Dryair UK Ltd.
96 Huddersfield Road
Brighouse
HD6 3RD
West Yorkshire

Laboratory evaluation of the Dryair drying and heating system for 'moisture flushing' of structural elements

May 2006
Report No. CIM 147/r2

Centre for Infrastructure Management
Sheffield Hallam University
City Campus
Howard Street
Sheffield
S1 1WB
UNITED KINGDOM
Tel: +44 (0)114 225 3339/3500
Fax: +44 (0)114 225 4546

MATERIALS AND ENGINEERING
RESEARCH INSTITUTE

Materials Analysis
& Research Services
Centre of Industrial
Collaboration

Laboratory evaluation of the Dryair drying and heating system for 'moisture flushing' of structural elements

Revision	Date	Ref.	Remarks
0	April 2006	CIM 147/r0	Report issued to client
1	May 2006	CIM 147/r1	Final report issued with minor amendments
2	May 2006	CIM 147/r2	Final report issued with further amendments

Originated: by — Original copy signed — Dr. Aleksander Lukojc — Date: 03/05/06

Checked: by — Original copy signed — Prof. Paul Lambert — Date: 03/05/06

Approved: by — Original copy signed — Prof. Pal Mangat — Date: 04/05/06

Centre for Infrastructure Management, Sheffield Hallam University, City Campus, Howard Street, Sheffield S1 1WB. **Telephone** 0114 225 3500 **Fax** 0114 225 4546 **Web** www.shu.ac.uk/cim

Executive Summary

An independent laboratory-based evaluation has been performed to establish the performance of the *Dryair "Moisture Flush"* process in returning water saturated building components, simulating the effects of flood damage, to their original, pre-flood state without incurring significant damage or distortion.

A representative range of construction materials have been tested, including solid and double-skin walls, suspended floors and composite timber elements. The various material samples and elements were weighed before and after drying and in addition to being subject to detailed visual inspection for signs of distress or distortion, were accurately monitored for changes in dimension.

The results demonstrate that the *Dryair "Moisture Flush"* process can be effective in removing water from a range of saturated construction materials, and that the system can assist in returning flood damaged structures and structural elements to an acceptable pre-flood condition.

Contents

1. Aim of the Investigation

To determine objectively the performance of the *Dryair* heating system in returning a range of water saturated building elements simulating flood damage to an acceptable condition similar to their original dry state.

A range of common construction materials and fabricated elements has been assessed including solid and double-skin walls, suspended timber floors and composite timber components such as doors.

The various material samples and structural elements were carefully weighed before and after drying to monitor the take-up and loss of water. Detailed dimensional monitoring and close visual inspections were carried out throughout the evaluation to identify any damage or distortion resulting from the wetting and drying cycle.

2. Test Materials

2.1. Wall Panels

In total five different types of masonry panel were constructed to produce three representative forms of wall construction:

a) Double leaf cavity wall of London Brick (LX) and Breeze Block (B) with a 100mm cavity.
b) Double leaf cavity wall of a Medium Brick (L) and Concrete Block (C) with a 100mm cavity.
c) Solid wall of Reclaimed Victorian Brick (R).

For the London brick (LX), Breeze Block (B), Medium Brick (L) and Concrete block panels a standard mortar mix was used in proportion by weight: 6 parts of builders sand, 1 par of ordinary portland cement (OPC), 1 part of hydrated lime. Water was added to achieve a suitable workability.

For the Reclaimed Victorian Brick panel a special mortar mix was used in proportion by volume: 2 parts of conservation grade sand, 1 part of NHL 3.5 natural hydraulic lime. Water was added to achieve a suitable workability.

The three brick panel wall sections are shown in Figure 1.

Figure 1: Brick wall panels, from left: London Brick / Breeze Block, Medium Brick / Concrete Block and Reclaimed Victorian Brick

2.2. Masonry Samples

In addition to the three wall panels representing five styles of masonry, additional individual bricks (in series of six) from each of the three brick types were also assessed for dimensional and weight changes, together with a sample of a natural building stone:

a) Series 1 - London Brick (LX),
b) Series 2 - Medium Brick (L),
c) Series 3 - Victorian Brick (R),
d) Sandstone (S)

2.3. Timber elements

Six types of timber element were selected for evaluation:

a) Hardwood External Door,
b) Internal Pine Door,
c) Floorboards on Joists, 1 metre long x 1 metre wide,
d) Plasterboard Panel,
e) Skirting Board,
f) Wooden Chair.

3. Laboratory Evaluation

3.1. Experimental conditions

The masonry wall panels were maintained in a saturated condition over a period of 5 days in a high-humidity mist room. The timber elements, individual bricks and stone sample were submerged in a water bath for 48 hours. These conditions were intended to simulate the environment resulting form a flood.

