RESEARCH REPORT

Moisture in Straw Bale Housing Nova Scotia

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Moisture In Straw Bale Housing
Nova Scotia

Final Report, November 1998

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ABSTRACT

The two main areas of interest in this study were: to test the 'breathability' of straw bale walls finished with a cement-based stucco on interior and exterior surfaces using a standard 'blower door' apparatus; and to monitor for one year the moisture content in straw bale walls in occupied houses, using a 'low-tech', easily replicable and inexpensive sensor assembly. Four houses in Nova Scotia were included for the study. The findings of this study will be of interest to those building with straw bale and other alternative building materials.

EXECUTIVE SUMMARY

Given the use of straw bales as building materials in several houses in the Atlantic Canada region over the past few years, the investigators saw a need to test and monitor the performance of these houses vis a vis moisture issues. The two main areas of interest in this study were: to test the 'breathability' of straw bale walls finished with a cement-based stucco on interior and exterior surfaces; and to monitor for one year the moisture content in straw bale walls in occupied houses in the region.

Four houses in Nova Scotia were chosen for the study. Each house differs in construction and finish technique, as well as in the attention paid to air sealing techniques and roof/ceiling/floor insulation for energy efficiency. However, all four houses feature straw bale walls finished with a cement based stucco (one with a soil-cement stucco, the other three with a conventional three coat cement stucco).

'Breathability' was tested by using the CGSB standard for air tightness testing and the Minneapolis Blower Door Apparatus, as used on housing of all types and ages. The results of this test indicate how many times the volume of air within the building envelope change at an induced pressure of 50Pa. This result is commonly used to gauge how 'leaky' any given house is, and also to discover the areas where the air leakage occurs. In all of the houses in the study, air leakage was found in the same areas as is typical to stick-frame construction of any vintage (to a greater or lesser degree): joist/header areas, wall/ceiling junction, penetrations through ceilings and walls, and incomplete air sealing at door and window frames. In the house with the lowest air test result (3.13ACH), the owner/builders had paid particular attention to air sealing in such areas as the wall/ceiling junction, the potlight and plumbing penetrations into the attic space and the spaces between the window units and the rough openings. Although this air test does not definitively prove or disprove claims of 'breathable' cement-based stuccoed straw bale walls, it does prove that air sealing techniques can be applied to any building media.

The results of the monitoring program indicate that the four houses tested have seasonal swings in moisture content, but apart from a few instances of actual water leakage into the walls (due to a leaky pipe in one case and a leaky roof in another), the average moisture content in the walls swings from readings of 6.8% in December/January to 12.2% in July, well under the 20% MC thought to be the threshold for structural and healthful damage to straw bale walls. These results auger well for those who wish to build with straw bale in this region where moisture issues due to climate can be problematic in the built environment.

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INTRODUCTION

Interest in straw bale construction has increased over the past decade in all regions of North America and parts of Europe. Although there are not large numbers of these houses built to date, the interest expressed in the construction method is widespread. High insulation levels, ease of assembly and the sustainable use of an annually renewable waste crop and the 'breathability' of the wall system are some of the merits of building attributed to straw bale construction.

Breathability can refer either to air movement through walls or to moiture movement. There has been much theoretical discussion about straw bale houses that centres on the healthfulness of this breathability, but not much discernible information available. The use of straw as a major component of an exterior wall assembly sends shivers down the spine of most conventional builders and potential home owners. One of the first questions asked is always: "what about moisture?' Most of the straw bale houses built to date are in warm and arid climates where concern about moisture revolves around its absence. Partially as a result of this, and partly because of demands from building code officials for proof of structural performance, technical research on straw bale construction has been mainly concentrated on those properties of straw and straw bales which relate directly to structural capacity or thermal resistance qualities.

Moisture in housing is one area of great concern in Canadian climates because the varying temperatures and humidity levels can result in the prime growing environment for moulds, some of which can cause allergies, asthma and other health problems. Moisture is also a serious problem for housing in the Atlantic Canada Region (Nova Scotia, New Brunswick, Prince Edward Island, Newfoundland and Labrador). We are located between the Atlantic Ocean and the Gulf of St. Lawrence, both of which remain unfrozen throughout the winter and contribute to fairly high relative humidity levels throughout the year. Our weather patterns are influenced by two major systems. The continental system comes from the north and northwest and the coastal system brings southerly and southwesterly weather from the Atlantic coast area of the US. As a result of the interaction of these two systems, we have changeable weather that can differ widely across the region on any given day. As well, settlement in this region is primarily in coastal and near coastal regions, where housing is subjected to multiple sources of multiple forms of moisture. High humidity, fog in coastal areas, rainfall with high winds and general wet weather conditions can produce long periods of poor drying conditions for construction materials in general.

Moisture issues in mainstream housing range from the common use of wet or unseasoned local lumber to foundation leakage, poor site drainage, drywall nail pops, leaks. floor squeaks. truss uplift and condensation problems. As well, poor installation of air and vapour barriers leads to deterioration of wall, ceiling and floor materials and finishes, excessive moisture in crawl spaces due to 'rising damp', high humidity related to poor ventilation of living spaces. Straw builders have to deal with all of these issues plus ones which are specific to straw: liquid moisture penetration, potential freeze/thaw spalling of exterior stucco finishes resulting in water damage, etc. Moisture content in straw bale walls is one aspect of the data required to come to an understanding of the tolerances and limits of this type of building in our climate.

Simple observation of a straw bale left out in the weather shows that after a few weeks or months, depending on the season, the straw begins to rot and mould and mildew growth is easily noted.[1] Without detailed analysis of what grows on said bale, we can conclude that under wet conditions, straw bales are a welcoming environment for microbial activity.[2] The actual measuring of colony forming units and species of moulds is beyond the scope of this investigation, but moisture testing can be one indicator of a 'mould-friendly' environment. Monitoring of one house in Nova Scotia has given some encouraging data on moisture levels in straw bale walls. Of great concern in cold, damp climates is the impact of water vapour on buildings in general.

1 The infamous 'fetid goo' described in graphic detail by David Eisenburg on the straw bale internet list.

2 "Deterioration of the straw can be a result of microbial activity, such as growth, survival, death, sporulation and toxin production. This activity is a function of such environmental variables as temperature, pH, oxygen, radiation and availability of moisture...It is a rule of thumb that below approximately 70% equilibrium relative humidity [approx. 20% moisture content], little microbial activity occurs and the straw is stable."
From the paper presented at the Agricultural Institute of Canada Annual Conference, 1995 on the Ship Harbour, Nova Scotia Project (*Thermal and Mechanical Properties of Straw Bales as They Relate to a Straw House*, 1995. Wilkie, Watts, Thompson & Corson).

WALL BREATHABILITY

1.0 Air Tightness Testing Results

This study used typical blower door equipment (Minneapolis Blower Door Model 3) and accepted standards and protocols to perform air tightness testing on four straw bale houses in Nova Scotia. Each house was tested 'as operated' and for the CGSB standard (as per NRCan/CANMET guidelines). Interior and exterior relative humidity and temperature levels were recorded, as were any notable air leakage points. All houses were investigated for ways in which homeowners can easily and affordably reduce their energy needs further

Table 1.a: CGSB Standard

	ACH @ 50 PA	VOLUME (m3)	SUR. AREA (m2)	ELA (cm2)	NLA
NSPSB01	3.1	423.4	502.7	470.9	0.9
NSPSB02	10.6	411.2	484.2	1382.4	2.8
NSPSB03	14.7	99.3	140.1	587.2	4.2
NSPSB04	10.7	477.9	307.9	2280.7	7.1
MIN	3.1	99.3	140.1	470.9	0.9
MAX	14.7	477.9	502.7	2280.7	7.1
MEAN	9.8	352.9	358.7	1180.3	3.8
STD DEV	4.8	171.6	170.2	838.0	2.6

Table 1.b: As Operated Results

	ACH @ 50 PA	VOLUME (m3)	SUR. AREA (m2)	ELA (cm2)	NLA
NSPSB01	3.1	423.4	502.7	449.1	0.9
NSPSB02	10.6	411.2	484.2	1382.4	2.8
NSPSB03	16.1	99.3	140.1	637.3	4.6
NSPSB04	10.7	477.9	307.9	2280.7	7.4
MIN	3.1	99.3	140.1	449.1	0.9
MAX	16.1	477.9	502.7	2280.7	7.4
MEAN	10.2	352.9	358.7	1187.4	3.9
STD DEV	5.3	171.6	170.2	832.9	2.8

1.1 Noticeable leakage areas

1.1a Straw Bale Walls

- Slight leakage at some electrical outlets on exterior walls where interior plaster is cracked or pulled away from the electrical box (electrical boxes 'bagged' in duct tape not leaking at all)

- Any testing holes and/or 'truth windows' without glass in front of the exposed straw

- Gaps/cracks at the top of wall to ceiling/rafter connection (plaster/stucco pulled away or not quite reaching)

- Window frames at the connection between the frame and the rough buck or straw where no silicone or latex caulking was used to seal the opening at the buck/stucco connection

1.1b Other locations:

- Connection between door bucks to door and/or window frames (present in all houses tested, but not in all doors or windows in all houses)

- 600 x 600mm (2x2 ft) ventilation windows (one house) filled with friction-fit rigid foam insulation

- At electrical service penetration

- Daylight visible at the window frame (one window in one house)

- Plumbing penetration through exterior wall and/or through slab

- Wood transfer box (one house, 900 x 1200mm (3x4 ft) ft hole with minimal weather stripping)

- Root cellar/continuous open dirt floor in greenhouse area (one house)

- Subfloor connection to post foundation (one house)

- Handmade door/latch (minimal weather stripping present) (three houses, not every door leaked)

- Attic hatch (one house)

- Rafter/roof decking at cathedral ceiling areas

- Salvaged single pane casement windows (one house, two windows)

- HRV ductwork in attic (one house)

- Some operable windows that had been salvaged, especially horizontal sliders

- Potlights in ceiling penetrating to attic (one house)

1.2 Discussion

It is felt that the majority of the typical leakage points found in the four straw bale houses tested are those found in conventionally built housing and are not inherent to the process of straw bale construction, unless the higher ratio of owner/builders to professional builders can be deemed an inherent part of the process. Houses created by owner/builders do not always feature those aspects of tighter, energy efficient building that typical stick-frame builders exhibit in most new house construction. All four of these houses were owner-built with varying degrees of input by professional contractors and with vastly different construction budgets.

Salvaged building materials were predominant in all houses, including windows. There is a higher percentage of site built and hand fashioned elements in all houses which do not fit well in the realm airtight building, including hand fashioned doors and latches, handcrafted stained glass windows site-built frames for windows. Temporary measures such as natural ventilation hatches sealed for winter with friction-fit rigid insulation, a dirt-floored root cellar with no continuous seal to the living space and a wood transfer box open to the outside with non-continuous weatherstripping all contribute to heavy leakage in three of the four houses. Again, these have nothing to do with the stuccoed straw bale walls and everything to do with owner/builder lifestyle choices and the longer finishing process that is fairly typical of owner/built housing.

