), which corresponds to one cavity space. In this context, "effective" permeance includes mass transport due to diffusion and convective air motion. Assuming that moisture loss occurs across the entire cavity area, effective permeances can be calculated using the initial moisture loss rates and vapour pressure differences, averaged over the period corresponding to the initial rates, listed in Table 1. The effective permeances are presented in Table 3; panel 6 is not included here since no appreciable drying was observed in this panel. These results show the relative ranking of each magnitude greater than panel 1. Clearly, vents at the top and bottom of the cavity not only provide a low resistance diffusion path, but also allow air to be convected directly into the cavity. This convective motion depends largely on the turbulent fluctuations in the wind. There may also be some natural convection which would draw air into the cavity through the bottom vent and expel it out the top vent although the horizontal battens would tend to restrict this flow. Nonetheless, natural convection would tend to be a directed flow, while wind-driven flows would be highly fluctuating. The combined diffusive and convective moisture flows result in an exterior sheathing assembly that has a large effective permeance. To reinforce this, the permeances of each panel were calculated based on the permeance of the individual components [7,8,9] and are shown in the last column of Table 3. Except for panel 5, calculated permeances assumed that all components were in series; for panels 1, 2, and 3, calculated permeances did not include the vinyl siding. The estimated permeance for panel 5 assumed that moisture diffused along three parallel paths; through the sheathing (same permeance as panel 4), through the top vent, and through the bottom vent. The permeance of the air paths depend on the diffusivity of water vapour in air (which depends on the square root of temperature) and the length of the pathway [10]. The presence of vents approximately doubles the permeance of panel 5 relative to 4. However, the effective permeance for panel 5 is still an order of magnitude larger than the estimated value. The difference can be attributed to convective moisture flow by air motion; thus, convection must be a dominant transport mechanism in panel 5.

Table 3. Effective Exterior Sheathing Permeance of Test Panels

Panel	Initial Rate (gm/day)	Cavity/Outdoor Vapour Pressure Difference (Pa)	Effective Permeance (perms*)	Calculated Permeance** (perms)	Leakage Area A_4 (cm^2)
N1	25	800	390	1723	4.03
N2	9.5	1050	113	45	1.48
N3	9.9	650	189	144	8.00
N4	8.6	550	196	104	1.20
N5	41	250	2020	223	59.5
S1	28	1000	342	same	4.37
S2	4.8	1250	47	as	7.75
S3	3.8	900	53	above	5.65
S4	17	1000	204		2.28
S5	55	200	3435		74.7

*1 perm = 1 nanogram/sec-m^2-Pa
**Does not include vinyl siding

The effective permeance of panel 1 is approximately four times lower than the calculated value. The difference may be due to the vinyl siding that was not included in the calculation. The permeance of vinyl siding is estimated to be on the order of 3 perms [7]; since this is much lower than the compressed fiberglass board, the resistance of the siding would dominate. However, the siding was not completely sealed to the exterior of the wall panel and some leakage paths for diffusion and air flow did exist. This is not the complete answer for the discrepancy because panels 2 and 3 also had vinyl siding and the effective permeances for these panels was larger than the calculated value. More detailed measurements would be required to determine the exact magnitude of the effect of siding on the permeance of the exterior sheathing.

For panels 2 and 3, effective permeances were approximately the same. The rigid foam, insulating sheathing (panel 2) performed no worse than panel 3 with conventional waferboard and building paper. Although the permeance of rigid foam (45 perms for 38 mm thickness) is quite a bit lower than that of waferboard (estimated to be 600 perms for 9.5 mm thickness), the mean cavity vapour pressure difference for panel 2 was 60% larger than in panel 3. The insulating sheathing tends to keep the cavity at higher mean temperatures, which result in higher mean vapour pressures than in cavities with conventional wood based sheathing. The net effect was that moisture loss rates were comparable for the two panels.

A comparison of the effective permeances on the north and south facing panels shows that, for some panels, effective permeance decreases (panels 2 and 3), while for other panels, it increases (panel 5). For panel 5, daytime heating of the exterior sheathing would strengthen natural convection in the air gap and thus, increase the convective moisture flow.

This would tend to increase the effective permeance of a south facing panel. On the other hand, for tightly sealed cavities (panels 2 and 3), solar gain tends to decrease the rate of moisture loss and thus, decrease effective permeance. It has been suggested [11] that, under certain conditions, solar gain tends to cause a reversal of temperature gradients in the cavity, and this would cause a reversal in moisture flow. Moisture would tend to be driven in alternate directions, resulting in a net decrease in the rate of moisture loss from the cavity, if diffusion were the primary mechanism.

4.2 Thermal Performance

Localized measurement of wall heat flux showed that the in situ thermal resistances of the wall assemblies were close to the values that would be predicted by conventional methods. Of course, the studs act as thermal bridges which tend to increase the total heat loss through the wall panel. In panels 3, 4, and 6, for dry studs (10% MC), it is estimated that the percentage increase in heat loss through the wall due to the studs is approximately 18%; for wet studs (30% MC), the increase is 24%. This change with moisture content is related to the increase in thermal conductivity of wood with higher moisture content. For spruce studs, thermal conductivity [12] increases from 0.129 W/m-K at 10% MC to 0.164 at 30% MC. For panels 1 and 2, with insulating sheathing, the increases in total heat loss due to thermal bridging, corresponding to the dry and wet studs is only 10% and 11%, respectively. The other observation made was that cavity thermal resistances remained relatively constant throughout the test period. The effects of any initial redistribution of moisture within the wall cavity (increase in sheathing moisture content) were minimal on thermal resistance. From these estimates and measurements for the test panels, initial in-place moisture had a negligible effect on the thermal performance of the wall panels.

4.3 Panel 5

Panel 5 had a unique design, with vents at the top and bottom of the cavity and a small air gap between the sheathing and the insulation. These vent openings allowed the cavity interior to communicate directly with the outside air. Of the panels tested, this panel had the highest moisture loss rate and an order of magnitude higher permeance than any other panel. It is suggested that a combination of directed air motion (natural convection) and fluctuating air motion (turbulence in the wind) enhanced the moisture loss rates over that of the other panels. On the north panel, there was some evidence of re-wetting in the exterior sheathing because of the high effective permeance (see Fig.9e); however, any short term re-wetting trend was followed by faiirly rapid drying. It would seem that this wall panel has the capacity to quickly release any initial, in-place moisture and to be able to quickly respond to changing outdoor conditions. If outdoor conditions tend to force moisture into the cavity, this will happen quickly, while drying will also occur rapidly when outdoor conditions are favourable. In the prairie climate in which this panel was tested it is anticipated that no significant re-wetting would occur over the course of a winter period since outdoor humidity ratios are generally quite low. It is difficult to say whether this panel would perform equally well in a maritime climate where winter and spring outdoor humidity ratios are quite high for prolonged periods of time.

The other main concern with cavity venting is the possible degradation in thermal performance caused by the convective air motion. Effective cavity thermal resistances for panel 5 were slightly higher than that of panel 4, which was identical to 5 except for the vented air gap. On average, the air gap seemed to have a slight positive effect by adding to the thermal resistance of the wall, although the difference in thermal resistances between the two panels may very well be due to construction variability. Although no heat flux measurements were taken directly opposite the vents, stud temperatures near the top and bottom of the cavity were, in fact, slightly warmer than the corresponding temperatures in panel 4. Had there been a significant increase in heat loss near the vents, these temperatures would have been, on average, colder than in panel 4. Thus, the thermal performance of panel 5 was probably not that much worse than panel 4, although more detailed measurements of heat flux distribution would have to be carried out to verify if the total heat loss through panel 5 is comparable to that of panel 4.

There is one word of caution about using cavity vents. Should there be any small leakage path between the wall cavity and interior of the house, significant amounts of moisture may accumulate in the wall cavity, from exfiltrating indoor air with a high humidity ratio. In this case, cavity vents are detrimental to the performance of the wall because they reduce the total resistance to air flow through the panel. This can be seen in Table 2 where the leakage area for panel 5 was an order of magnitude higher than in any other panel. Use of cavity vents would require that the interior surface of the wall be carefully sealed so that no leaks would develop as the house aged. Whether this is practical would depend on the builder, the skill and dedication of the trades, and probably, economic considerations.

5.0 CONCLUSIONS

Field tests were carried out to determine the drying performance of different exterior wall assemblies in a prairie climate. Three of the six panels tested were similar in construction (although not identical) to panels tested in Atlantic Canada; the remaining three were assemblies that are typical of construction in western Canada. The principal conclusions regarding moisture drying performance were:

i) effective permeances of exterior assemblies estimated from measured drying rates and averaged cavity/outdoor vapour pressure differences, were close to the values calculated by standard methods for panels 2, 3, and 4 (not including the vinyl siding). Since these three panels had relatively small leakage areas, drying rates were mainly dictated by diffusion from the cavity to outdoors. Thus, the drying rates for these panels were close to that which one would expect based on the permeance of the exterior sheathing components.

ii) panel 1, with the rigid fiberglass sheathing had a lower than expected effective permeance even though the drying rates were much higher than in panels 2, 3, and 4.

iii) venting of a small air gap between the sheathing and insulation increases the drying rates substantially, compared to unvented cavities, resulting in effective permeance that is an order of magnitude higher than the calculated value. Moisture transport is dominated by natural (solar heating of exterior sheathing) and forced convection through the cavity.

iv) for wall assemblies with no interior wall leakage sites in a prairie climate, there was little or no evidence of any wetting by condensation on exterior sheathing components, based on results from panel 6. Moisture drying rates remained positive throughout the test period and were unaffected by a decrease in outdoor temperature.

v) None of the sheathing assemblies tested experienced any major problems with prolonged periods of high moisture content or a failure to remove initial, in-place moisture.

Associated with the question of drying, was the thermal performance of the wall panels during this period. The main conclusions were:

vi) effective thermal resistance through the cavity insulation was approximately equal to calculated values for all test panels. There was no degradation in thermal resistance of cavity insulation due to moisture.

vii) on average, the vented cavity (panel 5) had a slightly higher cavity thermal resistance than panel 4. Convective air motion seemed to have a small positive effect on thermal resistance. Any convective cooling due to forced air movement through the vents seem to be confined to the area near the vents, although no direct measurements were made of this effect.

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[12] Wood Engineering Handbook, op. cit., pg. 3-19.

APPENDIX A

INSTRUMENTATION REPORT FOR MOISTURE TEST HUT

Introduction

The information contained in this report describes:

i) the layout and details of the test hut,

ii) the instrumentation that will be used to collect the meteorological data and the wall panel data,

iii) the data acquisition system, including associated hardware and the monitoring methodology, and

iv) the pre-test measurements on the wall panels

The main section on instrumentation is sub-divided into sensor descriptions and specifications, calibration, and placement of sensors. In addition, arguements are presented to justify not taking some of the data that was collected in the Atlantic Canada study.

Test Hut

The purpose of the test hut is to provide a stable, interior thermal and moisture boundary condition for each of the wall panels. It was decided, therefore, to simplify the construction of the test hut as much as possible. To this end, the hut sits on a welded steel sub-frame and is built according to standard frame construction practices. The floor is made from 2 x 6's and is insulated with fibreglass. The support walls are 2 x 4 construction with interior 1/2" drywall, 6 mil polyethylene vapour retarder, fibreglass insulation, exterior plywood sheathing and siding. The ceiling has drywall, vapour retarder and fibreglass insulation. The roof has a shallow slope with gable ends and has roof ventilators as per code requirements. The entire test hut measures 8' wide and 40' long and has an interior height of 8'. Openings for the wall test panels have been left on both lengthwise walls and a total of eight 4' x 8' test panels can be accommodated on each side. At this point in time, the total number of wall test panels has not been finalized. Figure 1 shows details and dimensions of the test hut.

The test hut will be heated with a small propane, forced air furnace which will be located at one end of the hut. An exhaust stack will be installed as required by the building code for this size of furnace. The heated air will be distributed through-out the test hut by a ceiling-mounted air duct with several take-off points. A drum-type humidifier will be mounted on the furnace to maintain a uniform humidity inside the test hut. Electrical service is available at the test site.

The test hut is located at the Alberta Home Heating Research Facility (AHHRF) at Ellerslie, just south of Edmonton. The site is adjacent to the existing test houses and provides an unobstructed exposure to wind and solar radiation. The hut is oriented in an east-west direction next to House six at AHHRF. Figure 2 through 5 provide some details of the test hut.

Instrumentation

The meteorological data includes wind speed, wind direction, ambient temperature, and ambient relative humidity. The wind speed and wind direction are currently being monitored with a Windflo 540 cup anemometer and vane (Athabasca Research Corporation Ltd.) The anemometer is located 10 m above ground on a tower, 30 m north of the east-west row of test houses. The instrument has been in operation over the past ten years and has provided trouble free operation. Specifications of the anemometer are provided on page 2 of Appendix A. The ambient temperature and relative humidity will be measured with a type T thermocouple and a resistance measuring RH sensor (details of this sensor are given below.) These two sensors will be placed side-by-side in a weather-shielded enclosure located halfway along the north wall of the test hut.