After being saturated, the elements were transferred to the drying chamber. This was a 28 cubic metre reinforced concrete chamber 3.46 metres long, 3.10 meters wide and 2.62 meters high with two of the *Dryair* powered heat exchangers in which the samples were dried, as shown in Figure 2.

a) b)

c)

Figure 2: Drying chamber (a), heat exchangers (a & b) and *heating module (c).*

Upon completion of the drying process, the individual bricks and stone sample were placed in an oven at 110 ºC for 24 hours.

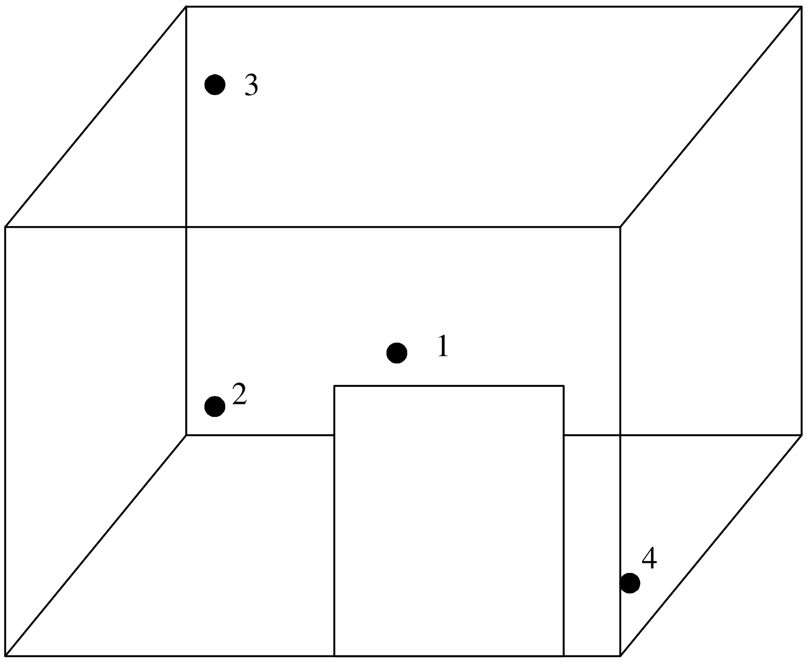

Figure 3: Temperature and humidity sensors location in the drying chamber - 1 - mid point. 2 - bottom back corner, 3 - top back corner, 4 - bottom door corner

3.2. Location of temperature and humidity sensors

Combined temperature and relative humidity probes were located around the drying chamber as shown in Figure 3 to monitor the air within the chamber during the drying operation. Additional thermocouples were employed to monitor the temperature of the centre of the wall panels plus the internal and external temperature, as shown in Figure 4.

3.3. Test methods

The following tests were conducted to determine the performance of the *Dryair "Moisture Flush"* process in returning flood damaged building elements to an acceptable condition:

- weight change

- dimensional change, and
- visual inspection.

LX - London Brick panel

B - Breeze Block panel

R - Reclaimed Victorian Brick panel

L - Medium Brick panel

C - Concrete Block panel

• - Locations of thermocouple

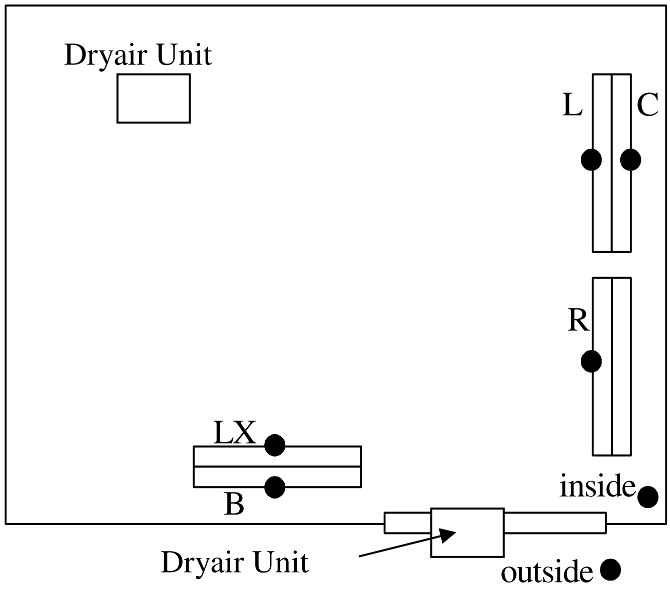

Figure 4: Thermocouple location in the wall panels and positions of the panels in the drying chamber