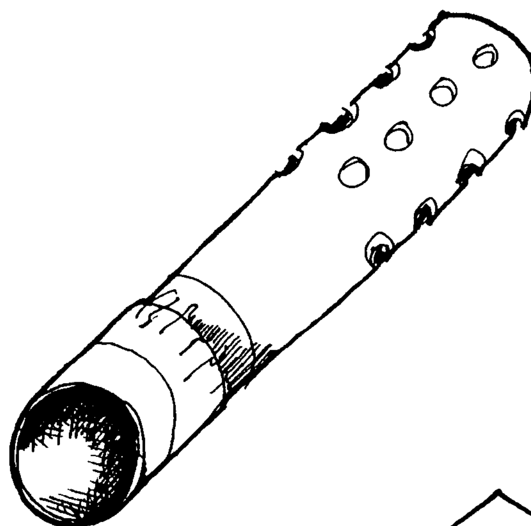
In conclusion, the results indicate that a straw bale house, plastered inside and out with cement-based stucco, can be as tight as (or possibly tighter than) conventional housing if attention is paid to air sealing at roof and ceiling areas, door and window frames and rim joists,etc. However, houses only roughly finished will be far from airtight and will likely suffer the drafts and energy costs associated with leaky buildings. The type of testing used does not quantify the rates of air and moisture transfusion through 'breathable' walls, but does indicate that a cold-climate home featuring stuccoed straw bale walls with no plastic vapour barrier can be made tight enough to warrant mechanical ventilation to maintain high indoor air quality, regardless of finish materials used.

MOISTURE CONTENT MONITORING

2.0 Moisture Content Sensors

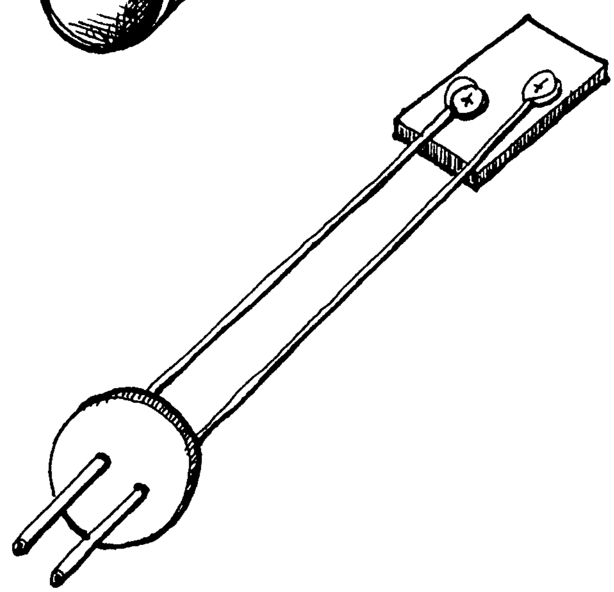
The moisture content of the bale walls was recorded using an Electrophysics wood moisture meter and a modified version of the wood block sensors described in the CMHC funded Straw Bale Moisture Sensor Study (Instruscience Ltd, Research Consultant). The modifications were made in an effort to create a working sensor that is easily replicated and almost free to build.

2.0a The sensor housing



Salvaged 36mm (1.5") diameter ABS piping were cut to 230mm (9") lengths. These lengths of pipe had a series of four 6 mm (0.25") diameter holes drilled through each quadrant of the first 100mm (4") from one end. Discarded film canisters were obtained from the local 1-hour photofinisher to be used to seal the other end of the sensor housing.The bottoms of each canister were cut and a prepared length of drilled ABS pipe was pushed into the bottom, extending into the canister by about 20 mm (0.75"). Red contractor's tape was used to seal these two pieces together.

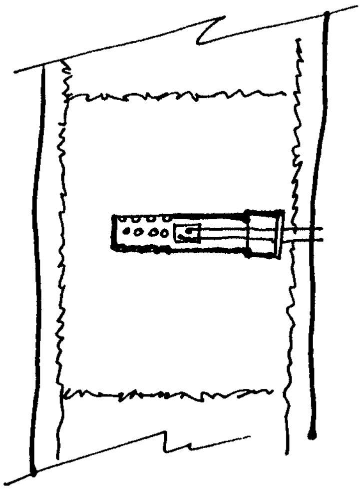
2.0b The sensor



A 38 x 32 x 3mm (1.5 x 1.25 x 0.125 inch) block of white pine was drilled through and two 6 mm (0.25") stainless steel screws with nuts were inserted in the drilled holes. Cast-off electrical wiring from building sites was cut into 300mm (12") lengths and had the ends stripped of their plastic coating to hook over the stainless steel screws. Two leads were attached to each block and each pair of leads was pushed through the pre-drilled holes in the soft lids of the film canister. (It was found that the type of canister with a softer plastic lid and uniform surface offered a better seal. The soft top of each canister was drilled through twice using a bit slightly smaller than the diameter of the salvaged wire leads.)

This sensor assembly was placed on the completed body of the housing after the housing was placed in the wall (to prevent the sensor from being pushed too far back into the unit and being exposed to the straw. The whole assembly is about 280mm (11") long, not counting the tails of the wire leads sticking out of the canister lid (100 to 150mm/ 4 to 6 inches). The moisture content in the wood block was recorded before being installed.

The sensor bodies were inserted into existing finished bale walls by first drilling and gouging out a 50mm (2") diameter hole in the stucco surface. A small plastic bag taped to the wall immediately below the location of the hole helped to keep the mess and dust to a minimum (wide masking tape was used here). A 900mm (36") length of dowel was sharpened and used to create a cavity in the bale behind the stucco. This was accomplished by hammering the dowel into the wall to a depth marked on the dowel equal to the average length of the sensor housing plus two inches for the depth of plaster.



The sensor housing was placed in the wall until it was slightly behind the bale-side surface of the stucco finish. The dowel was used to push it in further in necessary. A quick inspection of the empty housing was made to ensure no straw was invading the inner part of the housing above the drilled holes, and then the sensor unit was installed in the housing, with the end of the block approximately 130mm (5") down the housing to allow an inch or two of solid pipe between the sensor and the drilled holes. Sensor bodies were installed into walls so that the wood block sensor sits about halfway through the bale wall (approximately 230mm or 9"). The canister lid was then sealed onto the canister, the leads pulled straight and positioned to fit the width of the moisture meter pins, and the hole replastered. After the plaster dried, the leads were cut flush to the surface of the wall, or left slightly protruding, depending on the ease of access. All sensor sites were refinished to homeowners requirements.

2.0c Sensor Costs

The sensor materials cost approximately $42.78, including BST (stainless steel nuts & bolts, red contractor's tape), or $0.89 per sensor

The materials required to install the sensors cost approximately $54.50 including BST (cold chisel, large diameter masonry bit, Portland cement, small trowel and tray), or $1.13 per sensor

Labour was not included in this costing, as it is assumed that most straw builders are owner/builders and would do this particular task with unwaged labour. The estimated labour time to build and install 12 sensors is 3 hours (building sensors, about one hour; installing sensors about two hours — determining and preparing sites, drilling holes, installing housing, placing and sealing sensor unit in housing, replastering holes and refinishing walls) Installation time is reduced considerably when sensors are installed before walls are plastered (12 sensors in NSPSB02 were in place within 15 minutes in unplastered walls)

The total cost per sensor (materials only) is $2.02 including BST (15%). The total cost for building and installing 48 sensors was $96.96.

2.1 Sensor Readings

The moisture meter used in this study was an Electrophysics unit, model #CMT908, which features two modes of operation — pin and pinless mode. The unit was chosen because of the number of wood groups (16) and wood species (200) to which it can be calibrated. In addition, the pinless mode can be used to measure surface moisture content of materials, and the manual includes instructions on how to use the meter to quantify the moisture content of materials other than wood.

All sensors were tested for their moisture content immediately before installation, and all showed a moisture content for Eastern White Pine of 12%. The moisture meter was set at wood group density 16 and species density 35. All first readings were taken at least one week after the sensor had been installed and the hole replastered, to allow the wall and the sensor to regain equilibrium.

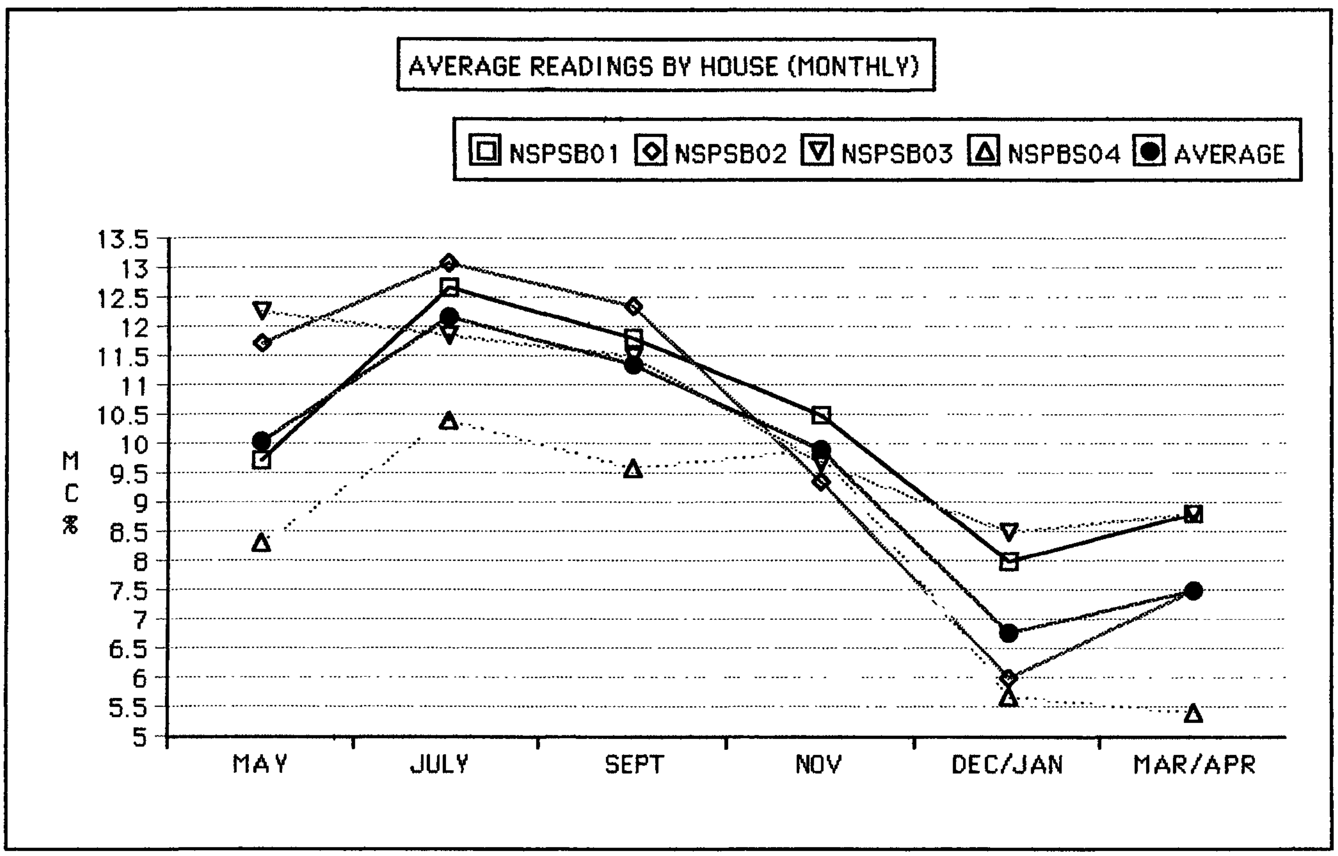
Three sensors were placed on each of the four main walls of each house.Readings were taken from May 1997 through to late April 1998. Interior and exterior air temperatures as well as relative humidity levels were also recorded at each visit. Where necessary, adjustments were made to readings to reflect the difference between outside temperatures below -20°C and the temperature of the wood block located in the centre of the straw bale.