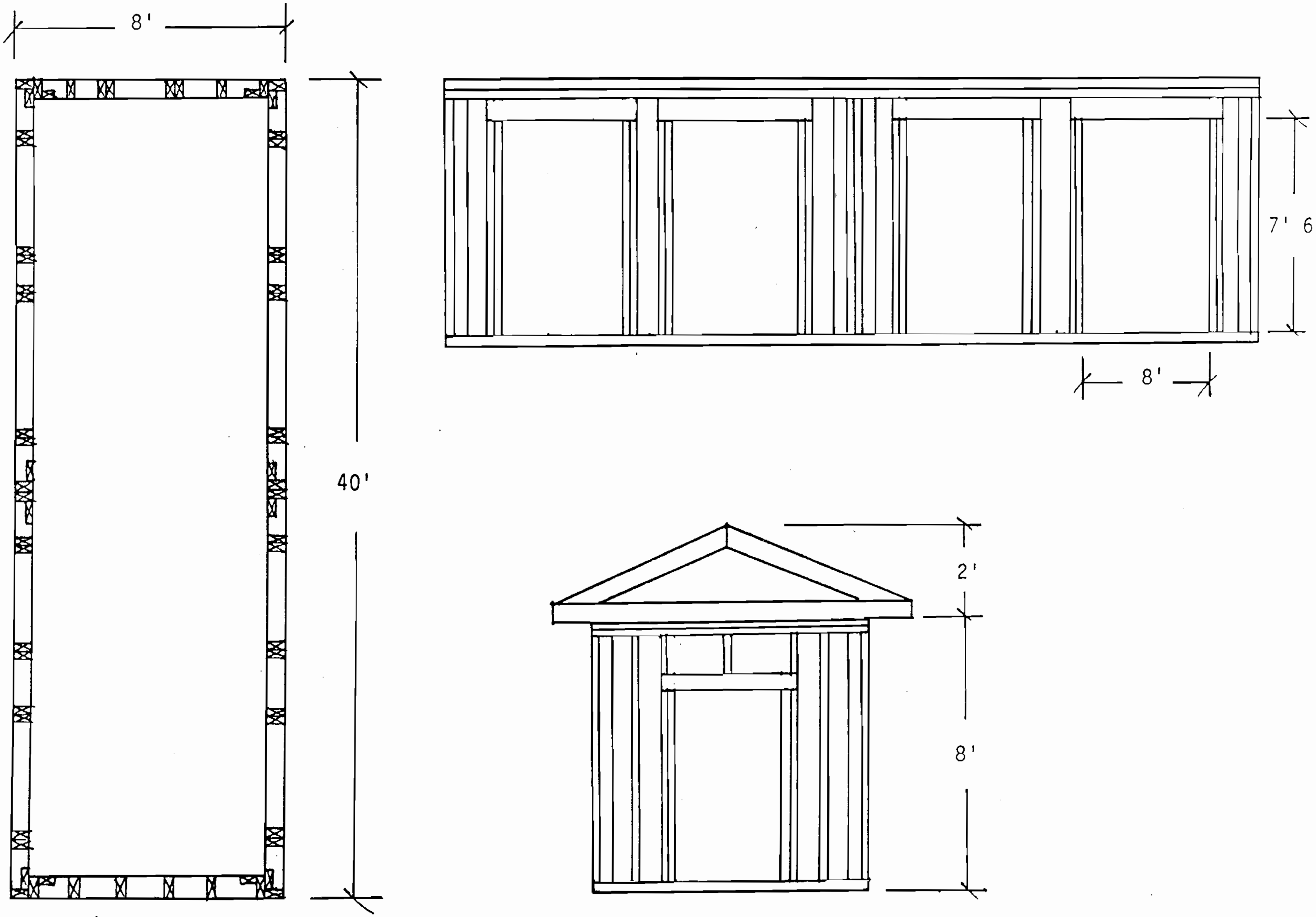


Fig. 1. Test Hut Details

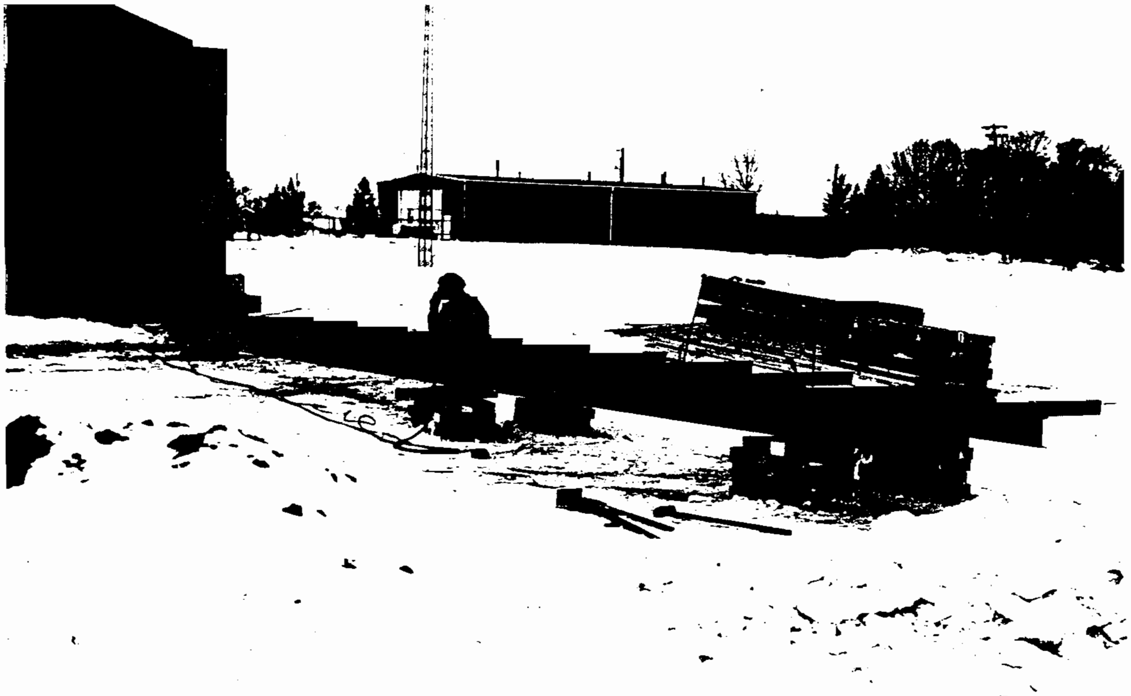


Fig. 2. Construction of the steel sub-frame

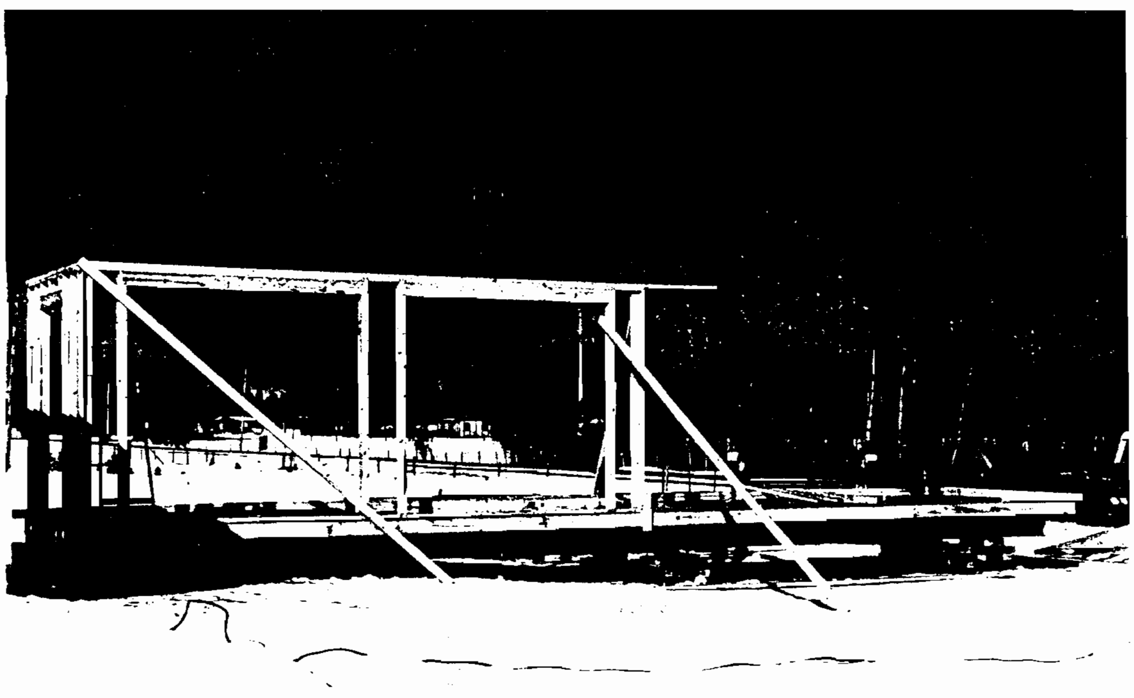


Fig. 3. Test hut framing

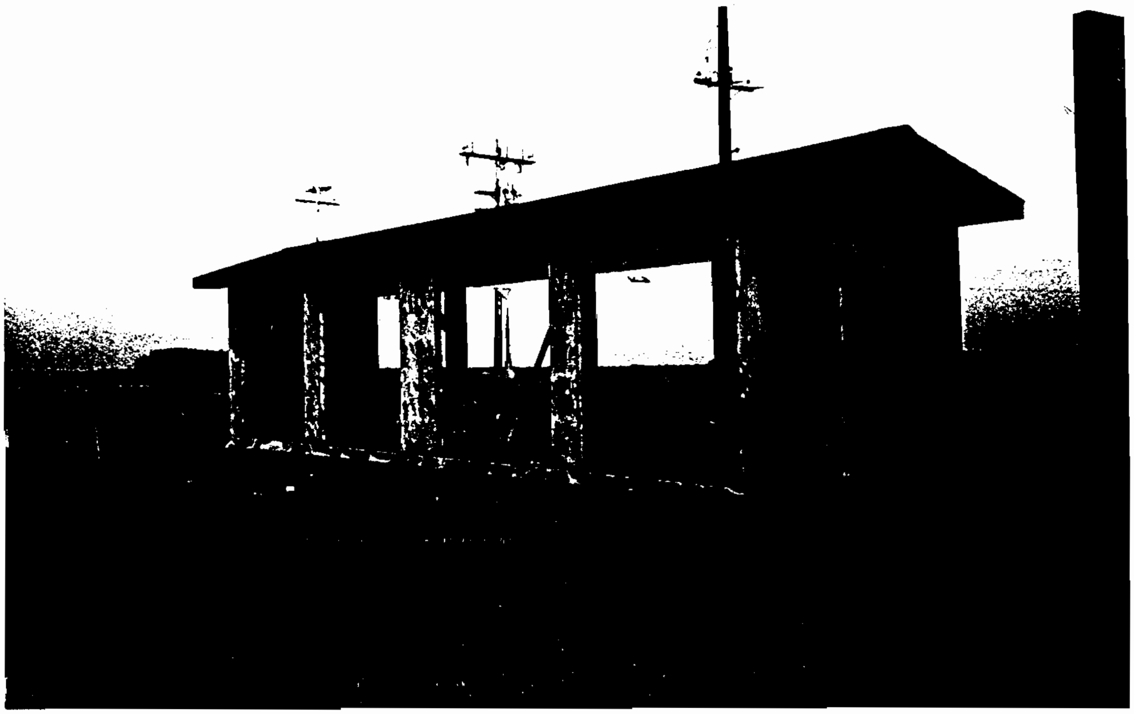


Fig. 4. Test hut with wall panel openings

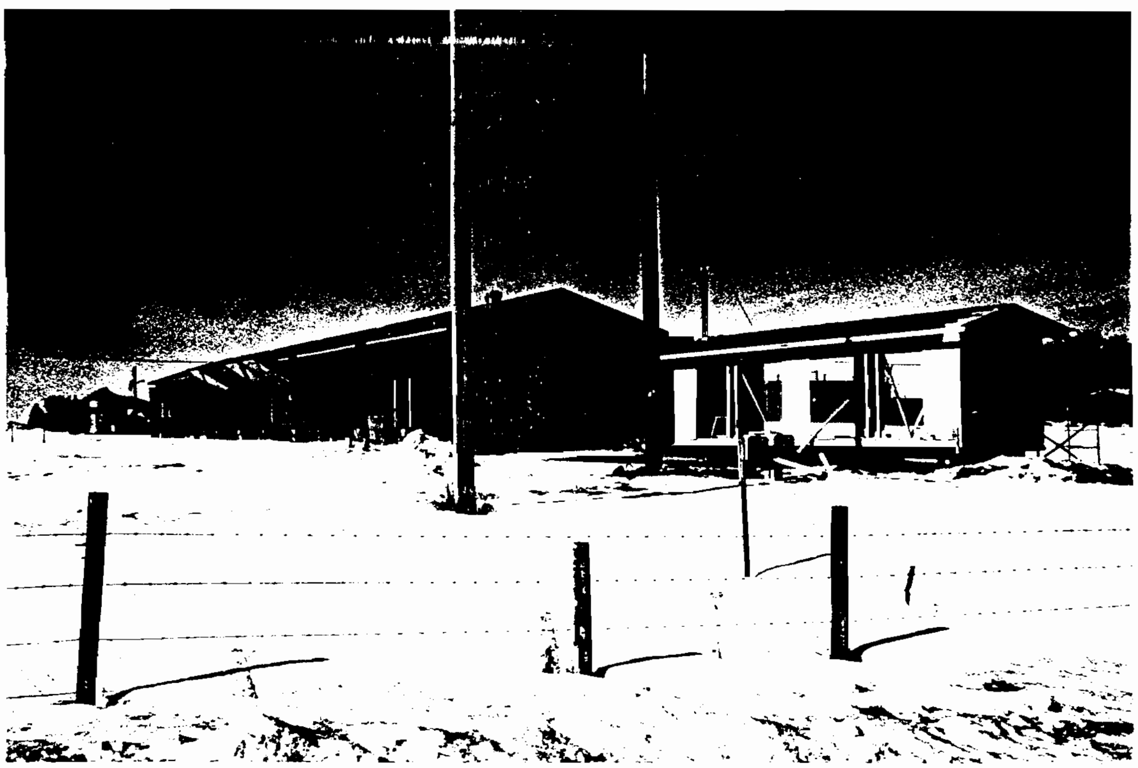


Fig. 5. Location of test hut at AHHRF

Calibration of these sensors will be the same as the sensors used in the test panels. In addition to these measurements, there are 5 Eppley pyronometers at the test site which read the total horizontal, diffuse horizontal, total on a vertical surface, total on an inclined surface and total transmitted through a south facing window. The total radiation on a vertical surface will be monitored as part of the meteorological data.

The temperature and relative humidity inside the test hut will be measured using the same type of sensors as above. The interior relative humidity will not be controlled by the computer used for the data logging. Instead the simgle on/off control supplied with the humidifier will be used. Measurements using this system have shown a variation of approximately ± 2 to 3% RH from the set-point. As each test panel is sealed from the inside with a polyethylene vapour retarder, a slight periodic variation in the interior relative humidity should have a negligible effect on the drying of the test panels.

The instrumentation for the test panels was designed to provide the same information as obtained in the Atlantic Canada study. Each panel has three 16" cavities and all measurements are carried out in the central cavity to minimize edge effects. The panels are instrumented to measure the temperature, wood moisture content and the relative humidity at the top and bottom of one of the central studs and the same three measurements are taken on the inside of the sheathing in the centre of the panel. For those panels which have a non-wood exterior sheathing (such as Styrofoam), the wood moisture content would not be measured.