To create as relevant a body of knowledge as possible, moisture content readings were done at six to eight week intervals over one year. This will show variations in moisture content in relation to the following:

- During the heating season, when the houses are closed up and the highest level of moisture is being generated from inside the house, potentially causing higher microbial activity inside the building envelope.
- During late August or early September, when the ambient relative humidity levels are highest in the Maritime Region, and past monitoring has shown that the straw bale walls have the highest relative humidity.[3] This, along with the warmer ambient temperatures, could be the basis for a higher level of microbial activity.

2.1a Summary of average MC readings by month

Chart of average monthly readings by house follows.
Tables for all readings are found in Section VI, pp1-6.



3 Ibid.

2.1b Summary of average MC readings by orientation

Average moisture content readings in walls (all houses):

S,SE: 9.2	W,SW: 8.9	N,NW: 9.4	E,NE: 9.3

On average, moisture content readings in the walls were highest in July.

S,SE: 11.5	W,SW: 11.4	N,NW: 12.0	E,NE: 13.3

On average, moisture content readings in walls were lowest in January.

S,SE: 6.8	W,SW: 6.3	N,NW: 7.0	E,NE: 6.9

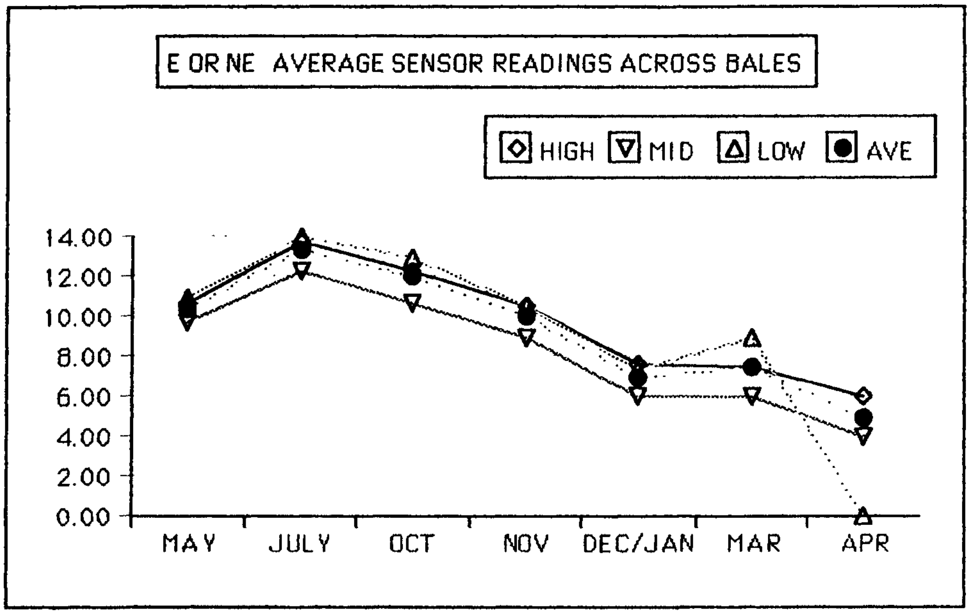
On average, moisture content is higher at the following sensor locations:

S,SE: top bale	W, SW: low bale	N, NW:middle bale	E, NE: low bale

On average, moisture content is higher at the following sensor locations:

S,SE: middle bale	W, SW: top bale	N, NW: top bale	E, NE: middle bale

Charts of results follow.
Tables of all readings are found in Appendices A & B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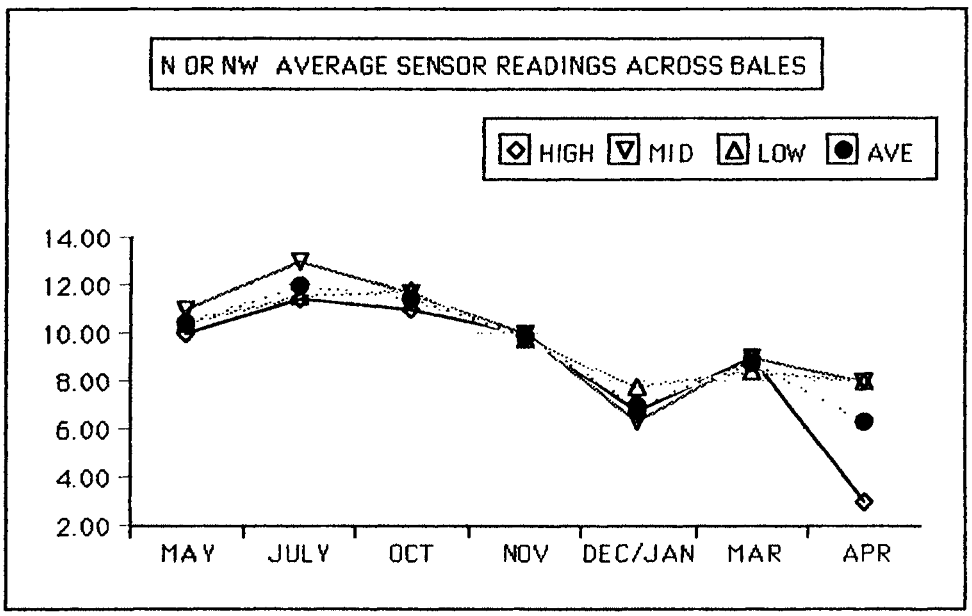
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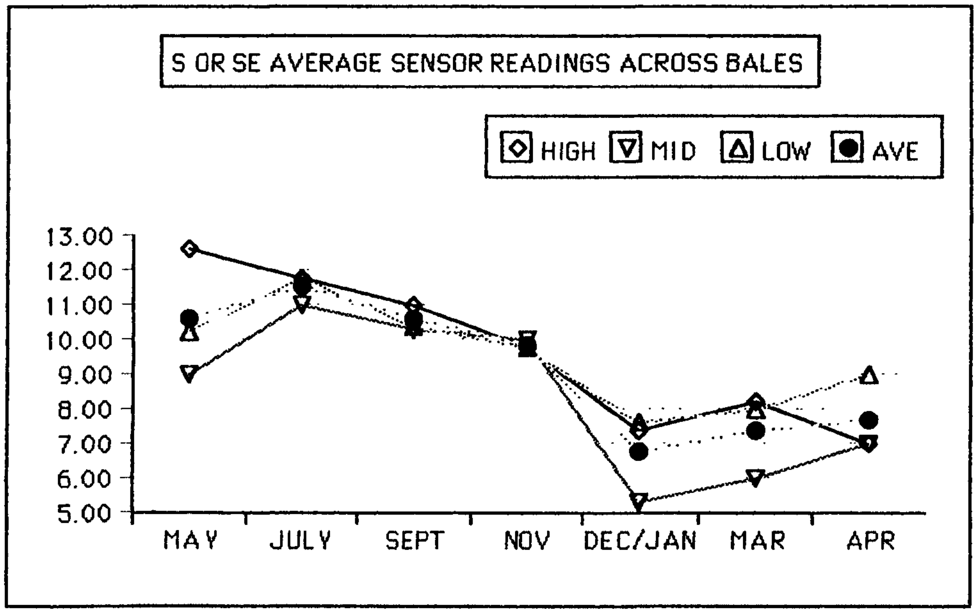
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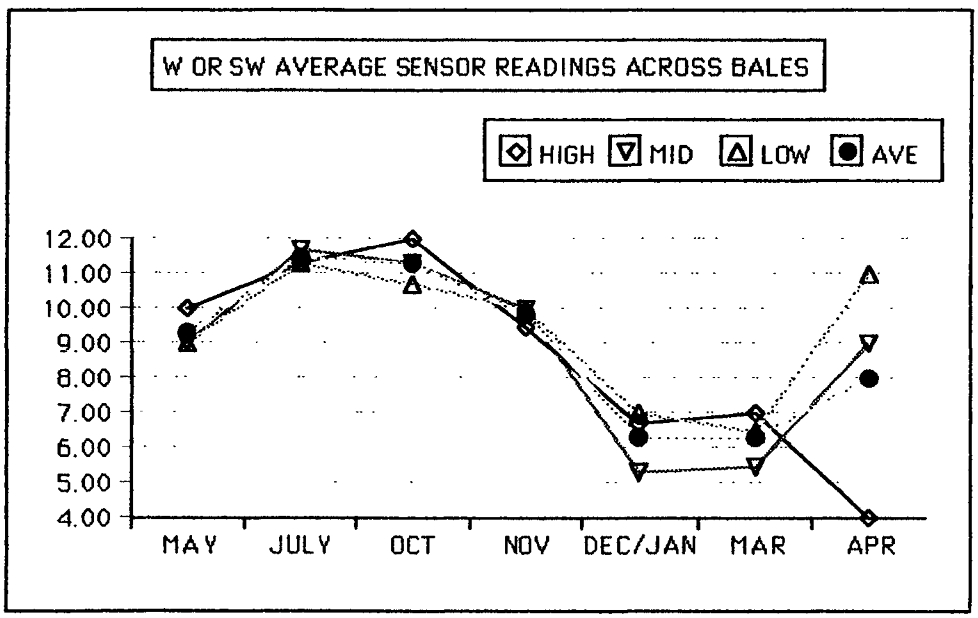
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2.2 Discussion

Moisture content readings in NSPSB01 varied slightly higher than the average except in May, increasing in variation from average (to + 1%) over the period of December through March. However, the trend in this house reflects the overall trend of the bale walls increasing in MC over the warm weather months, and decreasing over the heating season. On average, the walls to the W were driest (9.6%) while walls to the E were wetter (10.9%). One anomalous reading was taken in the E (17%) in July.

NSPSB02 was the most recently built of the houses in the study. The plastering activity that went on during the first half of the study period showing up as roughly one percent higher than the average readings for the months of May through September and then evening out to a closer to average reading for the remainder of the study period. On average, the walls to the N were driest (9.7%) while walls to the W were wetter (10.2%).

The moisture content reading in May for NSPSB03 were higher than average (+ 2.2%). One reading was well above the others (19%), at a location known to have been subject to leaking from the roof. This went down rapidly to meet the average readings for July through November, and then rose again above average levels for Dec/Jan and March readings (+1.5%). This is probably accounted for by the removal of an oversized tarp that was used to protect the leaking roof which was removed in June. This, combined with the operation of a small 75mm (3") 50l/s (100cfm) fan most likely account for the drying trend in this house while the MC in the walls of the other three houses was going up through July. On average, the moisture content in the bale walls to the N and S was equally distributed (10.5%).

The house with the consistently lowest overall MC (NSPSB04) is also the oldest of the four houses. This house differs from the other three in that it is built on a pole foundation, with half bales set into a 'cradle' in the floor joists (see discussion of individual houses). The other three houses are variations of slab-on-grade foundations (insulated monolithic raft, frostwall with poured slab, shallow frost protected footing with poured slab and straw insulation under). On average, the walls to the E,NE were driest (6.9%) while walls to the N,NW were wetter (8.6%).

The monitoring program showed one high peak period (during the summer) of MC in bale walls, whereas the study on the Ship Harbour project, carried out with nearly constant monitoring by computerised system, showed a slight rise during the heating season as well. The graphs on page 11 and 12 show a fairly distinct curve of high MC in walls (all orientations) that begins in March and peaks in July, then falls through the heating season until December/January. The one house with a low air change rate also is the only house with a mechanical ventilation system, which, when used consistently though the heating season, keeps indoor humidity in check. When lower exterior RH levels in the winter are also considered, this sounds like a plausible reason for lower moisture content in the bale walls.

Graphically, we see that the highest average MC in July was in the E,NE walls, while the W,SW were the lowest. The highest average MC in December/January was in the N,NW walls with the W,SW walls being the lowest. May and November readings are roughly the same.

Another finding during this study was the presence of huge quantities of plant or 'plaster' mites in the houses during the first summer after plastering, but only in houses, or areas of houses which had been finished with latex paint. Those areas finished with limewash were not affected by the infestation. The insects did not reappear in quantity the next year. A sample taken from house NSPSB02 in the spring of 1997 showed the following species of insects present: plant mites (ca.200), weevils, fungus gnats, drosophila sp. and 3 springtails (known to be cellulose eaters, especially by librarians). The sample was examined by a biologist at the Nova Scotia Museum of Natural History. A discussion with an old-time plasterer indicated that the presence of these creatures sometime after plastering was not unexpected, and that 'they just go away'. That is, at least in Nova Scotia.

2.2 Conclusions

The results of the air tightness testing indicate that a straw bale house, plastered inside and out with cement-based stucco, can be as tight as (or possibly tighter than) conventional housing if attention is paid to air sealing at roof and ceiling areas, door and window frames and rim joists,etc. However, houses only roughly finished will be far from airtight and will likely suffer the drafts and energy costs associated with leaky buildings. The type of testing used does not quantify the rates of air and moisture transfusion through 'breathable' walls, but does indicate that a cold-climate home featuring stuccoed straw bale walls with no plastic vapour barrier can be made tight enough to warrant mechanical ventilation to maintain high indoor air quality, regardless of finish materials used.

The results of the moisture monitoring portion of the study indicate that there is a higher moisture content at the mid-point of the bales in stuccoed walls during the summer in Nova Scotia. This rise in MC begins in March (ave reading: 7.5%MC) and peaks in July (ave reading: 12.2%MC) then falls through the heating season until December/January (ave reading: 6.8% MC). The summertime peak does not come close to the 20% MC level, which is regarded as the 'crisis' point for bale walls which, when coupled with consistent temperature levels of 20°C (70°F) could offer a prime colonizing environment for organisms which could destroy the integrity of the bale walls. This would indicate that strawbale construction is viable in Nova Scotia, however, in light of testing in Alberta that indicates much higher MC levels at the exterior face of bales under stucco, further monitoring should be done to determine if this is the case in the Maritime environment as well.

APPENDIX A: FIELD NOTES ON INDIVIDUAL HOUSES

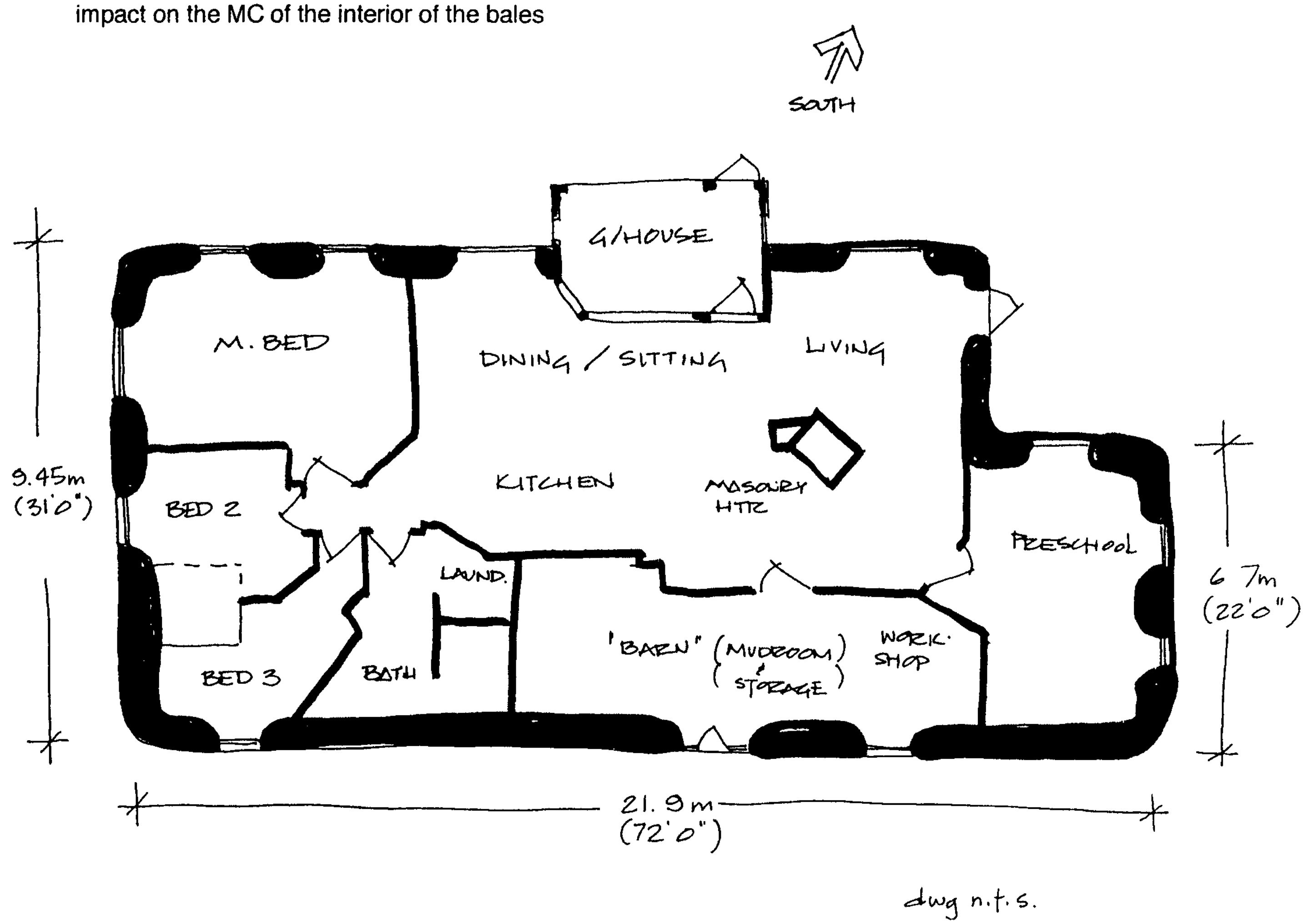
NSPSB01 (St. Margaret's Bay)

This house was built in the summer of 1995 on a monolithic slab with an 200mm (8") concrete curb wall to bring the bottom course of bales up above the splash zone. A 185 8 m2 (2000 s.f.) single storey building, it has a strong passive solar aspect, being situated at the top of a SSE facing hill. It is well protected around the W, N and NE quadrants by an established spruce forest, but is exposed on the S and SE to St. Margaret's Bay. The SE exposure has been problematic in the past, at one window in particular. Heavy winds carrying driving rain come out of this quadrant and push the rain to near horizontal Surface water and capillary action caused serious leakage at the southern-most E window until the window out and a new flashing detail was put in place

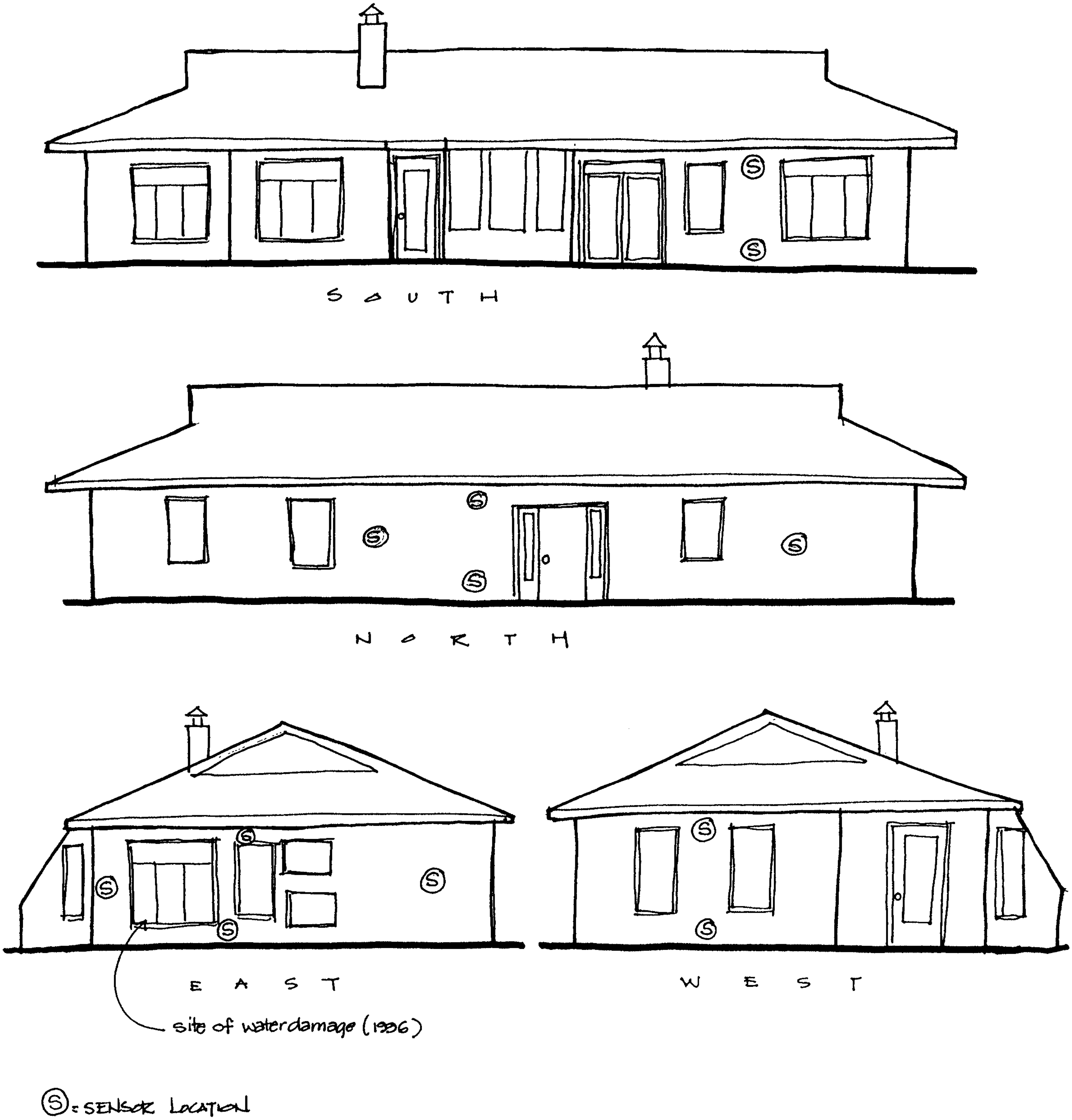
A 'Dutch hip' truss roof with metal cladding surmounts the load bearing walls (with a 6.7m/22 ft post and beam area over the greenhouse) and provides 600mm (24") overhangs all around for protection from the weather Ceiling insulation is R-50 blown in cellulose. Windows are low-e, argon with insulated fibreglass frames