The temperature will be measured with Type T thermocouples with a 0.5° accuracy. A three point calibration will be carried out using a platinum resistance thermometer. The wood moisture content will be measured using resistance measuring pins driven into the wood studs. A lignometer model H30

(Lignomat USA Ltd) with a measuring range of 4 to 30% MC will be used to convert the resistance readings to moisture content. The meter has an internal correction for different wood species with a variety of woods grouped into for different categories each with its own correction. The specifications for the model H30 is given on page 3 Appendix A. Since temperature is measured at the same location as the wood moisture content, a temperature correction can be made to each of the readings. The meter will be calibrated using small pre-conditioned samples of the same wood as the studs. The wood samples will be carefully prepared to insure a uniform moisture content which will be determined by gravimetric analysis. The calibration of the lignometer will be carried out during the course of the test.

The relative humidity will be measured using a sensor that consists of an electrode base-plate coated with a humidity sensitive macro polymer. Humidity is measured by a change in resistance between anode and cathode. The RH-8 sensor and voltage output circuitry (HMC-V) is manufactured by General Eastern Instruments Corporation. The sensor has an operating range of 0 to 99% RH with an accuracy of ±1% RH in the range of 10 to 99% RH. The specifications for this sensor are given on pages 4 and 5 of Appendix A. Calibration of the humidity sensors will be done using saturated salt solutions of lithium chloride (12% RH), potassium sulphate (97%) and possibly, sodium chloride (75% RH).

Unlike the Atlantic Canada study, the Epitek Serada condensation gauges will <u>not</u> be used in this study. Tests conducted in our laboratory have shown that gauge is basically a yes/no type gauge, i.e. if there is surface wetness then the gauge gives a certain voltage; if there is no surface wetness or if there is frost then there is zero voltage output. The gauge does not indicate how much surface moisture is present. This same information will be obtained from the RH sensor. If the relative humidity is 100% then there will be surface moisture. Furthermore, if there is frost on the surface, the RH reading and temperature will indicate this situation.

The other important deviation from the Atlantic Canada study involves the pressure measurement between the wall cavity and the interior. The current proposal is not to attempt this measurement. There are several reasons why this is a difficult measurement. Firstly, pressure on building envelopes due to stack and wind effects are small in magnitude, typically < 5 Pa. This is difficult to measure. Even with sensitive pressure transducers extremely careful calibration procedures must be followed. All transducers have some drift with time, humidity and/or temperature so the instrument zero must be regularly checked and subtracted from the readings taken. A small zero shift of a few millivolts is significant for typical transducers (Validyne, Setra) when attempting to resolve small pressures. Secondly, the temperature of air in the tubing should be constant along its length, or horizontal tubing runs must be used to eliminate stack pressure changes within the tubing. With tubing in a wall cavity the air in it will be at cavity, not room temperature and will produce a pressure of the same magnitude as those one is attempting to measure. e.g. 20°C room, 0°C in cavity, a hose run to the top of the wall produces about 2 Pa pressure change due to the higher density of air at cavity temperature. This is significant if one wants to measure pressures < 5 Pa. Thirdly, the pressure experienced by a building envelope varies rapidly due to fluctuations in windspeed. The variation can easily be the same magnitude as the mean pressure and long time averages are required to eliminate this effect. (at least 30 seconds).

<u>Data Acquisition System</u>

Although the final number of test panels has not been determined, the following discussion regarding the data acquisition system will assume a total of 6 pairs of panels. This gives 36 measurements of temperature, moisture content and relative humidity, respectively plus the meteorological and interior conditions (total of 7 additional readings).

The data logging system consists of an IBM PC/XT clone with a minimum of 640 K memory, an internal clock and two disk drives, a Sciemetrics data acquisition system (Model 641) with 64 channels and three 24 channel relay boards (Model ERB-24, Metrabyte Corp). Specifications for the data acquisition unit and the relay boards are given on pages 6 and 7 of Appendix A. A schematic of the data logging system is shown in Figure 6.

The 36 thermocouples will be read directly by the Sciemetrics A/D system. The 36 RH sensors will be switched via 24 channels on relay board #1 to a single, signal processing chip (HMC-V) and then fed into one channel on the A/D system. The remaining 12 RH channels will be switched on relay board #2 to a second signal processing chip and then fed into another channel on the A/D system. The remaining 12 relays on board #2 and the 24 relays on board #3 will be used to switch the wood moisture pins to the H30 lignometer and then into a third channel on the A/D system. Each meteorological and interior measurement will be fed to one channel on the A/D system.

The monitoring methodology consists of the following sequence (refer to Fig. 6) The main program (written in Quick Basic 4.0) will tell the A/D system to scan channels 0 through 36 for temperature. The program then sends a signal to the PIO-12 controller for relay boards 1 and 2 to close channel 1 on both relay boards; at the same time, the program tells the A/D system to scan channels 36 and 38. This sequence is reported for all 24 channels on relay boards 1 and

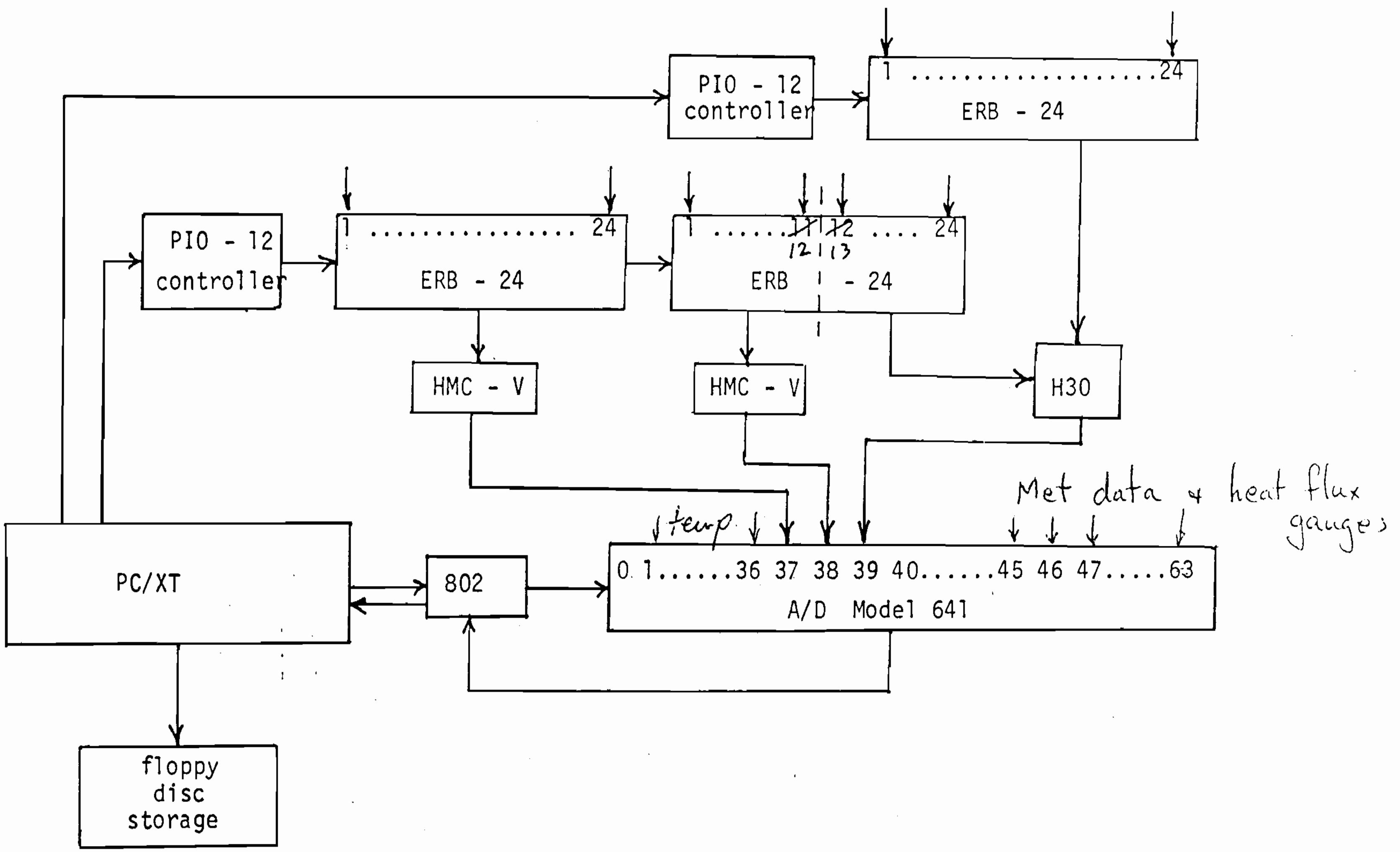


Fig. 6. Lay-out for the Data Acquisition System

2. This sequence will then record all 36 relative humidity readings and 12 wood moisture content readings. The program then moves to the relay board 3 where the above sequence is repeated for the remaining 24 wood moisture content readings. These readings are recorded on channel 39 of the A/D system. The program then tells the A/D system to scan the meteorological and test hut interior readings and record them on channels 40 through 46. A flow chart of the data collection is shown in Fig. 7. It is estimated that all readings can be recorded once per minute and 15 minute averages will be stored onto floppy discs in a compact form. Ultimately, this data will be used in the WALLDRY simulator which will necessitate some re-arrangement of the data. However, it was felt that it will be better to do this at a latter date with a separate program thereby, avoiding any restrictions on the initial data collection.

Pre-test Measurements

Each test panel will be depressurized to measure the leakage flow characteristics. A 1" tube will be sealed to the vapour retarder and protrude inside the test hut. A blower, flowmeter and pressure gauge will be attached to measure flowrate versus pressure difference. These measurements will be carried out soon after the test panels are installed in the test hut. The depressurization tests will be done on days where the wind speed is less than 1 m/sec. This is done to minimize the effect of wind speed on the pressure difference measurement. Samples of all materials used in the test panels will be collected. Some of the important initial parameters will be measured e.g. initial moisture content of the wood studs and vapour permeability of some exterior sheathings.

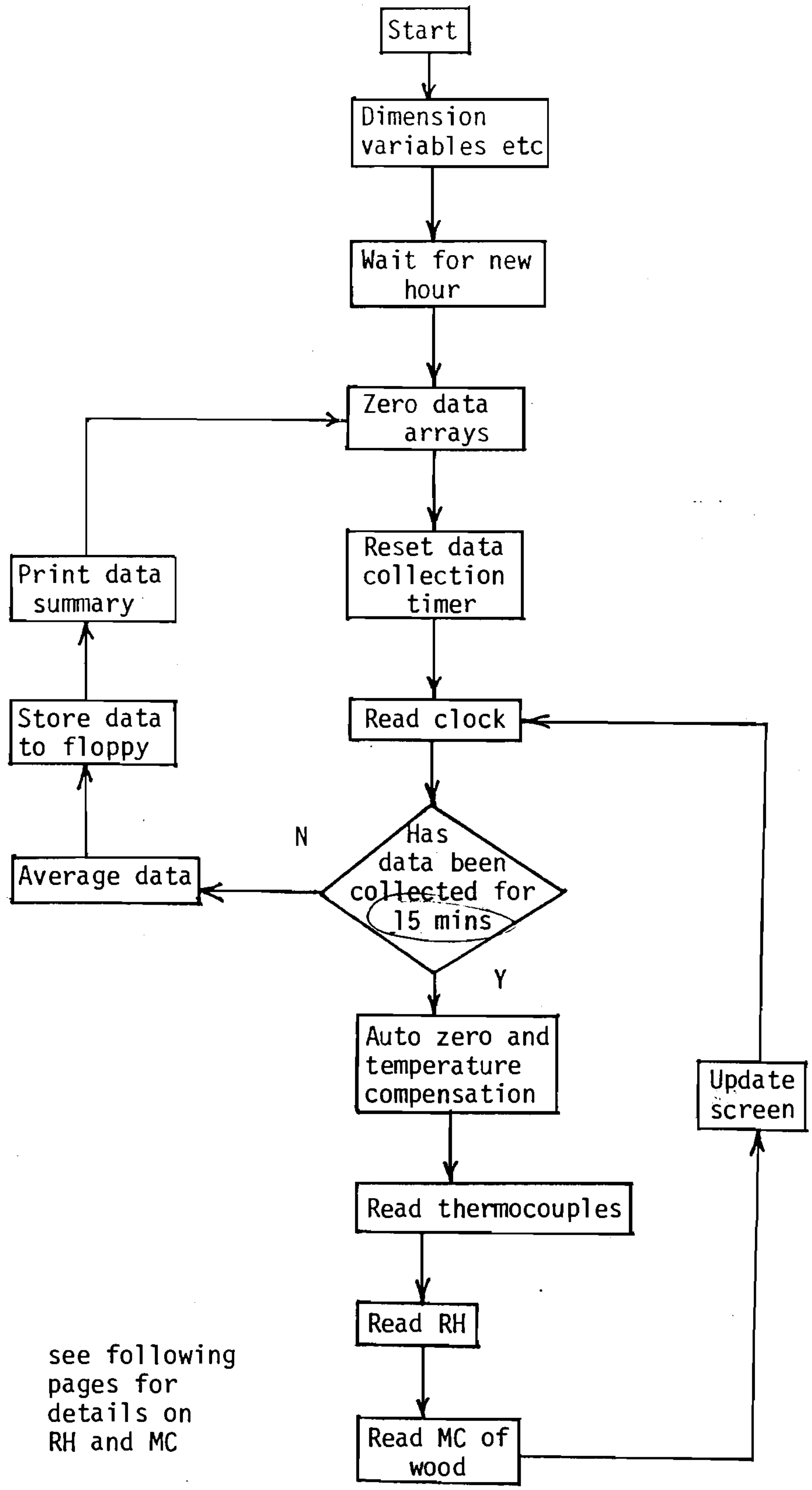
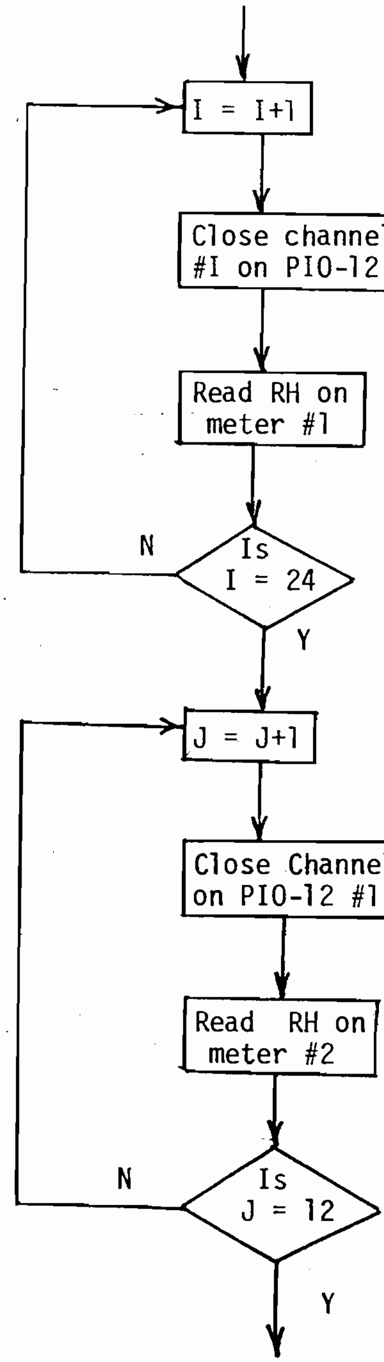
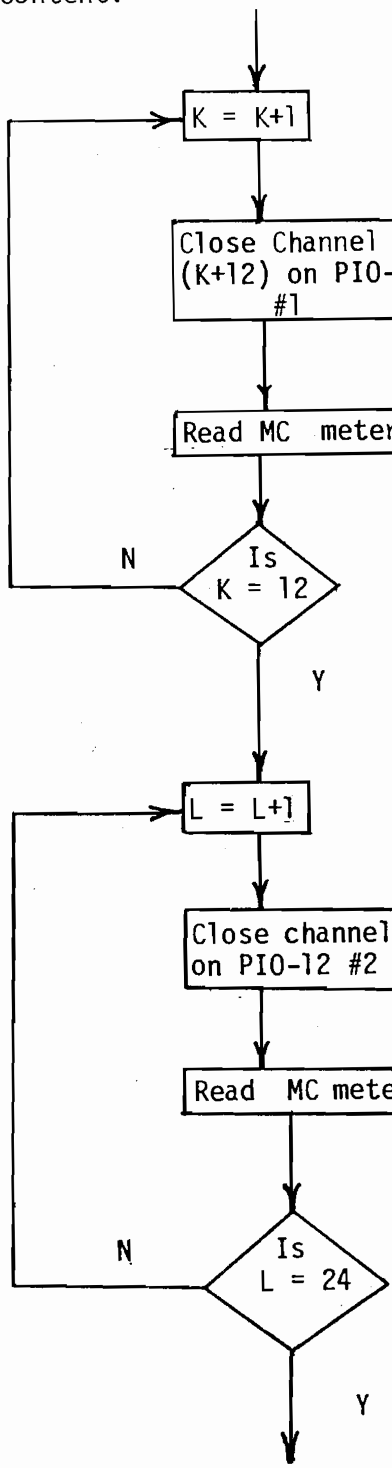


Fig. 7 Flow Chart for Data Collection

Relative Humidity:



Wood Moisture Content:



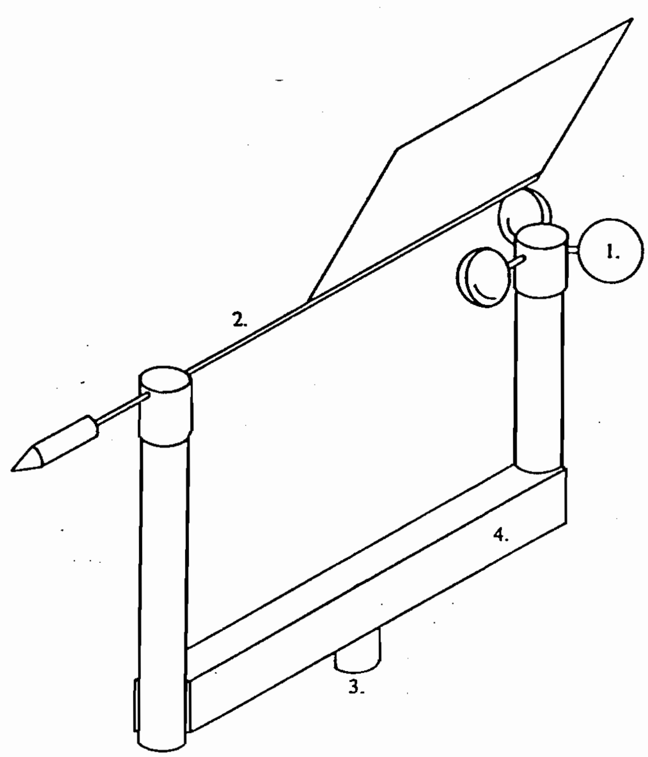
APPENDIX 1

DATA ON INSTRUMENTATION

The Windflo 540 wind measurement system has been designed by Athabasca Research Corporation Ltd. to meet the need of industry for a reliable wind speed and direction monitoring instrument. Special design features and use of the latest electronic techniques have produced a system which meets the strictest requirements for precision and mechanical durability.

The unit consists of an electronic signal translator which converts the transducer signals to a form compatible with standard recording devices; a sensing head equipped with a three-cup anemometer speed detector; and a vane direction detector.

1. Rotating three cup anemometer head drives a 48-slot chopper drum which alternately passes and interrupts an infra red light beam. The pulsed light is detected by a photo transistor and the resulting frequency modulated signal, directly related to wind speed, is applied to the translator circuitry section for conversion to a 0 to 1 volt D.C. analog signal. The optical signal imposes no mechanical loading on the anemometer. Precision stainless steel bearings help reduce the possibility of friction and provide a low starting threshold. Direct current power is received in the head and signals are returned to the translator through a five conductor cable.
2. Aluminum direction vane is coupled to the transducer potentiometers via magnetic drive. This coupling provides a compliant linkage which greatly extends the life of the potentiometers by eliminating high frequency, low amplitude fluctuations.
3. The Windflo mounting hub fits a standard one inch pipe mast and is easily installed in the field. The unit is normally supplied with 15 m of five conductor cable and mil. spec. connectors to couple the transmitters to the translator.
4. Designed to withstand the rugged north Canadian climate, the Windflo body is constructed of anodized aluminum. Shafts, bearings and counterweight are made from stainless steel. The rotating anemometer cups are of die cast aluminum machined to final dimensions and coated with teflon to inhibit ice accretion. The slim configuration of the transducer minimizes aerodynamic interference.



Specifications

AERODYNAMIC:

	Speed	Azimuth Direction
Accuracy	± 1% F.S.	± 2°
Starting Threshold	0.8 km/hr	0.8 km/hr
Distance Constant (63% Recovery for Step Change)	7.0 m	
Delay Distance (50% Recovery for Step Change)		3.0 m

ENVIRONMENTAL:

Sensing Unit Operating Temperature	–40°C to +65°C
Signal Translator Operating Temperature	0°C to 30°C

ELECTRICAL:

Signal Translator Input
- 120 V.A.C.
- 60 Hz
- < 10 Watts

Signal Translator Output*
- Minimum Load Impedence 1M Ω
- 0 - 1 V D.C. each Signal
- 0 - 10 V D.C. each Signal

MECHANICAL:

Overall Height	45.7 cm
Body Length	68.6 cm
Anemometer Diameter	21 cm
Vane Sweep Diameter	103 cm
Mounting Socket**	
Diameter	3.36 cm
Depth	5.4 cm
Sensing Unit Weight	4.5 kg

CONTACT OUR DESIGN ENGINEERS IF YOU HAVE A SPECIAL REQUIREMENT.

*On request, Athabasca Research can integrate the WINDFLO 540 electronics with rack mounted potentiometric stirp chart recorders. We will provide the mast, also.

**Other mounts can be made on request.

USE THIS BLOCK DIAGRAM TO ORDER

540 – [ ] – [ ] – [ ] – [ ] — Specify cable length 15 m Std.

INTERFACE ELECTRONICS
- XF - Analog Signal Translator Free Standing Box
- XR - Analog Signal Translator Rack Mounted Box
- S - Digital I/F to Scanalog

SPEED RANGE
- 10 0 - 100 km/hr
- 15 0 - 150 km/hr
- 30 0 - 30 m/s
- 45 0 - 45 m/s

OUTPUT
- 0 - If Scanalog Interface Chosen
- 1 - Std. 0 - 1V D.C.
- 9 - Option 0 - 10V D.C.

Athabasca Research Corporation Ltd.

11210 - 143rd Street, Edmonton, Alberta T5M 1V5
(403) 453-6151

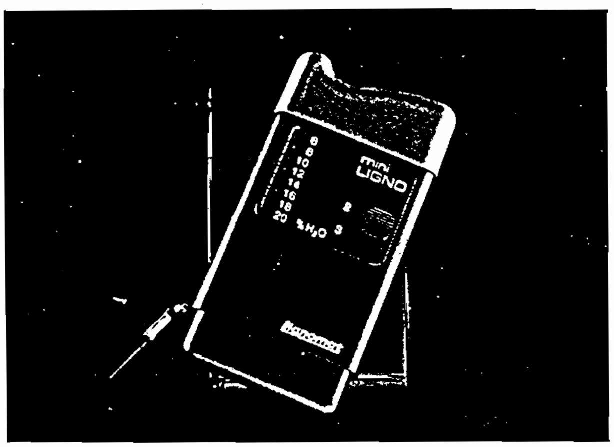
From Lignomat...an Expert in Moisture Detection

THE LIGNOMETERS

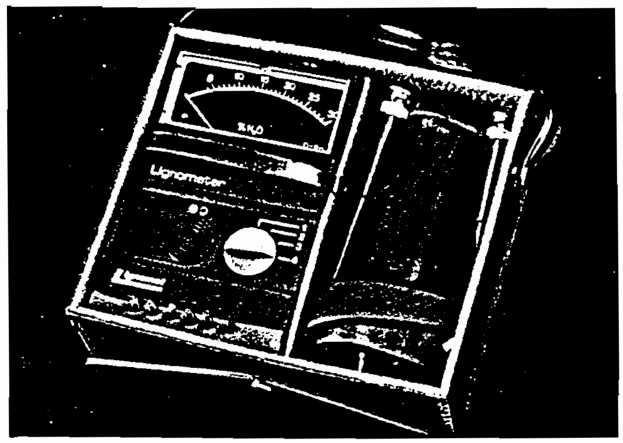
A Complete Line of Portable Wood Moisture Meters

From the pocketsize Mini-Lingo (6 to 20%) to the top of the line Lignometer HT 100 (4 to over 100%), LIGNOMAT has a moisture meter for everybody's needs. Reliable, accurate measurements and easy, convenient handling are the leading considerations for the design of the moisture meters.
The latest developments in IC Technology made the following outstanding features possible:

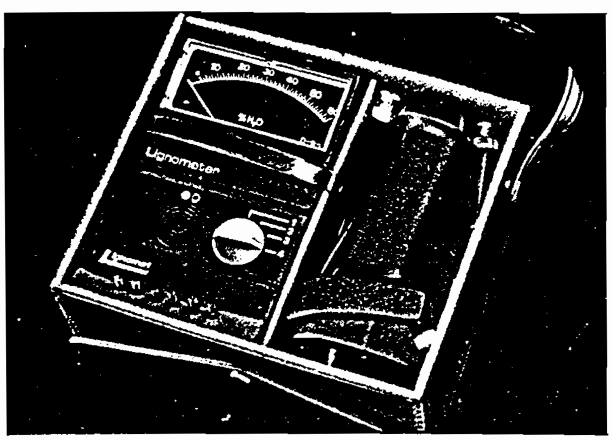
- Instant and direct readout of moisture content with no calibration adjustment
- Built-in compensation* for different wood species. NO MORE CORRECTION CHARTS!
- Built-in temperature compensation for top of the line models HT 60 and HT 100
- Complete line of different interchangeable electrodes
- Cable and probe systems for measuring moisture in stacked lumber



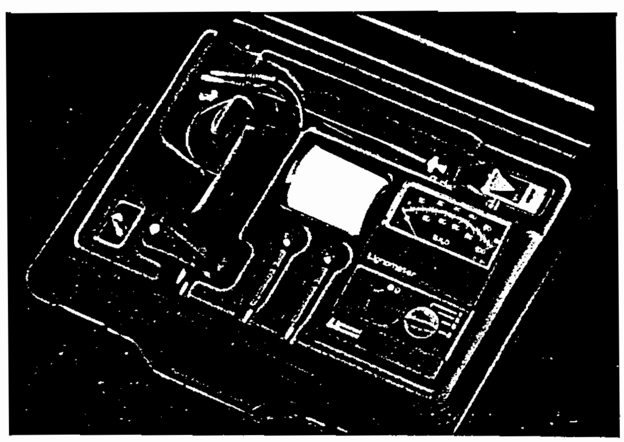
MINI LIGNO Range: 6 to 20%
An inexpensive pocket-size instrument with automatic calibration. Selector switch for 2 wood groups. Size: 1" x 2¾" x 5½," Weight: 7 ounces, 2 standard 9V batteries.



LIGNOMETER H30 Range: 4 to 30%
A low cost instrument with automatic calibration. Selector switch for four wood groups. Size of case (CS): 7½" x 6½" x 2½," Weight: 2 pounds, 1 standard 9V battery.



LIGNOMETER H60 Range: 4 to 60%
A low cost and wide range instrument with automatic calibration. Selector switch for 4 wood groups. Size of case (CS): 7½" x 6½" x 2½," Weight: 2 pounds, 1 standard 9V battery.



LIGNOMETER HE 60
A multipurpose instrument with a double scale for measuring wood from 4 to 60% or concrete, cement, brick and other building materials using scale from 0-100 and chart. Specifications for measuring wood are the same as for Lignometer H60. Size of case (CL): 14" x 11" x 3¼," Weight: 3½ lbs.