The two string bale walls of this house are covered in 50 to 75mm (2 to 3") of concrete stucco, applied in three coats over the straw and 75mm (3") square galvanized fencing (less expensive than stucco wire) The scratch coat (inside and out) had lime to portland ratio of 1:2; the brown coat was a 1:1 ratio, and the finish coat was 2 1 lime. Walls were then painted with no VOC latex paints

The interior of this house was re-painted just before July readings were taken, which may have had a small impact on the MC of the interior of the bales



NSPSB01 (St. Margaret's Bay)



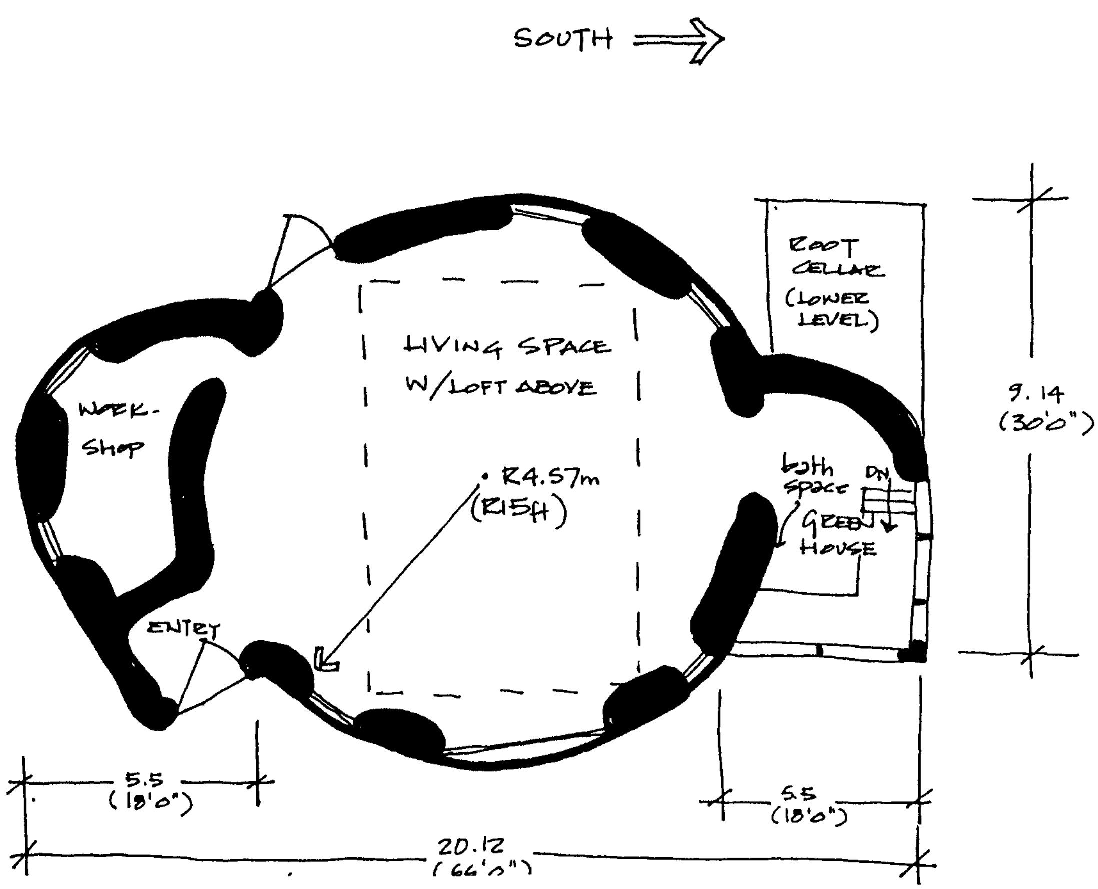
NSPSB02 (Walton)

This is the newest of the houses in this study. The two-string straw bales were set into the post and beam frame in fall 1996. It is a single storey house with a loft area above the central room. The layout roughly consists of three circles butted together under a rectangular post and beam roof that creates varying overhangs. The S circle is a greenhouse/bathing area with a root cellar to the E. The central circle is a living/dining/kitchen area with sleeping loft above. The N circle is a workshop. The house is situated in a clearing in a well-established forest at the top of a cliff overlooking the Bay of Fundy. The N and E sides of the house are extremely well protected, while S has been cleared somewhat for solar gain. The W face is open to the Bay of Fundy, and receives the brunt of winter gale-force winds coming from the N and NW. However, these winds seldom carry rain. The house sits on a slab foundation insulated with straw bales and has a living roof over rafters in the single story areas. The sleeping loft has a 12/12/ pitch and has a metal roof over rafters. Blown-in cellulose insulation in the roofs is approximately R40. The windows are a mix of double pane, thermopane and salvaged single pane 'feature' windows from various sources.

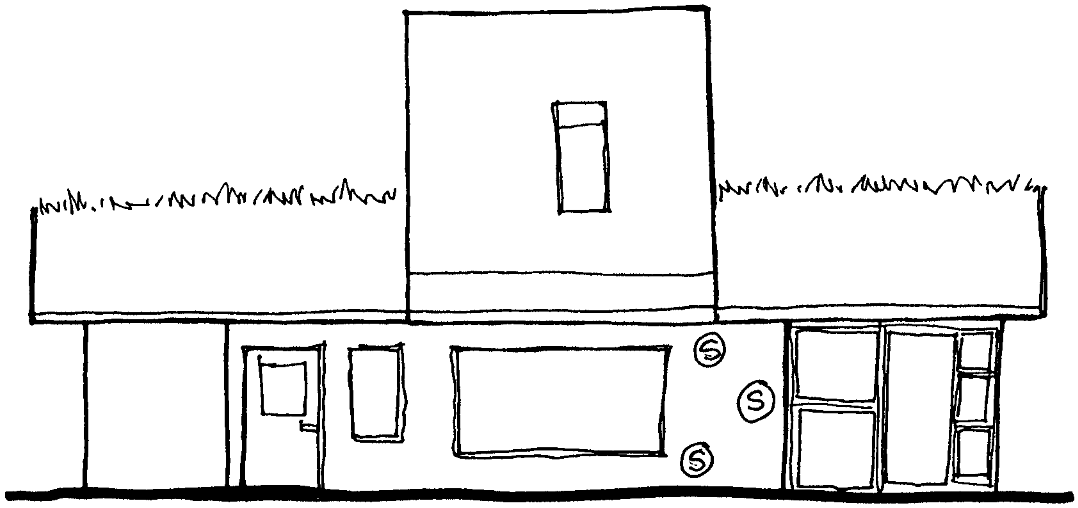
The house was plastered on the outside in fall 1996, and inside during the spring and early summer 1997, except for the workshop area which was plastered in fall 1997. The sensors were put in place before the house was plastered on the interior, so it should give a reasonable indication over the testing period as to the performance of the straw bales over the first year of the life of a straw bale house. The plastered finish is a soil cement mixture in three layers using a 10% cement mixture. The walls are finished in no VOC latex paint.

Consultant suggestions:

- Seal off dirt floor in greenhouse area by laying down 6mil poly sheeting and covering it with a protective layer of sand where it will be left exposed (most of floor will eventually be covered with a finished wood floor)
- Seal off root cellar from living space with heavier duty weatherstripping at door, silicone caulking at floor joists and other connections.

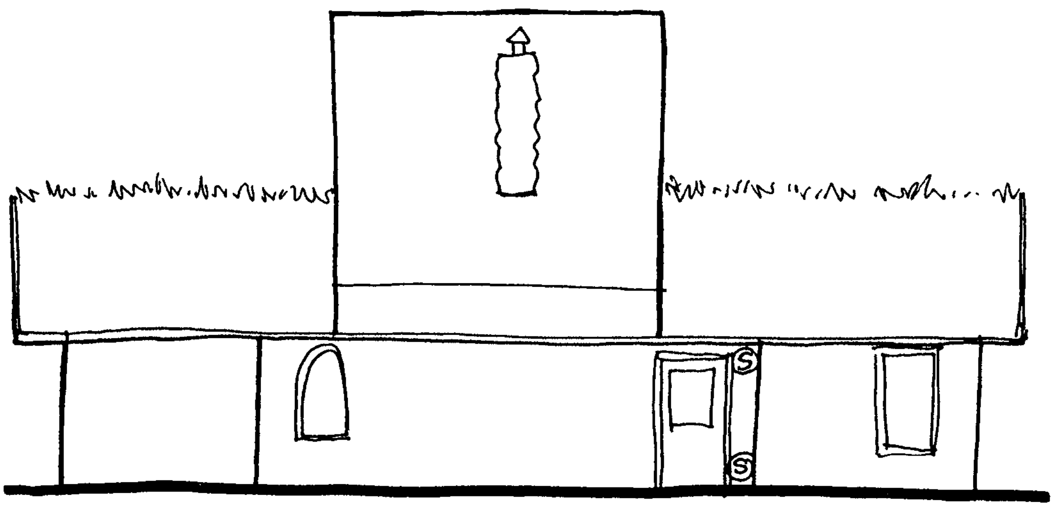


NSPSB02 (Walton)

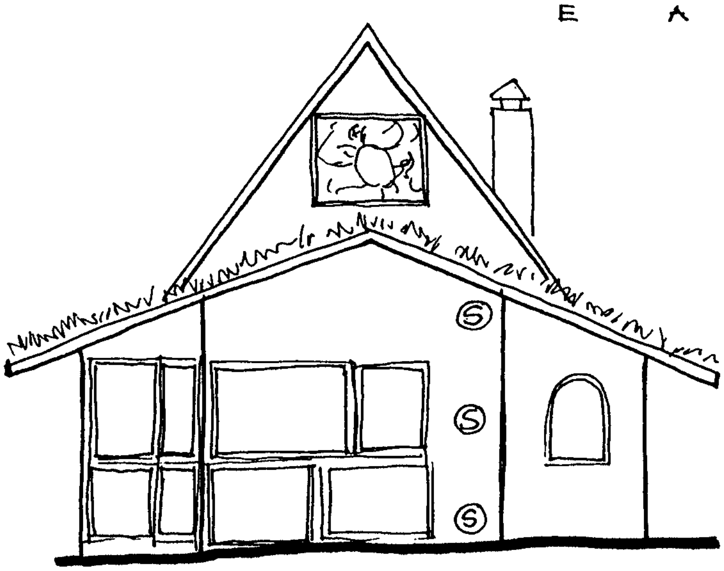


W E S T

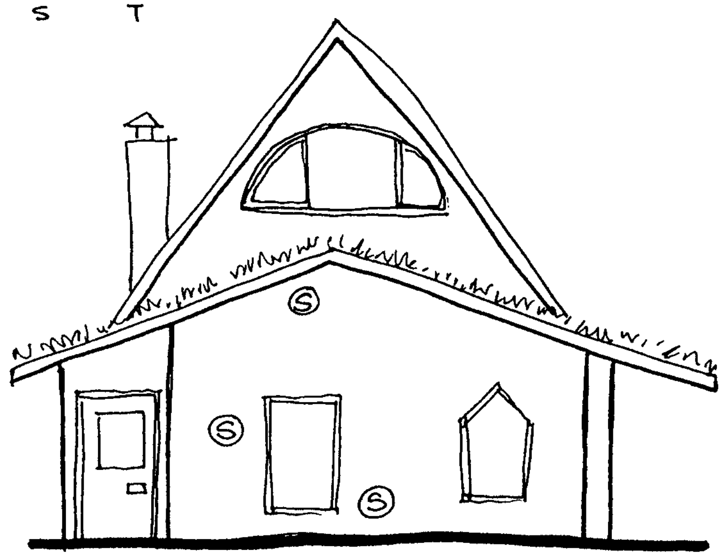
(S) = SENSOR



E A S T



S O U T H



N O R T H

NSPSB03 (Canada Creek)

This load-bearing studio was built over the period of September to December 1993. The walls were left open for a long period of time, and some water damage was seen before the roof went on. The building was not lived in year round until 1997, when a family of three (now four) moved in. Before this, it was rented out through the framing seasons and used sporadically through the winters. The building is shaped like an eye, with the 'corners' to the E and W. A bank of windows is located to the western end of the S face and a light frame greenhouse that serves as a kitchen and shower area (as well as a greenhouse) is attached to the eastern end of the S face. The N side is a deeper curve (almost a half circle), with a 120mm (48") berm around it that stands off by about 120mm (48").