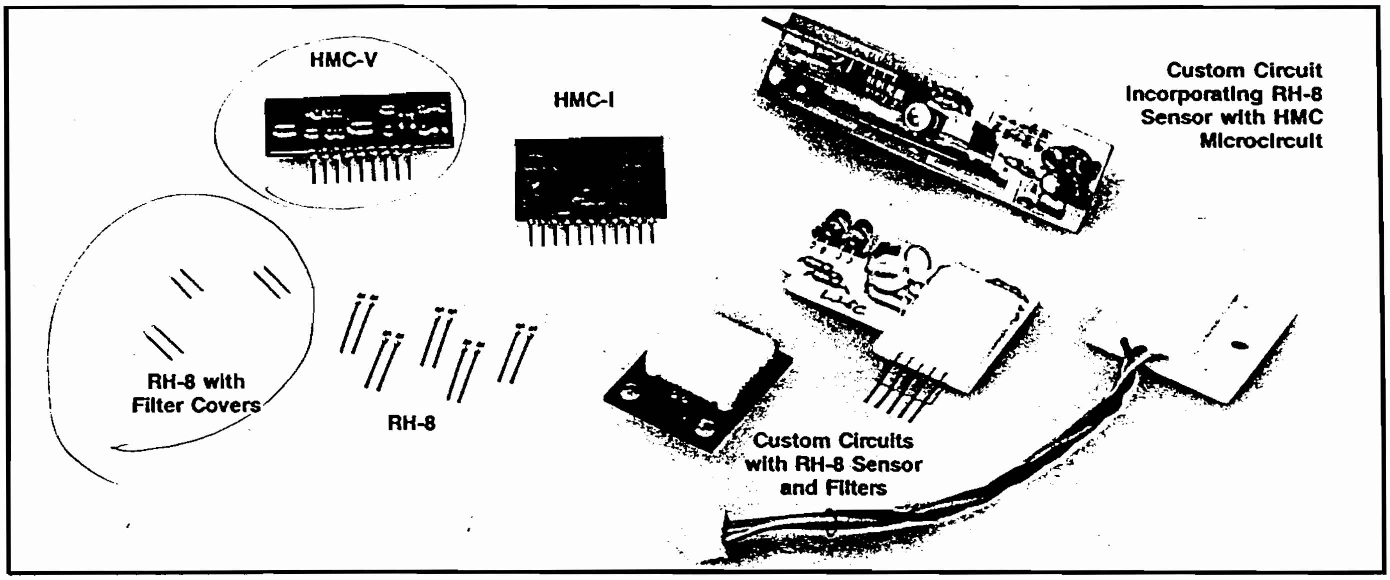
*BUILT IN COMPENSATION FOR WOOD SPECIES:
Different wood species exhibit various electrical conductivity curves. To correct the readings of the moisture meter, all meters from Lignomat are equipped with a wood group correction switch. Wood species with similar electrical conductivity belong to the same wood group.

After dialing the corresponding wood group, the compensation circuitry within the meters corrects the readout of the moisture percentage instantly. Each meter comes with a specification card that lists the most common wood species and the corresponding wood groups.

GENERAL EASTERN
The Humidity Company

RH-Series Humidity Instrumentation

RH-8 Relative Humidity Transmitter



FEATURES

- ► RH-8 Sensor and HMC Hybrid Microcircuit provide accurate humidity measurements
- ► Optional temperature compensation produces accurate humidity readings from 30° to 120°F
- ► Voltage and current output options allow design flexibility
- ► Sensor interchangeability without recalibration provides ±3%RH accuracy, typical
- ► Bulk resistance polymer RH sensor minimizes contamination effects for long-term stability

SENSOR SPECIFICATIONS

Resistance at 20%RH:	2.9M Ohms
Resistance at 90%RH:	2.4K Ohms
Excitation Frequency:	100Hz to 10KHz
Interchangeability Tolerance:	±3%RH, typical
Stability:	Stable to 1% per year
Operating Range:	Humidity: 0-99%RH Temperature: 10°-170°F

DESCRIPTION

The General Eastern Relative Humidity Sensor and Microcircuit comprise the building blocks for a complete humidity transmitter. The hybrid humidity microcircuit (HMC) is available with current or voltage output. The HMC-V provides a voltage output and the HMC-I provides a 2-wire 4-20mA output.

These components can be incorporated into OEM product designs. Accuracies as good as ±1.0%RH can be achieved. With fewer components, circuit accuracies of ±3% or ±5% can be designed. Simple on/off circuits to operate over narrow RH ranges and transmitters to ±7% accuracy can be built without requiring calibration.

CAN YOUR PRESENT SENSOR PASS THESE TESTS?

ENVIRONMENTAL TEST	CHANGE IN %RH (LESS THAN)
Stability: 75°F 1KHz, 24 months:	2.0%RH
Stability: 120°F 1KHz, 24 months:	3.0%RH
Temperature Cycle: 4000 cycles at 1 hour, 30°-120°F:	1.0%RH
Condensation Cycle: 1000 cycles at 30 min. 0-100%RH:	2.0%RH

RH-8 Relative Humidity Transmitter
and Hybrid Microcircuit

SPECIFICATIONS

Circuit design determines the total system performance. Specifications which can be achieved are shown below.

Accuracy at 75°F:	To ±1%, 10-99%RH
Sensor Interchangeability:	To ±3% without calibration
Sensitivity:	To 0.1%RH
Hysteresis:	Negligible
Repeatability:	±0.5%RH
Temp. Comp. Operating Range:	10°F-170°F 0-99%RH

SPECIFICATIONS FOR CIRCUITS SHOWN

Accuracy at 75°F:	±3%, 20-90%RH, typical
Sensor Interchangeability:	To ±3%, typical, without calibration
Sensitivity:	To 0.1%RH
Hysteresis:	Negligible
Repeatability:	±0.5%RH
Temperature Compensation:	30°F-120°F

ADJUSTMENTS

High Humidity:	±20%, non-interacting
Low Humidity:	±20%, non-interacting
Mid, Current Only:	±20%, non-interacting

OUTPUT Linear, Proportional	0-1VDC, 0-100%RH or 4-20mA, 0-100%RH
POWER REQUIREMENTS	As shown

SENSOR OPERATING RANGE

Humidity:	0-99%, non-condensing
Temperature:	10°F-170°F

HMC MICROCHIP OPERATING RANGE

Humidity:	0-99%, non-condensing
Temperature:	30°F-120°F

SIMPLIFIED CIRCUITS SPECIFICATIONS

Simple circuits can be designed for ±5% and ±10% accuracies or on/off characteristics.

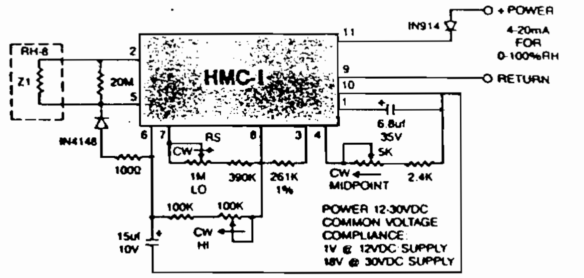
VALUE ADDED SERVICES

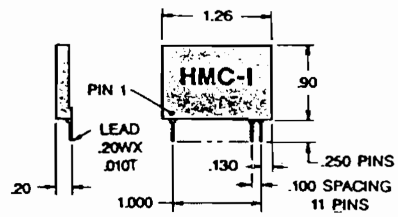
General Eastern maintains full design, calibration, testing and production facilities. Support services are availble to custom design and produce circuits and circuit boards exactly to your specification. Technical data is also available describing the sensor and its capabilities. Please call for full details.

ORDERING INFORMATION

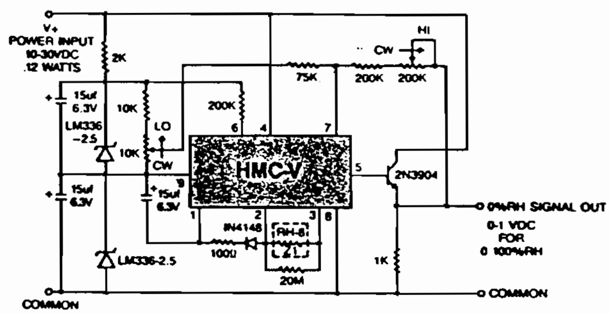
Specify RH-8 Relative Humidity Sensor, HMC-V or HMC-I microchip. RH-9 and RH-10 sensors calibrated to ±5 and ±10%RH tolerances are also available. Please consult current price list.

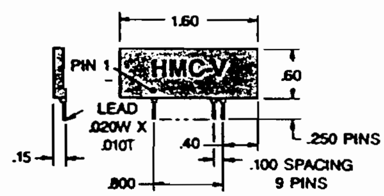
Current Output with HMC-I

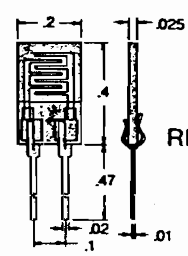




Voltage Output with HMC-V







RH-8

All dimensions in inches

All specifications are subject to change without notice.

GENERAL EASTERN
A Division of High Voltage Engineering Corp.

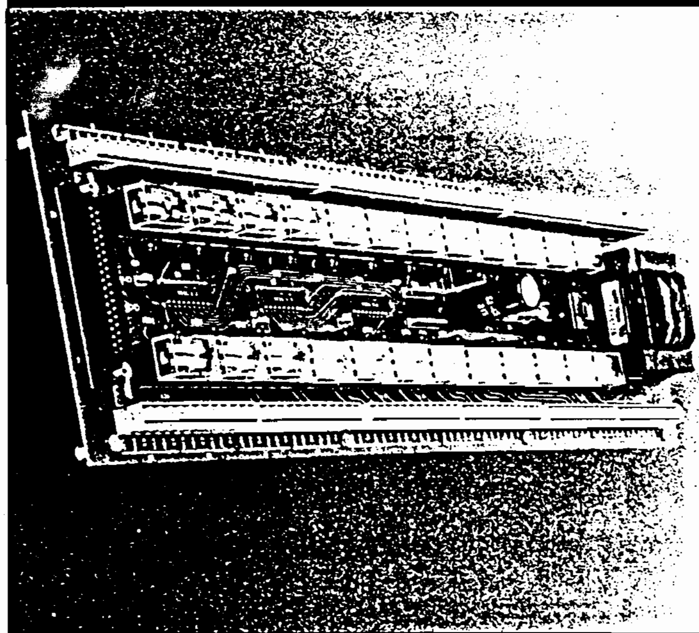
Sales Office:
3506 Bienville Blvd., Ocean Springs, MS 39564 (601) 872-2948
50 Hunt Street, Watertown, MA 02172 (617) 923-2386

Printed in U.S.A. 1/87

MetraByte Corporation

24 CHANNEL DPDT RELAY OUTPUT ACCESSORY BOARD MODEL ERB-24

UNIVERSAL TTL HIGH LOAD CURRENT SWITCHING INTERFACE



FEATURES

- 24 Double Pole Double Throw Relays
- 3 Amp Contact Rating
- Built In Power Supply
- Screw Terminations accept 12–22 AWG wire
- Easy to use
- LEDS Indicate Activated Relays

APPLICATIONS

- Energy Management
- Laboratory Automation
- Product Testing
- Process Control
- Activate Alarms
- Annunciator Lights

FUNCTIONAL DESCRIPTION

MetraByte's 24 Channel DPDT Relay Output Board, Model ERB-24 offers the programmer 24 Electromechanical Double-Pole-Double-Throw relays for efficient switching of loads by programmed control. Each relay contains two N.C. and N.O. contacts for controlling up to a 3 Amp load (resistive) at 120 Vrms per contact. These relays offer the user zero leakage output currents, compared to the solid state relay alternative.

The relays may be energized by applying a 5 Volt signal level to the appropriate relay channel on the 37 Pin D connector located on the board. Another method is to connect the board directly to any digital output board which provides TTL switching capabilities. The signal driving current for each relay is 1.4mA max.

The ERB-24 may also be operated by directly connecting to MetraByte's 24 Bit Parallel Digital I/O Interface, Model PIO-12.

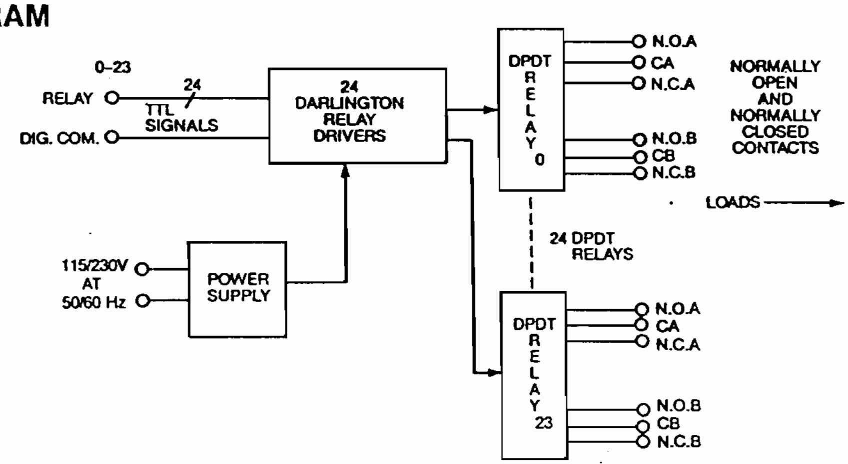
This interface when used with the ERB-24 will permit the user to control 24 loads such as heaters, fans, pumps, solenoid valves, lights and more at reasonable cost with the IBM PC and Compatible computers.

24 Annunciator LEDS, one for each relay, light when their associated relay is activated. This feature aids in trouble shooting and ease of use.

Screw terminals on the board offer easy connection to your application and will accept wire sizes 12–22 AWG. The board may be rack mounted with 4–40 screws for your convenience.

A built-in power supply operating on 115/230 Vrms 50/60 Hz powers the unit and will accept ± 15% voltage fluctuations and operating temperatures of 0 to +60 Degrees C.

BLOCK DIAGRAM



PROGRAMMING

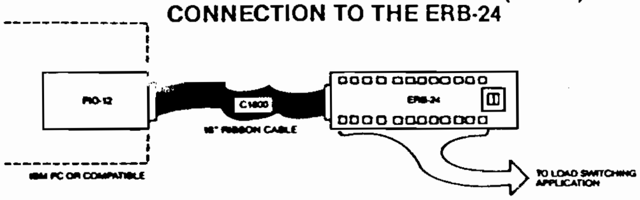
The following example illustrates how easy it is to activate a relay in BASIC using MetraByte's 24 Bit Parallel Digital I/O Board (PIO-12).

```
10 OUT &H313, &H80     'sets all PIO-12 ports to outputs
20 OUT &H310, 1        'activates relay 0   (port A, Bit 0)
30 OUT &H311, 16       'activates relay 20   (port B, Bit 4) .
40 OUT &H312, 3        'activates relays 8 and 9 (port C, Bit 0 and 1)
```

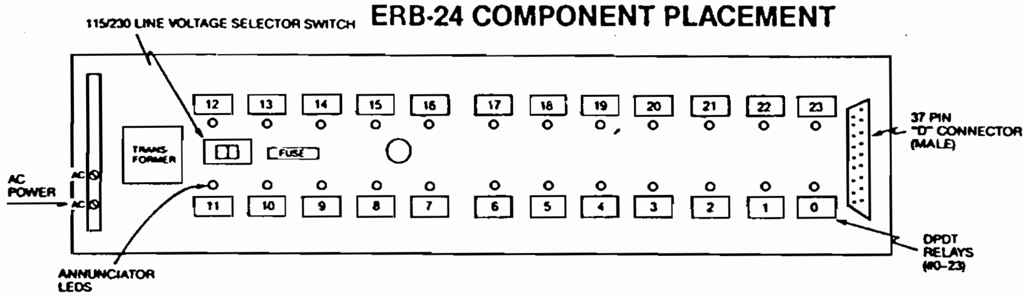
The following table lists the corresponding signal names on the PIO-12 which activates the corresponding relay on the ERB-24.

RELAY	PIO-12	RELAY	PIO-12
0	PA0	12	PC4
1	PA1	13	PC5
2	PA2	14	PC6
3	PA3	15	PC7
4	PA4	16	PB0
5	PA5	17	PB1
6	PA6	18	PB2
7	PA7	19	PB3
8	PC0	20	PB4
9	PC1	21	PB5
10	PC2	22	PB6
11	PC3	23	PB7

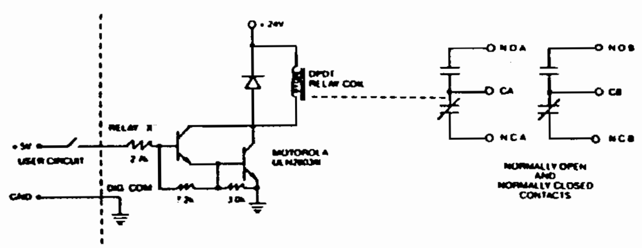
24 BIT PARALLEL DIGITAL I/O BOARD (PIO-12) CONNECTION TO THE ERB-24



ERB-24 COMPONENT PLACEMENT



ONE RELAY CHANNEL OF THE ERB-24



CONNECTOR PIN ASSIGNMENTS

All Digital inputs to the ERB-24 are through a standard 37 pin D type male connector that resides on the printed circuit board. For soldered connections, a standard 37 pin D female (ITT/Cannon DC-37S or equivalent) is the correct mating part and can be ordered from MetraByte as part #SFC-37. Insulation displacement (flat cable) connectors are available from Amp (#745242-1), 3M, Winchester, Robinson-Nugent etc.

The connector pin assignments are as follows:

N/C	19	37	RELAY 0
N/C	18	36	RELAY 1
N/C	17	35	RELAY 2
N/C	16	34	RELAY 3
N/C	15	33	RELAY 4
N/C	14	32	RELAY 5
N/C	13	31	RELAY 6
N/C	12	30	RELAY 7
DIG. COM.	11	29	RELAY 8
RELAY 16	10	28	RELAY 9
RELAY 17	9	27	RELAY 10
RELAY 18	8	26	RELAY 11
RELAY 19	7	25	RELAY 12
RELAY 20	6	24	RELAY 13
RELAY 21	5	23	RELAY 14
RELAY 22	4	22	RELAY 15
RELAY 23	3	21	DIG. COM.
N/C	2	20	N/C
N/C	1		

REAR VIEW

SPECIFICATIONS

RELAYS

Quantity and Type:	24 DPDT (DUAL FORM C)
Contact Material:	Gold overlay silver
Contact Rating:	3A at 28V DC, resistive
	3A at 120V AC, resistive
Operate Time:	20 milliseconds max. at rated voltage
Release Time:	10 milliseconds max.
Life Expectancy:	
Mechanical:	10 Million ops. min.
Electrical:	100 Thousand ops. min. at rated load

ENVIRONMENTAL

Operating Temperature Range:	0 to 60 Deg. C.
Storage Temperature Range:	−40 to +100 Deg. C.
Humidity:	0 to 90% Non-Condensing

POWER CONSUMPTION

Input Power	115 VAC ±15% (2 Amp Fuse)
	230 VAC ±15% (1 Amp Fuse)
	50/60 Hz. 14.5 VA Max

PHYSICAL

Dimensions:	16"L×4.75"W×2"H
Weight:	2.2 Lbs. (1 Kg)
Screw Terminal Wire Spacing:	.197" (5 mm)
Screw Terminal Wire Sizes:	12-22 AWG
Mounting Screws for Board:	4-40

THE PRICE $395.00

APPENDIX 2

CALIBRATION OF INSTRUMENTATION

Moisture Meter Calibration

Gravimetric moisture contents of wood samples were found by weighing before and after drying in an air convection oven. Wood samples were taken from framing lumber which was used in constructing the wall panels. Meter output versus gravimetrically determined moisture contents are shown in the table below; all measurements were taken at 20°C.

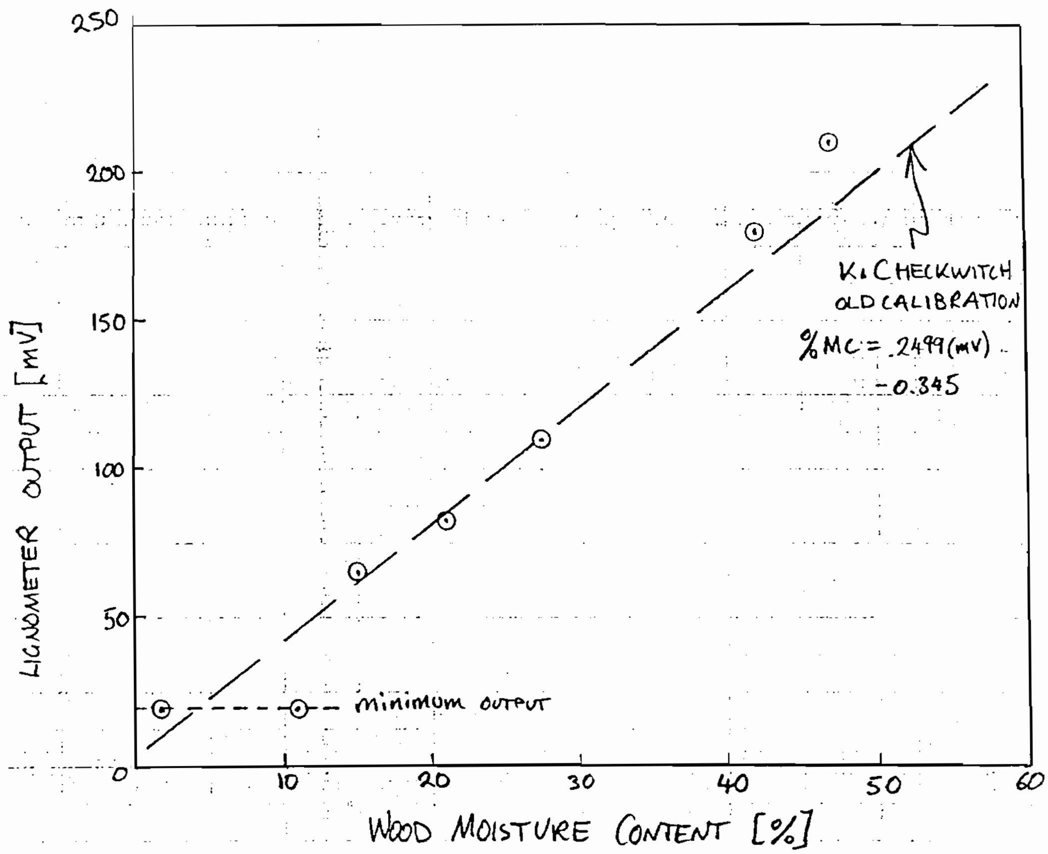
Sample	Indicated M.C.%		Gravimetric M.C.%		
	Scale	Voltage MV	Before gm	After gm	%
A	<5	17	23.730	22.920	3.5
*B	>30	200	33.323	23.585	41
*D	>30	148	30.202	23.455	29
F	<5	18	25.400	22.909	11
G	27½	111	29.046	23.036	25
H	16	66	26.230	22.808	15
B2	>30	210	33.76	22.945	47
P2	>30	184	32.600	22.930	42
G2	20	82	27.626	22.862	21
H2	16	66	26.213	22.851	15

*Not used due to uneven moisture distribution

The room temperature calibration equation that was used is:

$$\% \, MC = 0.2499(mV) - 0.345$$

A plot of the calibration equati·n is shown in the figure below:



A temperature correction was made to the meter output based on equations that were presented by Pfaff and Garrahan [1].

Relative Humidity Sensors

The RH sensors were calibrated over three different saturated aqueous salt solutions at 20°C and room RH (which was measured with a sling psychrometer). The salt soltions used were: K_2SO_4 (97%), $MgCl_2$ (33%), LiCl (12%), and room RH which varied between 38 and 53%. A total of four different sensor output conditioners (HMC-V in Fig.6) were calibrated, one for ambient RH, second for indoor RH, third for a group of 18 sensors that had 9 m (29.5 ft) of cable, and forth for a group of 18 sensors that had 7.5 m (24.6 ft) of cable.

Sensor	Voltage Output for Calibration RH (volts)			
	97%	Room RH	33%	12%
Ambient RH	1.11	0.41 (38%)	0.37	0.16
Indoor RH	0.97	0.52 (53%)	0.44	0.24
Sensors with 9m cable	0.91	0.51 (40%)	0.45	0.435
Sensors with 7.5 m cable	0.96	0.36 (45%)	0.33	0.29

A least squares method was used to fit a linear calibration curve to these data points:

$$indoorRH: \quad RH\ (\%) = 116(volts) - 14$$

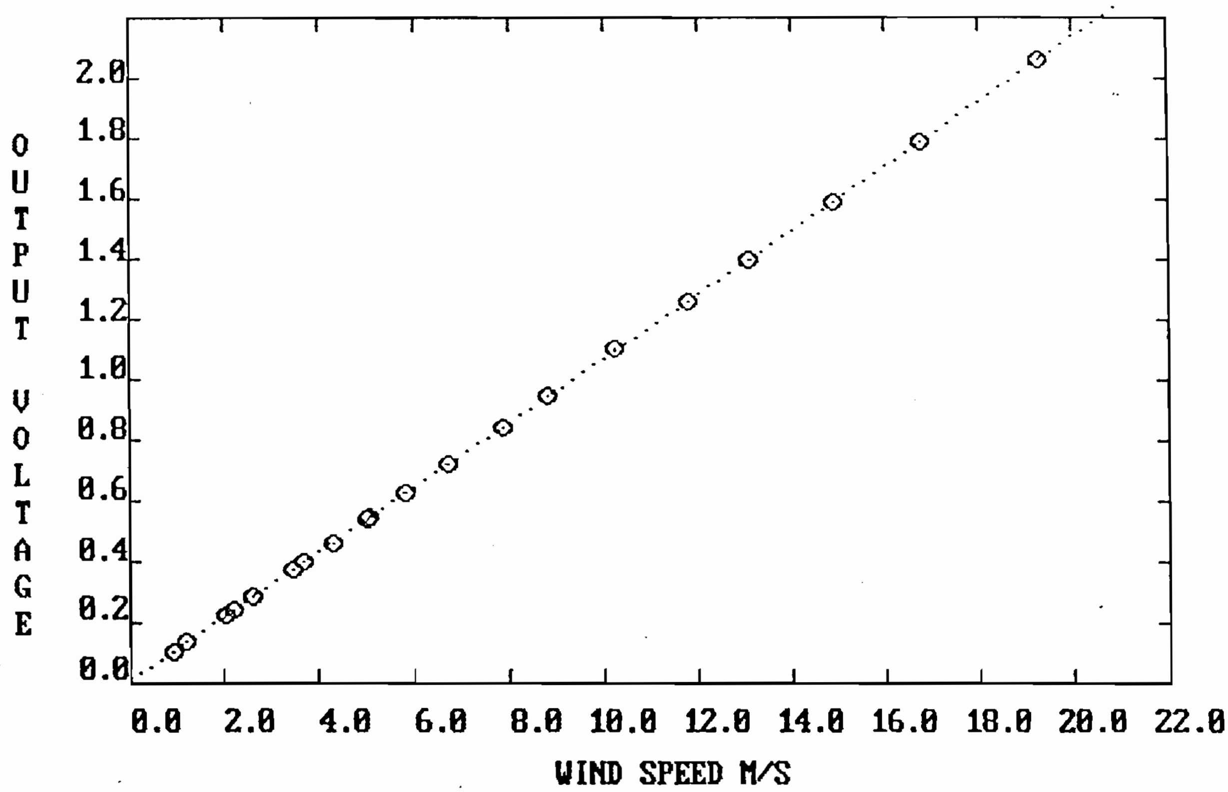
$$outdoorRH: \quad RH(\%) = 88(volts) - 6$$

$$7.5\ m\ of\ cable: \quad RH(\%) = 109(volts) - 6$$

$$9\ m\ of\ cable: \quad RH(\%) = 157(volts) - 45$$

Vane Anemometer

Calibration of the Windflo 540 anemometer was carried out in the wind tunnel at the University of Alberta and the resultant calibration curve is shown in the figure below:



Pyranometers

The Kipp and Zonen pyranometers were calibrated by Environment Canada and the calibration report is appended.

Heat Flux Gauges

A set of heat flux gauges were designed and built in our laboratory. Each gauge was calibrated using a guarded hot box. Gauge output was found to be linear with heat flux and a the average calibration factor was on the order of

Use of galvanometer type AL 4 - MICROVA in conjunction with thermopiles

The calibration certificates of the thermopiles give the electromotive force (EMF) produced by the pile for a certain amount of incident radiation.