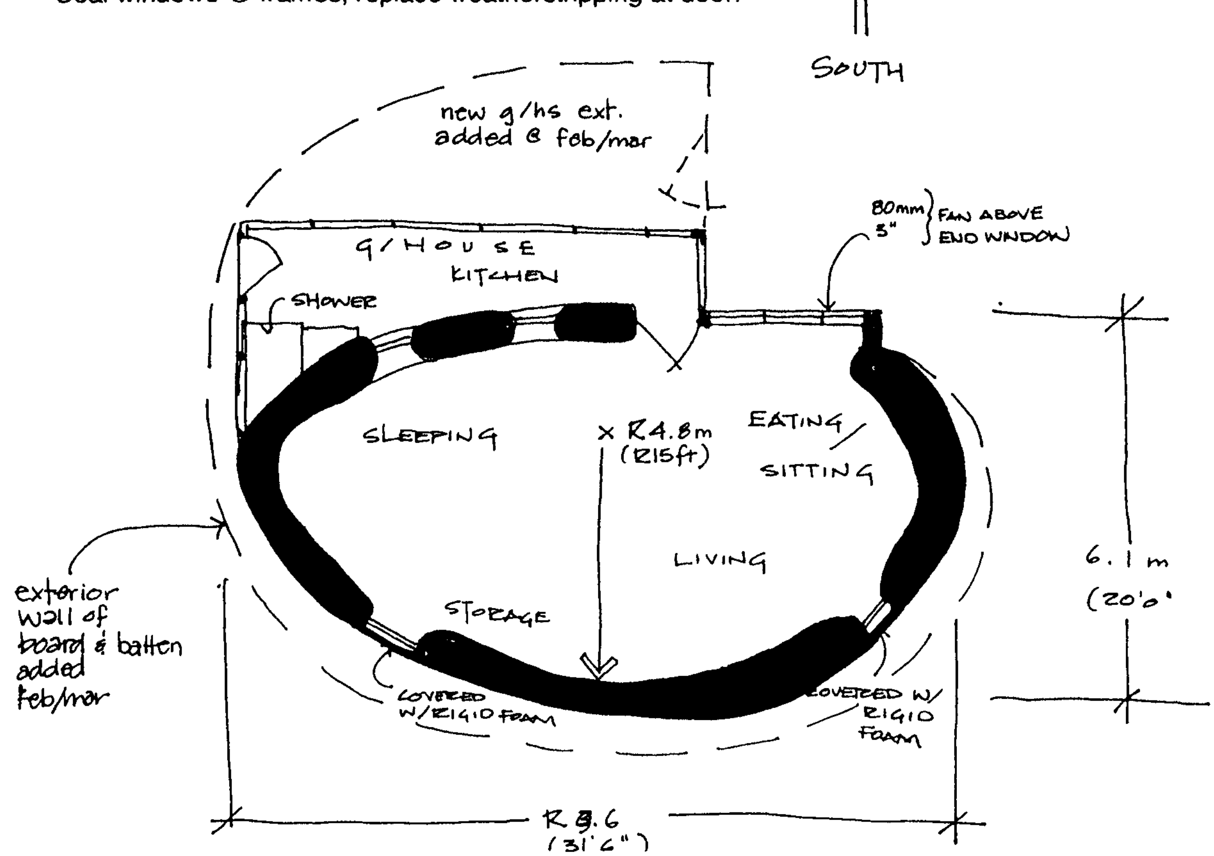
The building sits on a slab foundation with in-floor hydronic heating fuelled by a wood furnace in a small nearby greenhouse/shed. The glazing is a mixture of aluminium frame horizontal sliders (N face and into attached greenhouse) and thermopanes (bank of windows on S face) The attached greenhouse has a polypropylene translucent 'fabric' for glazing, set on 2x4 studs. the floor of the greenhouse area is pea gravel. The slightly pitched shed roof is local unpeeled softwood rafters with decking and R10 rigid board insulation over At the onset of the study, a large tarp covered the roof, which was leaking severely in some places. During the course of the study, several changes happened to the house: the tarp was removed and a new roof and further greenhouse extension were added to the building over the course of the study; a stand-off wood frame wall with cedar siding was added to the exterior of the bale walls for further protection.

The walls were coated with an unspecified concrete stucco mixture, several relief sculptures were incorporated into the finish work (making sensor placement problematic in the small space). The walls were finished in natural and pigmented limewash.

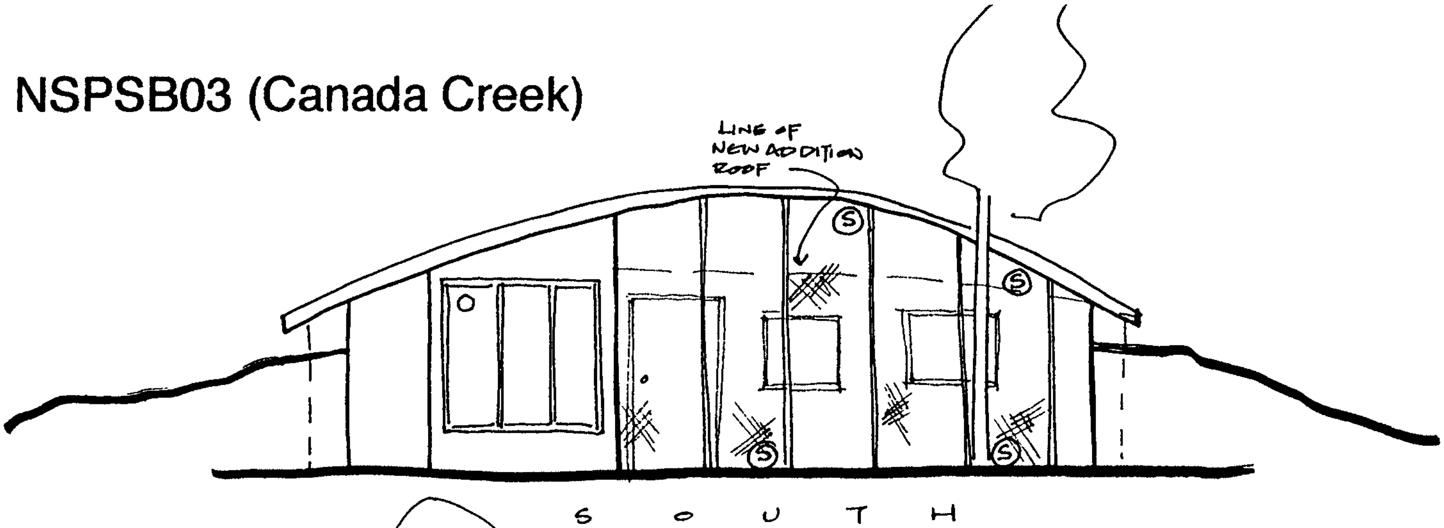
Sensors were placed close to areas indicated by homeowner to be 'known' leakage areas.

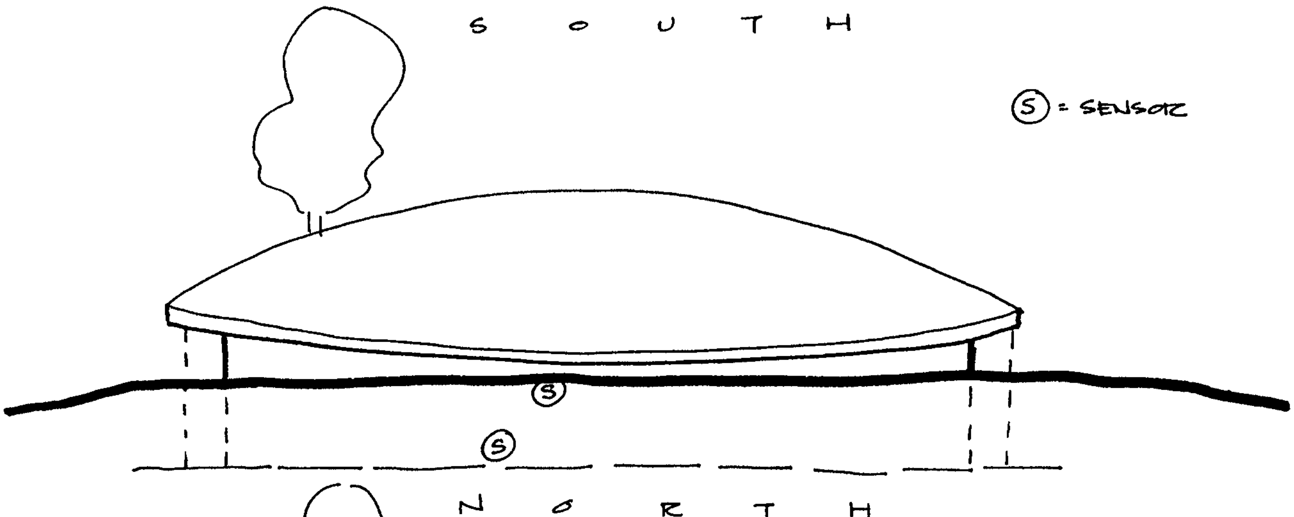
Consultant suggestions:

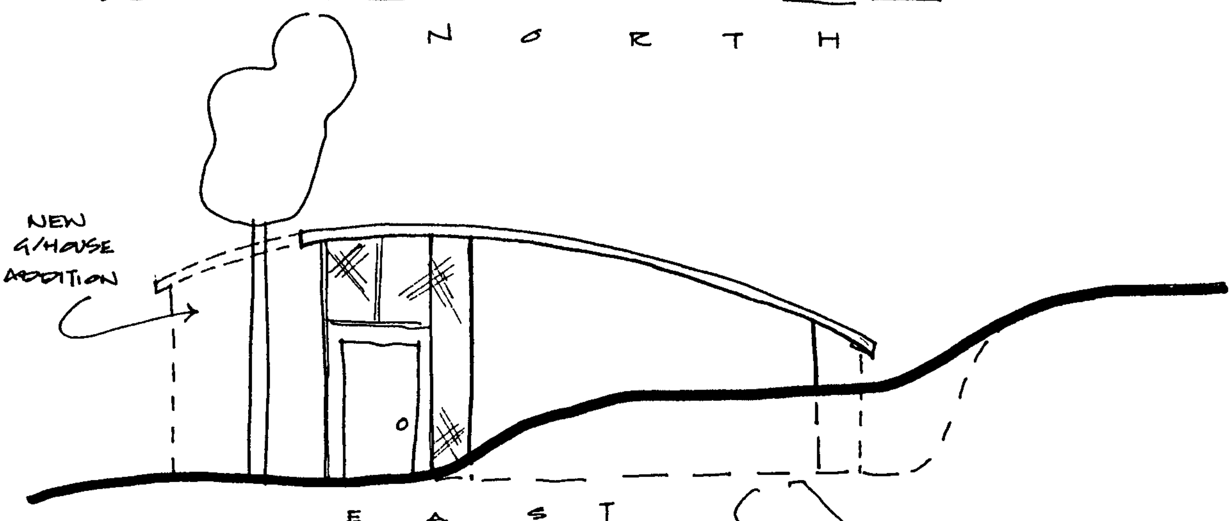
- Remove tarp covering building and repair roof
- Seal windows @ frames, replace weatherstripping at door.