The voltage read on the galvanometer is related to the EMF of the thermopile by the simple equation:

$$V_g = \frac{R_g}{R_s + R_g} \cdot (EMF) \text{ or } EMF = \frac{R_s + R_g}{R_g} \cdot V_g$$

R_g is the galvanometer resistance at the relevant range

where V_g is the voltage read on the galvanometer

R_s is the resistance of the source (thermopile)

The input resistance of the galvanometer AL 4 equals 500.000 Ohms/Volt or:

0.5 mV	range R_g	= 250	Ohms
1.5 „	„	750	„
5.0 „	„	2500	„
15 „	„	7500	„
50 „	„	25k	„

EXAMPLE:

The thermopile has a resistance of R_s = 60 Ohms and produces an EMF of 50 microvolts. for an incident radiation of 1 $Cal.m^{-2}.h^{-1}$.

For the radiation to be measured, we get a deflection of 100 scale divisions on the 1.5 mV range of the galvanometer.

The voltage measured thus equals 1 mV and R_g = 750 Ohms.

The EMF of the pile is now evaluated tot be : $EMF = \frac{60 + 750}{750} . 1 = 1.08$ mV.

The incident radiation was $\frac{1.08 . 10^{-3}}{5.10^{-5}} = 21.6 \ Cal.m^{-2}.h^{-1}$.

Channel 42, North Side

Environment Canada | Environnement Canada
Atmospheric Environment Service | Service de l'environnement atmosphérique

NATIONAL ATMOSPHERIC RADIATION CENTRE

Calibration Certificate No. 84-144

Type of Radiometer: PYRANOMETER

Manufacturer: KIPP & ZONEN

Model Number: CM-5

Serial Number: 78-4337

Calibration Factor, Short-Wave: 10.95 $\mu V\ W^{-1}\ M^2$

Calibration Factor, Long-Wave:

Temperature of Calibration: 25 °C

Temperature Coefficient: -0.00117 /°C

Internal Resistance:

Remarks: ALBERTA RESEARCH COUNCIL

In Charge of Test:

Approved:

D. Wardle
for Assistant Deputy Minister

Date of Approval: 20 10 84

NOTES: a. Short wave calibration factors are based on the World Radiometric Reference (WRR). The reference which was used by NARC prior to 1982 and which was identified as the "Smithsonian Scale of 1913 reduced by 2.0%" was intended as a true radiometric scale and has proved to be indistinguishable from the WRR.

b. Calibration factor valid for 2 years after date of approval.

c. 1 langley min^{-1} = 1 Calorie $cm^{-2}\ min^{-1}$
= 697.5 $W\ m^{-2}$
= 221 BTU $ft^{-2}\ hr^{-1}$

4

Environment Canada | Environnement Canada

Atmospheric Environment Service | Service de l'environnement atmosphérique

NATIONAL ATMOSPHERIC RADIATION CENTRE

Calibration Certificate No. 84-139

Type of Radiometer PYRANOMETER

Manufacturer KIPP & ZONEN

Model Number CM-5

Serial Number 78-4330

Calibration Factor, Short-Wave 10.52 $\mu V\ W^{-1}\ M^2$

Calibration Factor, Long-Wave ______

Temperature of Calibration 25 °C

Temperature Coefficient -0.00117 /°C

Internal Resistance ______

Remarks ALBERTA RESEARCH COUNCIL

In Charge of Test ______

Approved ______

D. Warren

for Assistant Deputy Minister

Date of Approval 20 10 84

NOTES: a. Short wave calibration factors are based on the World Radiometric Reference (WRR). The reference which was used by NARC prior to 1982 and which was identified as the "Smithsonian Scale of 1913 reduced by 2.0%" was intended as a true radiometric scale and has proved to be indistinguishable from the WRR.

b. Calibration factor valid for 2 years after date of approval.

c. 1 langley min^{-1} = 1 Calorie $cm^{-2}\ min^{-1}$
= 697.5 $W\ m^{-2}$
= 221 BTU $ft^{-2}\ hr^{-1}$

References

[1] Pfaff, F. and Garrahan, P., "New Temperature Correction Factors for the Portable Resistance-Type Moisture Meter", Forest Prod. J., Vol.36, 1986, pp.28-30.

APPENDIX B

MICROBIOLOGICAL TESTING IN MOISTURE TEST HUTS

FORINTEK CANADA CORP.
800 Montreal Road
Ottawa, Ontario
K1G 3Z5

CONFIDENTIAL

MICROBIOLOGICAL TESTING IN MOISTURE TEST HUTS

2nd Interim Report

by

Keith A. Seifert and Brian T. Gryll s

prepared for

CANADA MORTGAGE AND HOUSING CORPORATION

October 31, 1990

Contract No.: 42-59C-542

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1.0 INTRODUCTION

As part of a project to assess the drying characteristics of different wall constructions, Forintek has been contracted to assess microbiological hazards associated with these techniques. Fungal hazards are the primary concern, and comprise three separate phenomena. Wood decaying fungi cause strength losses in wood that may render the structures unsafe. Moulds produce spores or volatile metabolites that may be health hazards. Finally, sapstaining fungi discolour the wood, but are not otherwise considered hazardous. All three groups of fungal degradation occur when wood is wet, and consequently, any changes in wall construction that affect the drying time may also affect the extent of fungal development.

In this interim report, the preliminary results of the second microbiological analysis of the test hut constructed in Edmonton, Alberta are presented. Unfortunately, no sampling was done at the time this hut was constructed. Therefore, these results give a relative indicator of mould colonization of the different wall panels.

2.0 MATERIALS AND METHODS

Work on Site

Sampling was done on site at the Alberta test hut by Lynne Sigler of the University of Alberta on 28 June 1990. The methods employed were identical to those reported in the 1st interim report for this project (see Appendix Two). Rather than a 0-5 rating scale for estimating fungal growth, only areas of profuse growth (+++) were noted.

Laboratory Work

The samples were air freighted to Ottawa for isolation work. Isolations were made from the samples on July 2nd, using the same methods as those reported in the 1st interim report (see Appendix Two).

Identifications were confirmed at the Biosystematics Research Centre, Agriculture Canada, Ottawa.

3.0 RESULTS

Isolations

The results of the isolations from the studs are shown in Table One. At least twenty-seven fungal species were isolated from the studs. The species were predominantly moulds, but a small number of possible wood-decaying basidiomycetes were isolated. The moulds *Trichoderma harzianum* and *Paecilomyces variotii* were isolated from most samples. A number of other moulds were common, including *Penicillium* spp., *Aureobasidium pullulans*, *Aspergillus niger*, *Phialemonium dimorphosporum*, *Ulocladium atrum* and *Verticillium psalliotae*.

The results of the isolations from the panelling are shown in Table Two. At least seven species were isolated, six moulds and one possible wood-decaying basidiomycete. The species isolated were the same as those common on the studs.

Panel ratings

This data has been submitted as a separate report by Lynne Sigler, dated 10 August 1990.

4.0 DISCUSSION

The studs and panelling of many of the wall panels are heavily colonized by fungi. Twenty-seven species of fungi, most of them moulds, were isolated and identified on the samples. The heavy mould colonization was also noted visually by Sigler at the time of sampling. She observed white mould growth on fibreglass insulation, and white, green, grey or brown mould growth on many of the studs.

As indicated by the total number of species isolated from each panel, some panels appeared to be more heavily colonized than others. For the S-series of panels, the highest number of species was isolated from panel S-1, and there are generally progressively less fungi isolated in panels S-2 through S-6. A similar pattern is seen in the N-series. This would indicate that the most favourable conditions for mould growth are present in panels S-1 and N-2, and the conditions are progressively less optimal in the higher numbered panels.

We are not privy to the results of the air analysis, therefore we cannot comment on any correlation between the fungi that we have isolated, and the occurrence of moulds in the air. However, of the fungi isolated, we believe that the relatively high incidence of *Paecilomyces variotii* may be a cause for concern. This mycotoxigenic fungus is known to be common in dust in Canadian homes (Health & Welfare, 1986) and sporulates profusely. It might be considered an indicator species of mould related air quality problems. Although the relatively high number of different mould species may indicate the potential for air problems, this analysis was not quantitative. The results must be compared with the quantitative results from the air sampling to determine if the species isolated are also occurring in the air.

In contrast to the isolations made at time zero for the Waterloo hut, some possible wood-decaying basidiomycetes were isolated from the studs of the Alberta hut. The significance of this is unknown, although it indicates that decay is possible under the moisture conditions present. It is impossible to speculate on changes in structural integrity based on our results. The studs in the Waterloo hut were also heavily colonized with sapstaining fungi, particularly *Ophiostoma* spp. Fewer sapstaining fungi were isolated from the Alberta hut, and apparently no *Ophiostoma* spp.

Notes on the biology of the fungal species isolated to date are included in Appendix One.

Acknowledgement: We are grateful to Lynne Sigler for providing some of the information on pathogenicity of individual fungi presented in Appendix 1.

5.0 REFERENCES

Health and Welfare Canada. 1986. Significance of fungi in indoor air: report of a working group.

Table One

Fungi isolated from Alberta test hut.

Fungus	Panel # S-1	S-2	S-3	S-4	S-5	S-6	N-2	N-3	N-4	N-5	N-6
Alternaria alternata	I	-	-	-	-	-	-	-	-	-	-
Alternaria tenuissima	I	-	-	-	-	-	-	-	-	-	-
Arthrinium phaeospermum	-	I	-	-	-	-	I	-	-	-	-
Ascomycetes	I	-	-	-	-	-	-	-	-	-	-
Aspergillus niger	-	I	-	I	I	-	-	I	-	-	-
Aureobasidium pullulans	I	I	I	I	-	-	-	-	-	-	-
Basidiomycetes	I	-	I	-	-	-	I	-	-	-	-
Byssochlamys fulva	-	-	-	-	-	-	-	-	-	I	-
Fusarium equisiti	-	-	-	I	-	-	-	-	-	-	-
Gliocladium roseum	-	I	-	-	-	-	-	-	-	-	-
Paecilomyces variotii	I	-	I	I	I	-	I	I	I	I	-
Penicillium citrinum	I	-	-	-	-	-	-	-	-	-	-
Penicillium decumbens	-	-	-	-	-	-	-	I	-	-	I
Penicillium mineoluteum	-	-	-	I	I	I	-	I	I	I	I
Penicillium solitum	-	-	-	I	-	-	-	-	-	-	-
Penicillium spinulosum	I	-	-	-	-	-	-	-	-	-	-
Penicillium variabile	-	I	-	-	-	-	-	I	-	-	-
Phialemonium dimorphosporum	I	I	I	-	I	-	I	I	-	-	-
Phialophora sp.	I	I	-	-	-	-	-	-	-	-	-
Phoma sp.	-	I	-	-	-	-	I	-	-	-	-
Rhinocladiella atrovirens	-	-	-	I	-	-	-	-	-	-	-
Sporobolomyces roseus	-	-	I	I	I	-	I	-	I	-	-
Sporothrix sp. 1	-	-	-	-	-	-	-	-	I	-	-
Trichoderma harzianum	I	I	I	I	-	-	I	I	I	I	I
Trichoderma sp.	-	-	-	-	-	-	I	-	-	-	-
Ulocladium atrum	I	I	I	-	-	-	I	-	-	-	-
Verticillium psalliotae	I	I	I	-	-	-	-	-	-	-	-
Total # of species	13	11	8	9	5	1	9	7	5	4	3

I= isolated from samples

Table Two

Fungi isolated from waferboard panels in Alberta test hut.

Fungus	Sample S-3 OSB1	S-3 OSB3	N-3 OSB
Basidiomycete	I	-	-
Paecilomyces variotii	-	I	I
Penicillium chrysogenum	-	-	+
Penicillium spinulosum	I	-	-
Trichoderma harzianum	I	I	-
Ulocladium atrum	I	-	-
Verticillium psalliotae	I	-	-

APPENDIX 1

This appendix includes notes on the fungi isolated from the Alberta test hut, and listed in Tables 1 and 2. These notes are not intended as an extensive review, but rather as points of reference for readers unfamiliar with the fungi. Complete reviews for several species can be found in Domsch et al. (1980).

Alternaria spp.

TAXONOMIC GROUP: Deuteromycetes (moulds).

OCCURRENCE: Plurivorous, including soil, air, plant debris, food (Domsch et al.). Common in house dust (HWC 1986).

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Abundant, dry spores dispersed by air currents.

HUMAN OR ANIMAL PATHOGENICITY: *A. alternata* has been reported as a pathogen of humans and animals (de Hoog 1985), but see notes below.

PLANT PATHOGENICITY: Causes fruit rots and various other plant disease symptoms in a variety of plants (Domsch et al. 1980).

MYCOTOXINS: Alternariols, alterotoxins, tenuazonic acid (Frisvad 1988). See also HWC 1986, p. 27.

OTHER NOTES: *Alternatia alternata* is a name applied to a complex of species, or subspecies, that vary widely in their physiological and pathogenic abilities. The majority of isolates are saprobic, and may be unable to cause infections of plants or animals. Both species recorded here are common in air. *A. alternata* is used as an antigen source to test people for mould allergies.

Arthrinium phaeospermum (Corda) M.B. Ellis

TAXONOMIC GROUP: Deuteromycetes (moulds).

OCCURRENCE: Frequently found on rotting plant material, less frequently in soils. Also on rotten wood, wood pulp and paper.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Dry spores, dispersed by wind.

HUMAN OR ANIMAL PATHOGENICITY: One recent report of cutaneous infection from India (Mycoses 32: 572-475).

PLANT PATHOGENICITY: No.

Aspergillus niger van Tieghm

TAXONOMIC GROUP: Deuteromycetes (moulds).

OCCURRENCE: Plurivorous, in soil, on vegetation, and in the air.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Abundant, dry spores dispersed by air currents.

HUMAN OR ANIMAL PATHOGENICITY: Relatively common from ear infections. Rarely isolated from lung tissue; involvement in aspergillosis is uncertain (Domsch et al. 1980).

PLANT PATHOGENICITY: Causes decay of cotton bolls, "smut" of white fig, and is a potential facultative parasite of potatoes.

MYCOTOXINS: Malformins, napthoquinones, nigragillin.

OTHER NOTES: *Aspergillus niger* is a very common fungus in indoor environments, particularly in bathrooms.