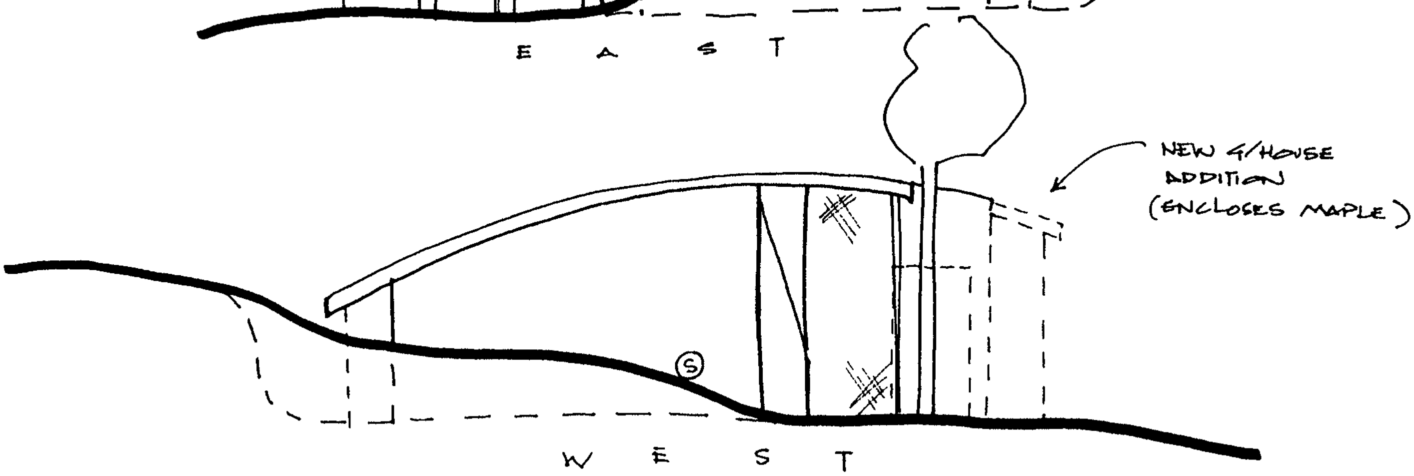


NSPSB03 (Canada Creek)









NSPSB04 (Ship Harbour)

This is the oldest of the load-bearing plastered straw bale houses in Nova Scotia. It was built in 1993 and has been continuously occupied and monitored since then. The pattern of moisture content that has been seen in the results of a 'high tech' monitoring system have shown that the walls have two peak 'wet' times, one in the late winter and one in the late summer/early fall. This would fall in with the pattern of moisture collecting in a house during the heating season, dispersing over the spring/summer when windows and doors are open and less moisture-producing activities are confined to the interior of the house. The summer peak, which has been higher than the winter peak, is indicative of the consistently high RH levels experienced in Nova Scotia over the summer months.

The house is built on a pole foundation with half-bales cradled in the floor joists. A two-storey building (full storey plus upper walls of 3 courses high along eaves of gable roof), the roof is carried by heavy exposed rafters with a double layer of rigid board insulation over. Asphalt shingle cladding surmounts a plywood deck. Windows are thermopanes

There has been some noticeable rot and black 'goo' in a few areas of the under the floor straw, partially because there is not an effective vapour/air barrier under the straw. A polyethylene film is in place, but it is not sealed nor is it continuous. The area under the post foundation was used as a storage area, reducing air flow under the house and decreasing the drying conditions there. This has been cleared out somewhat,so the increased air flow should help dry the bottom of the house.

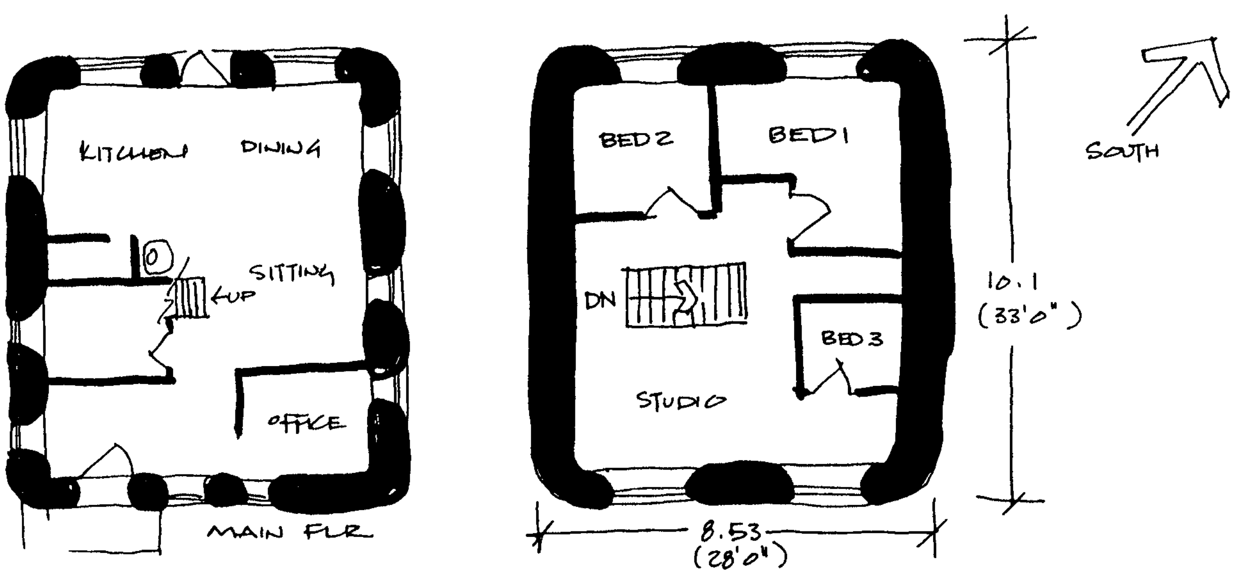
One sensor was located in the immediate area of a known leaky water pipe to monitor the performance of the wall in proximity to the presence of water on the interior of the wall.

During the course of the study, the house experienced a small but dramatic fire at the front entrance area. The fire started during attempts to thaw a frozen water pipe and took out the first 600 to 1000mm (24 to 36") of the first few joists under. The fire was contained, the straw in the floor smouldered and blackened but didn't catch fire. However, due to water damage during the fire fighting process, the half-bales had to be removed and fibreglass batts were set in place instead. There was not damage to the surrounding straw bale walls.

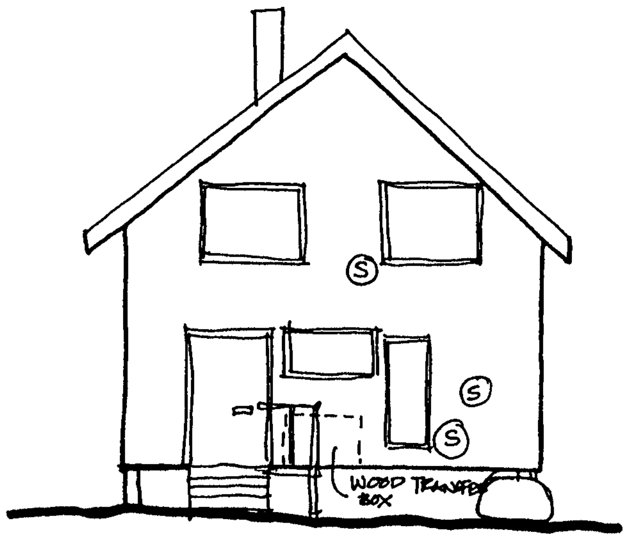
Consultant suggestions:

- A heavier weight poly film could could be laid directly on the ground below the house and covered with a layer of sand for protection. This would potentially reduce the dampness 'trapped' below the house via wet, poorly drained soil, although the bottom of the bales would still be subject to more extreme swings in moisture levels and temperatures, which could result in the continuation of moisture problems in the floor.

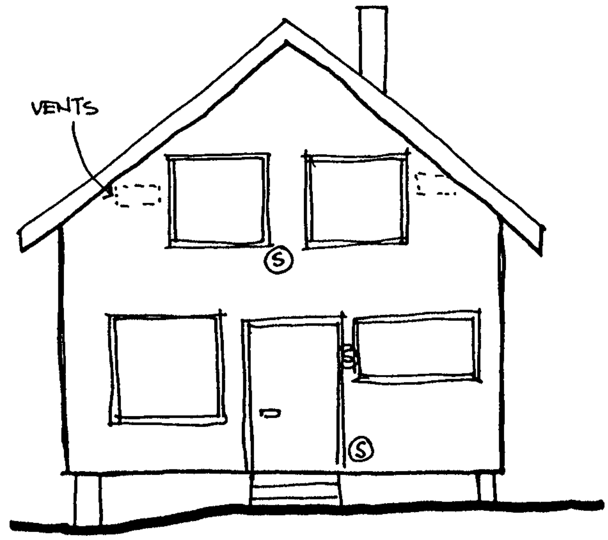
- Weatherstripping/air sealing at various places: door frames, window frames, wood transfer box and summer ventilation windows.