Aureobasidium pullulans (de Bary) Arnaud var. *melanogenum* Herminides-Nijhoff

TAXONOMIC GROUP: Deuteromycetes (black yeasts, sapstain).

OCCURRENCE: Plurivorous, in soil, phylloplane.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Abundant, slimy spores. Growth often yeast-like.

HUMAN OR ANIMAL PATHOGENICITY: Often isolated from human tissues as a contaminant: rarely, if ever, pathogenic (de Hoog 1985).

PLANT PATHOGENICITY: No. Sometimes isolated as an endophyte (Domsch et al. 1980).

OTHER NOTES: *Aureobasidium pullulans*, a "black yeast", is a very common fungus in indoor environments, particularly in bathrooms. It will grow on practically anything provided there is sufficient moisture, but it is not considered to be a dangerous fungus.

Byssochlamys fulva Oliver & G. Smith

TAXONOMIC GROUP: Ascomycetes. Also produces an asexual stage very similar to *Paecilomyces variotii* (see below).

OCCURRENCE: Common in soil, often a contaminant of food.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Abundant, dry asexual spores dispersed by air currents.

HUMAN OR ANIMAL PATHOGENICITY: Unknown.

MYCOTOXINS: Patulin, byssochlamic acid, byssotoxin.

OTHER NOTES: Some of the isolates of *Paecilomyces variotii* may have been this species.

Fusarium equisiti (Corda) Sacc.

TAXONOMIC GROUP: Deuteromycetes.

OCCURRENCE: Common in soil and on plant debris.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Slimy spores.

HUMAN OR ANIMAL PATHOGENICITY: Unknown. Cutaneous and systemic infections caused by *Fusarium* species are being reported with increasing frequency, but so far *F. equisiti* has not been implicated in these infections.

PLANT PATHOGENICITY: A mild root pathogen, not considered of economic importance.

MYCOTOXINS: Equisetin, Trichothecens A, Zearalenone.

Gliocladium roseum Bainier

TAXONOMIC GROUP: Deuteromycetes.

OCCURRENCE: Soil, plant debris, wood.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Abundant slimy spores, probably dispersed by water and/or insects.

HUMAN OR ANIMAL PATHOGENICITY: No.

PLANT PATHOGENICITY: Possible for some forms.

OTHER NOTES: *Gliocladium roseum* is a species aggregate. The form isolated here is isolated relatively frequently from wood. The species is considered an aggressive parasite of other fungi.

Paecilomyces variotii Bainier

TAXONOMIC GROUP: Deuteromycetes (moulds).

OCCURRENCE: Plurivorous. In soil and on plant material.

DISTRIBUTION: Cosmopolitan. Obvious concentration in warmer climates.

MODE OF SPORULATION: Abundant, dry spores dispersed by air currents.

HUMAN OR ANIMAL PATHOGENICITY: Occasionally isolated from man in cases of endocarditis and infection of the lacrymal sacs in pneumonia patients. May colonize necrotic tissue.

MYCOTOXINS: Patulin, byssochlamic acid, variotin.

OTHER NOTES: A common agent of biodeterioration. See also *Byssochlamys fulva* above. These species are easily confused.

Penicillium spp.

TAXONOMIC GROUP: Deuteromycetes (moulds).

OCCURRENCE: Abundant in soil, air, plant debris. Common in house dust (HWC 1986).

DISTRIBUTION: Ubiquitous.

MODE OF SPORULATION: Abundant, dry spores, dispersed by air.

HUMAN OR ANIMAL PATHOGENICITY: No, but probably involved with allergies.

PLANT PATHOGENICITY: No.

MYCOTOXINS: Many, see individual species below.

OTHER NOTES: For specific identification of *Penicillium* spp., it was necessary to purify the cultures and cultivate them using a particular experimental regime. Not all the *Penicillium* colonies on the isolation plates could be reisolated.

Penicillium chrysogenum Thom

OCCURRENCE: Ubiquitous.

DISTRIBUTION: Cosmopolitan.

MYCOTOXINS: Penicillin, PR-Toxin, Roquefortin, Xanthocillin.

Penicillium citrinum Thom

OCCURRENCE: Ubiquitous in soil, decaying vegetation, air.

DISTRIBUTION: Cosmopolitan.

MYCOTOXINS: Citrinin.

NOTES: An extremely common fungus capable of causing biodeterioration of textiles, paints and plastics (Pitt 1988).

Penicillium decumbens Thom

OCCURRENCE: Soil, decaying vegetation, food.

DISTRIBUTION: Cosmopolitan.

HUMAN OR ANIMAL PATHOGENICITY: One record from lungs of diseased chickens.
MYCOTOXINS: Decumbin.

Penicillium mineoluteum Dierckx sensu Pitt
OCCURRENCE: Soil, plant material. Relatively common on wood.
DISTRIBUTION: Cosmopolitan.
NOTES: As noted by Pitt (1988), this species will ultimately be known by a different name. The true *P. mineoluteum* is a different species. Consequently, there is considerable confusion about biological information attributed to this species.

Penicillium solitum Westling
OCCURRENCE: Food.
DISTRIBUTION: Temperate.
PLANT PATHOGENICITY: Pathogenic to apples (Pitt 1988).
MYCOTOXINS: Compactin, Cyclopenin, Viridicatin.

Penicillium spinulosum Thom
OCCURRENCE: Soil, plant debris, dung, food.
DISTRIBUTION: Cosmopolitan.
MYCOTOXINS: Spinulosin, fumigatin (Domsch et al. 1980).
OTHER NOTES: In our experience, the most frequently isolated *Penicillium* sp. on wood in Canada.

Penicillium variabile Sopp
OCCURRENCE: Soil, decaying plant debris, air.
DISTRIBUTION: Cosmopolitan.
MYCOTOXINS: Rugulosin.

Phialemonium dimorphosporum W. Gams & Cooke
TAXONOMIC GROUP: Deuteromycetes.
OCCURRENCE: Soil, water, wood.
DISTRIBUTION: North America.
MODE OF SPORULATION: Slimy spores.
HUMAN OR ANIMAL PATHOGENICITY: One report from human finger nail.
NOTES: The ascomycete reported in Table 1 may represent the sexual state of this fungus. See also notes on *Phialophora* sp. below.

Phialophora sp.
TAXONOMIC GROUP: Deuteromycetes (sapstain).
OCCURRENCE: Plurivorous. Common on wood.
DISTRIBUTION: Cosmopolitan.
MODE OF SPORULATION: Abundant, slimy spores, insect or water dispersed.
HUMAN OR ANIMAL PATHOGENICITY: Some species produce mycotic diseases in man, but these species were not isolated in this study.
PLANT PATHOGENICITY: Some species cause diseases of grasses, but these were not isolated in this study.
OTHER NOTES: Several strains similar to *Phialophora hoffmanii*

and *P. lignicola* were obtained in this study. These two species are very similar, and are also similar in many characters to *Phialemonium dimorphosporum*. Unfortunately, the literature on these three species is incomplete, and it was not possible to assign all isolates to a taxon unequivocally.

Phoma sp.
TAXONOMIC GROUP: Coelomycetes.
OCCURRENCE: Plurivorous. Soil and plant matter.
DISTRIBUTION: Cosmopolitan.
MODE OF SPORULATION: Abundant, slimy spores dispersed by rain or insects.

Rhinocladiella atrovirens Nannfeldt
TAXONOMIC GROUP: Deuteromycetes (moulds, sapstain).
OCCURRENCE: Wood.
DISTRIBUTION: Cosmopolitan.
MODE OF SPORULATION: Abundant, dry spores dispersed by air currents.
HUMAN OR ANIMAL PATHOGENICITY: Not known to cause infection.
OTHER NOTES: A very common fungus on lumber in western Canada.

Sporobolomyces roseus Kluyver & van Neil
TAXONOMIC GROUP: Yeasts.
OCCURRENCE: Aerial contaminants, decaying plant material.
DISTRIBUTION: Cosmopolitan.
MODE OF SPORULATION: Yeast-like growth, spores shot off violently.
OTHER NOTES: A widely distributed, benign organism.

Sporothrix sp. 1
HUMAN OR ANIMAL PATHOGENICITY: Pathogenic species of *Sporothrix* are known: however, the species isolated in this study is not one of these known pathogenic species.
PLANT PATHOGENICITY: Possible. However, the species isolated is likely to be a saprobic sapstaining fungus.
OTHER NOTES: This species is presently undescribed, but is a common inhabitant of lumber in western Canada.

Trichoderma sp.
TAXONOMIC GROUP: Deuteromycetes (mould).
OCCURRENCE: Wood, soil, food.
DISTRIBUTION: Ubiquitous.
HUMAN OR ANIMAL PATHOGENICITY: No.
PLANT PATHOGENICITY: No.
MYCOTOXINS: Many toxic metabolites known.
OTHER NOTES: Identification of *Trichoderma* species isolated during this study is continuing.

Trichoderma harzianum Rifai
OCCURRENCE: Soil, wood, plant debris. Common in house dust

(HWC 1986).

DISTRIBUTION: Cosmopolitan.

HUMAN OR ANIMAL PATHOGENICITY: No.

PLANT PATHOGENICITY: No.

MYCOTOXINS: Gliotoxin, trichodermin, trichoverrins (HWC 1986).

OTHER NOTES: Known to be an aggressive parasite of other fungi. Used as a biological control agent.

Ulocladium atrum Preuss

TAXONOMIC GROUP: Deuteromycetes (moulds).

OCCURRENCE: Wood, seeds, leaves and stems.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Abundant dry spores dispersed by air currents.

Verticillium psalliotae Treschow

TAXONOMIC GROUP: Deuteromycetes (moulds).

OCCURRENCE: Plants and insects.

DISTRIBUTION: Cosmopolitan.

MODE OF SPORULATION: Abundant, slimy spores dispersed by water or insects.

HUMAN OR ANIMAL PATHOGENICITY: No.

PLANT PATHOGENICITY: Brown spot disease in cultivated mushrooms. Parasitic on insects.

References Cited in Appendix

Domsch, K. H., W. Gams and T.-H. Anderson. 1980. Compendium of soil fungi. Academic Press, London, New York, Toronto, Sidney, San Francisco.

Frisvad, J. C. 1988. Fungal species and their specific production of mycotoxins. pp. 239-249. In: Introduction to Food-Borne Fungi, 3rd ed. R. A. Samson and E. S. van Reenan-Hoekstra. Centraalbureau voor Schimmelcultures, Baarn, Netherlands.

Health and Welfare Canada. 1986. Significance of fungi in indoor air: report of a working group.

de Hoog, G. S. 1985. On the potentially pathogenic dematiaceous Hyphomycetes. pp. 149-216. In: Fungi Pathogenic for Humans and Animals, Part A. Ed. D. H. Howard.

Pitt, J. I. 1988. A laboratory guide to common *Penicillium* species. CSIRO, North Ryde, Australia.

APPENDIX TWO

Details of methodology employed, extracted from the 1st Interim Report for this project.

Work on Site

The studs were inspected for evidence of fungal growth as the panel frames were constructed, or in some cases, in the fog chamber after construction. Fungal growth was evident by grey to black patches of sapstain and pockets of softened, evidently decayed wood. An estimate of the extent of sapstain was made using a subjective 0 to 5 rating scale, with 0 being no sapstain and 5 being complete coverage with sapstain.

Two kinds of samples were removed from the studs for subsequent isolation work. Wood shavings were removed using a small plane, and stored in sterile polystyrene test tubes. Sterile swabs were passed along a length of wood to collect superficial spores, and stored in sterile polystyrene tubes for transport back to the laboratory.

Laboratory Work

Isolations were made from the collected material two days after sampling. Two percent malt extract agar (2% MA) supplemented with 100 µg/mL of the antibacterial antibiotic tetracycline was used as a basal medium for all isolations. In an attempt to isolate wood decaying fungi, 2% MA was supplemented with 2 µg/mL Benomyl. This compound inhibits the growth of many fungi, but is less inhibitory to wood decaying fungi.

The wood samples were examined directly for evidence of fungal growth using a stereo dissecting microscope at 32 x and 50 X magnification. Isolations were made by streaking the sample swabs across 6 cm petri dishes containing 2% MA or 2% MA with benomyl. In addition, small slivers were removed from the wood samples, and placed on the agar media. Incubations were carried out at 27°C, 75% RH, in the dark. Plates were examined periodically for signs of growth. Identifications were made directly from the isolation plates when possible. Selected fungi were transferred onto 2% MA with no additives for subsequent identifications.

Some fungal groups require specialized techniques for identification. *Penicillium* species were identified using the manual and methods of Pitt (1988), *Aspergillus* species using Klich and Pitt (1988) and *Fusarium* using Nelson et al. (1983).

References cited in this appendix:

Klich, M.A. and J.I. Pitt. 1988. A laboratory guide to common *Aspergillus* species and their teleomorphs. CSIRO, North Ryde, Australia.

Nelson, P.E., T.A. Toussoun and W.F.O. Marasas. 1983. *Fusarium* species, an illustrated manual for identification. Pennsylvania State U. Press., University Park & London.

Pitt, J.I. 1988. A laboratory guide to common *Penicillium* species, 2nd edition. CSIRO, North Ryde, Australia.

APPENDIX THREE

AIR SAMPLING PROTOCOL

Microbiological Testing of Wall Cavity Air Samples

The following is a summary of the test protocol for air sampling from wall cavities, prepared by Dr. Miller of Agriculture Canada:

1. Air sampling from each wall panel will be done by on-site staff by extracting 100 L (3.5 ft^3) of air from the central cavity of each wall panel. Air will be drawn from the cavity through an in-line 0.45 μm Millipore 3-piece monitor (40 mm diameter). An oil-less vacuum pump should be used to draw the air sample through the filter to prevent contamination of the filter. Samples will be appropriately packaged and sent by overnight courier to the Agriculture Canada, Ottawa offices.
2. Analysis of the samples will be done by:
   - removing the filter under aseptic conditions and placing in a sterile 250 ml flask containing 20 ml of 0.1% Tween 20 solution. The flask will be placed on a rotary shaker at 200 rpm for 1 hour.
   - spreading the plate in triplicate on a 2% malt extract agar and 2% malt extract agar with 35 mg/L rose bengal at 0, 10, and 100-fold dilutions.
   - counting fungal colonies (in CFU/L) and identifying species where possible.