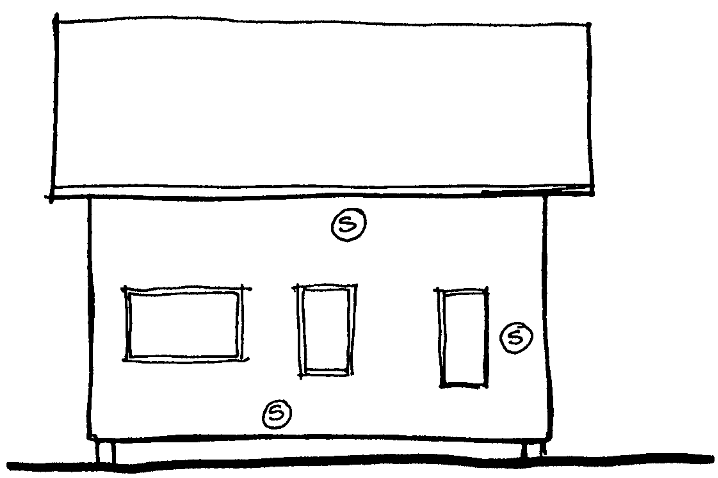
NSPSB04 (Ship Harbour)



NORTH WEST

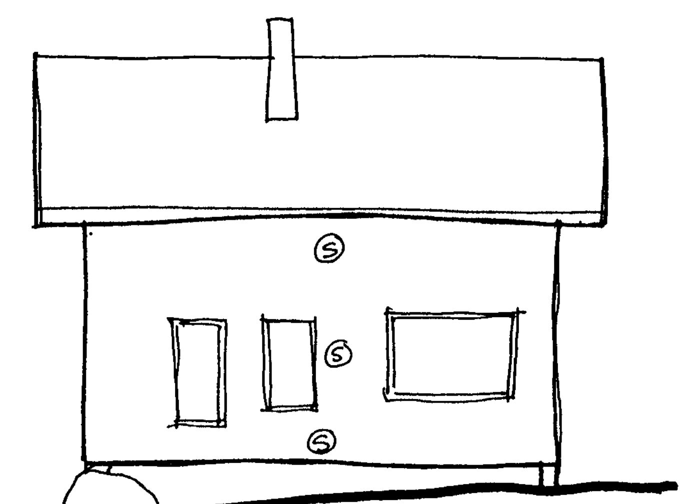


SOUTHEAST



NORTHEAST

Ⓢ = SENSOR



SOUTHWEST

APPENDIX B: TABLES OF READINGS

Sensor Readings by House

NSPSB01	sensor	MAY	JULY	SEPT	NOV	DE/JA	MAR/ APR		AVE
(ST MG BY)									
East (H)	A	11	17	14	11	10	10		12.2
(M)	B	9	14	12	9	6	7		9.5
(L)	C	11	14	13	12	8	9		11.2
South (H)	D	11	13	12	10	8	9		10.5
(M)	E	10	11	11	11	8	9		10.0
(L)	F	10	13	13	11	9	9		10.8
West (H)	G	9	11	12	11	8	9		10.0
(M)	H	7	11	11	10	7	7		8.8
(L)	I	9	12	12	11	7	9		10.0
North (H)	J	9	12	11	10	9	10		10.2
(M)	K	11	13	11	9	5	11		10.0
(L)	L	10	11	10	11	11	7		10.0
MONTHLY	MIN	7.0	11.0	10.0	9.0	5.0	7.0		5.0
	MAX	11.0	17.0	14.0	12.0	11.0	11.0		17.0
	MEAN	9.8	12.7	11.8	10.5	8.0	8.8		10.3
	ST DEV	1.2	1.8	1.1	0.9	1.7	1.3		0.3
BY HEIGHT	HIGH	MED	LOW		OR'NT	S	W	N	E
MIN	8.0	5.0	7.0		MIN	10.0	8.8	10.0	9.5
MAX	17.0	14.0	14.0		MAX	10.8	10.0	10.2	12.2
MEAN	10.7	9.6	10.5		MEAN	10.4	9.6	10.1	10.9
ST DEV	2.0	2.3	1.9		ST DEV	0.4	0.7	0.1	1.3

NSPSB02									AVE
(WALTON)	sensor	MAY	JULY	SEPT	NOV	DE/JA	MAR/ APR		
West (H)	A	13	13	14	8	6	4		9.7
(M)	B	12	14	13	10	6	9		10.7
(L)	C	10	12	11	9	9	11		10.3
South (H)	D	12	14	13	10	8	7		10.7
(M)	E	10	12	11	9	5	7		9.0
(L)	F	13	13	11	8	5	9		9.8
East (H)	G	14	15	13	10	7	6		10.8
(M)	H	12	13	11	9	5	4		9.0
North (H)	J	10	11	12	10	4	3		8.3
(M)	K	13	15	14	11	7	8		11.3
(L)	L	10	12	13	9	5	8		9.5
MONTHLY	MIN	10.0	11.0	11.0	8.0	4.0	3.0		3.0
	MAX	14.0	15.0	14.0	11.0	9.0	11.0		15.0
	MEAN	11.7	13.1	12.4	9.4	6.1	6.9		9.9
	ST DEV	1.5	1.3	1.2	0.9	1.5	2.5		0.5
BY HEIGHT	HIGH	MED	LOW		OR'NT	S	W	N	E
MIN	3.0	4.0	5.0		MIN	9.0	9.7	8.3	9.0
MAX	15.0	15.0	13.0		MAX	10.7	10.7	11.3	10.8
MEAN	9.9	10.0	9.9		MEAN	9.8	10.2	9.7	9.9
ST DEV	3.6	3.1	2.4		ST DEV	0.8	0.5	1.5	1.3

NSPSB03	sensor	MAY	JULY	SEPT	NOV	DE/JA	MAR/ APR		AVE
(CAN CRK)									
South (H)	A	12	11	11	10	9	11		10.7
(L)	B	10	11	9	10	11	9		10.0
(H)	C	19	11	10	9	7	8		10.7
(L)	D	11	13	12	10	9	9		10.7
North (H)	E	12	13	12	10	8	11		11.0
(L)	F	11	13	14	9	5	5		9.5
(L)	G	11	11	12	10	11	11		11.0
MONTHLY	MIN	10.0	11.0	9.0	9.0	5.0	5.0		5.0
	MAX	19.0	13.0	14.0	10.0	11.0	11.0		19.0
	MEAN	12.3	12.0	11.5	9.7	8.5	8.8		10.5
	ST DEV	3.3	1.1	1.8	0.5	2.3	2.2		1.0
BY HEIGHT	HIGH	MED	LOW		OR'NT	S	W	N	E
MIN	7.0	n/a	5.0		MIN	10.0	n/a	9.5	n/a
MAX	19.0	n/a	14.0		MAX	10.7	n/a	11.0	n/a
MEAN	10.8	n/a	10.3		MEAN	10.5	n/a	10.5	n/a
ST DEV	2.6	n/a	2.1		ST DEV	0.3	n/a	0.9	n/a

NSPSB04	sensor	MAY	JULY	SEPT	NOV	JAN	MAR/ APR		AVE
(SHIP HBR)									
SE (H)	A	9	10	9		5	5		7.6
(M)	B	7	10	9		3	3		6.4
(L)	C	6	10	9		4	5		6.8
SW (H)	D	8	10	9		6	5		7.6
(M)	E	8	10	10		3	4		7.0
(L)	F	8	10	9		5	4		7.2
NW (H)	G	9	10	9		6	6		8.0
(M)	H	9	11	10		7	7		8.8
(L)	I	10	11	10		8	7		9.2
NE (H)	J	7	9	9		6	5		7.2
(M)	K	8	10	9		6	5		7.6
(L)	L	11	14	13		9	9		11.2
MONTHLY	MIN	6.0	9.0	9.0		3.0	3.0		3.0
	MAX	11.0	14.0	13.0		9.0	9.0		14.0
	MEAN	8.3	10.4	9.6		5.7	5.4		7.9
	ST DEV	1.4	1.2	1.2		1.8	1.6		0.3
BY HEIGHT	HIGH	MED	LOW		OR'NT	SE	SW	NW	NE
MIN	5.0	3.0	4.0		MIN	7.0	8.0	7.2	6.4
MAX	10.0	11.0	14.0		MAX	7.6	9.2	11.2	7.6
MEAN	7.6	7.4	8.6		MEAN	7.3	8.7	8.7	6.9
ST DEV	1.9	2.6	2.8		ST DEV	0.3	0.6	2.2	0.6

Compiled data by orientation of monthly readings at all sensor locations

S OR SE	HIGH	MID	LOW	AVE	W OR SW	HIGH	MID	LOW	AVE
MAY	12.6	9.0	10.2	10.6	MAY	10.0	9.0	9.0	9.3
JULY	11.8	11.0	11.8	11.5	JULY	11.3	11.7	11.3	11.4
SEPT	11.0	10.3	10.4	10.6	OCT	12.0	11.3	10.7	11.3
NOV	9.8	10.0	9.8	9.8	NOV	9.5	10.0	10.0	9.8
DEC/JAN	7.4	5.3	7.6	6.8	DEC/JAN	6.7	5.3	7.0	6.3
MAR/APR	8.0	6.3	8.2	7.5	MAR/APR	6.0	6.7	8.0	6.9
AVE	10.1	8.7	9.7	9.5	AVE	9.2	9.0	9.3	9.2
E OR NE	HIGH	MID	LOW	AVE	N OR NW	HIGH	MID	LOW	AVE
MAY	10.7	9.7	11.0	10.4	MAY	10.0	11.0	10.4	10.5
JULY	13.7	12.3	14.0	13.3	JULY	11.5	13.0	11.6	12.0
OCT	12.3	10.7	13.0	12.0	OCT	11.0	11.7	11.8	11.5
NOV	10.5	9.0	10.5	10.0	NOV	10.0	10.0	9.8	9.9
DEC/JAN	7.7	6.0	7.3	7.0	DEC/JAN	6.8	6.3	7.8	7.0
MAR/APR	7.0	5.3	9.0	7.1	MAR/APR	7.5	8.7	8.4	8.2
AVE	10.3	8.8	10.8	10.0	AVE	9.5	10.1	10.0	9.8

Indoor/outdoor temperatures and relative humidity levels at site visits

NSPSB01	TEMP IN (°C)	TEMP OUT (°C)	RH IN (%)	RH OUT (%)
MAY	21	20	55	58
JULY	24	22	41	45
SEPT	21	17	70	62
NOV	21	18	63	59
DEC/JAN	15	2	52	24
MAR/APR	19	2	50	31
NSPSB02	TEMP IN (°C)	TEMP OUT (°C)	RH IN (%)	RH OUT (%)
MAY	16	14	71	66
JULY	24	18	57	64
SEPT	18	17	73	65
NOV	20	12	48	46
DEC/JAN	19	0	48	36
MAR/APR	17	2	51	40
NSPSB03	TEMP IN (°C)	TEMP OUT (°C)	RH IN (%)	RH OUT (%)
MAY	19	19	66	54
JULY	16	22	66	68
SEPT	15	14	67	46
NOV	20	6	52	40
DEC/JAN	23	-25	49	24
MAR/APR	25	7	42	40
NSPSB04	TEMP IN (°C)	TEMP OUT (°C)	RH IN (%)	RH OUT (%)
MAY	15	6	53	84
JULY	19	17	76	80
SEPT	21	16	59	62
DEC/JAN	18	-1	34	24
MAR/APR	18	-2	31	35
AVERAGE	TEMP IN (°C)	TEMP OUT (°C)	RH IN (%)	RH OUT (%)
MAY	18	15	61	66
JULY	21	20	60	64
SEPT	19	16	67	59
NOV	21	12	54	48
DEC/JAN	19	-6	46	27
MAR/APR	20	2	44	36

• APPENDIX C: SAMPLE OF SENSOR READINGS CHART

... WOOD BLOCK SENSOR READINGS...

FROM: ____________TO: ________________

SITE LOCATION: _________________________

INITIAL MOISTURE CONTENT OF PINE BLOCK SENSOR: ___%

MOISTURE CONTENT READINGS

	RUN # 1	RUN # 2	RUN # 3	RUN # 4	RUN # 5	RUN # 6	RUN # 7	RUN #8
ORIENT'N/ SENSOR ID TAG HT: H/M/L	T/IN: T/OUT: RH/IN: RH/OUT:	T/IN: T/OUT: RH/IN: RH/OUT:	T/IN: T/OUT: RH/IN: RH/OUT:	T/IN: T/OUT: RH/IN: RH/OUT:	T/IN: T/OUT: RH/IN: RH/OUT.	T/IN: T/OUT: RH/IN: RH/OUT.	T/IN: T/OUT: RH/IN: RH/OUT:	T/IN: T/OUT: RH/IN: RH/OUT
A								
B								
C								
D								
E								
F								
G								
H								
I								
J								
K								
L								

NOTES @ SITE/WEATHER CONDITIONS & DATE FOR EACH READING):