4. Test Results

4.1. Heat distribution

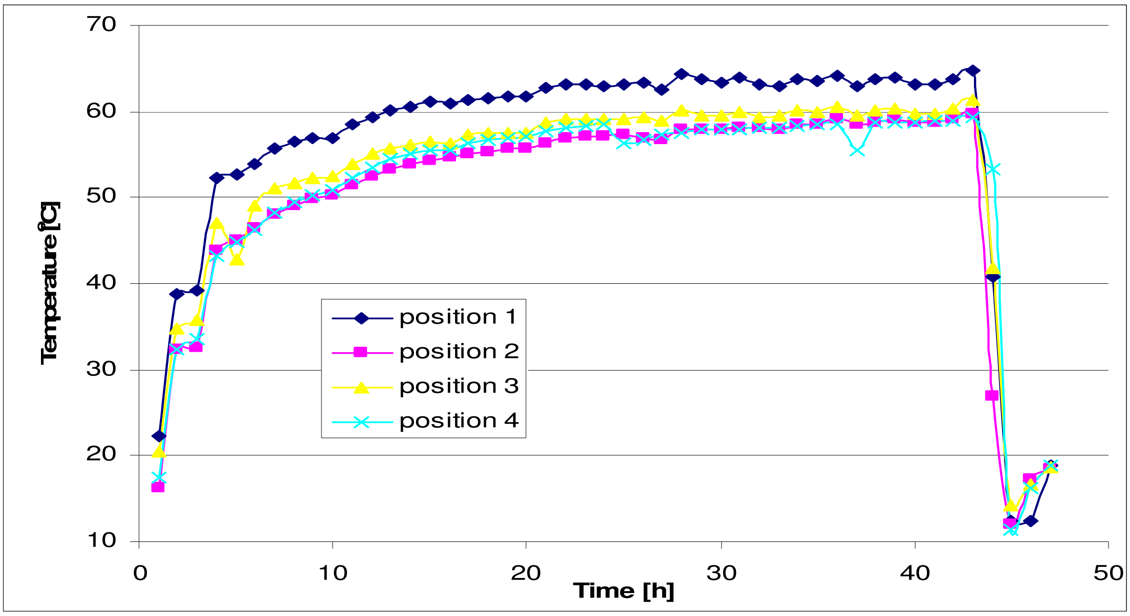

Figure 5: Heat distribution in the chamber during the drying process (thermocouple locations as indicated in Figure 3).

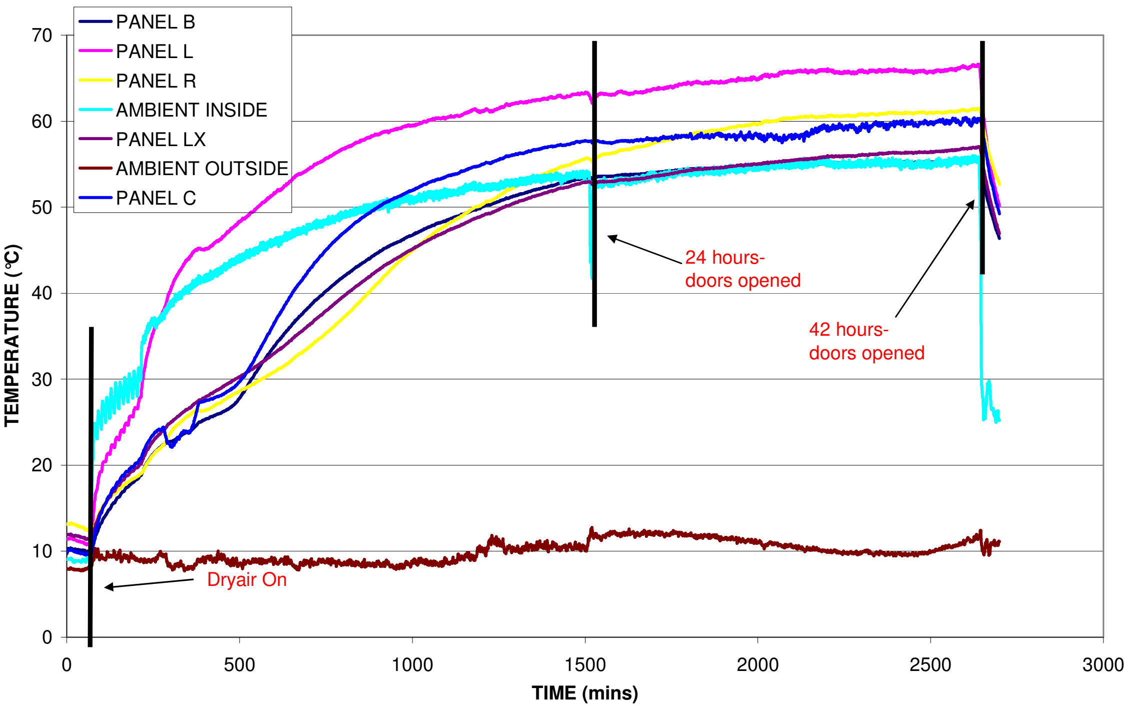

Figure 6: Heat distribution of brick panels during drying process (thermocouple locations as indicated in Figure 4).

Temperature measured during drying process (Figures 5 and 6) indicate that there are no significant differences of heat distribution after 20 hours heating between bricks panels and heating chamber. After 20 hours during heating process the thermal equilibrium state in the chamber has been achieved at 70ºC.

4.2. Humidity

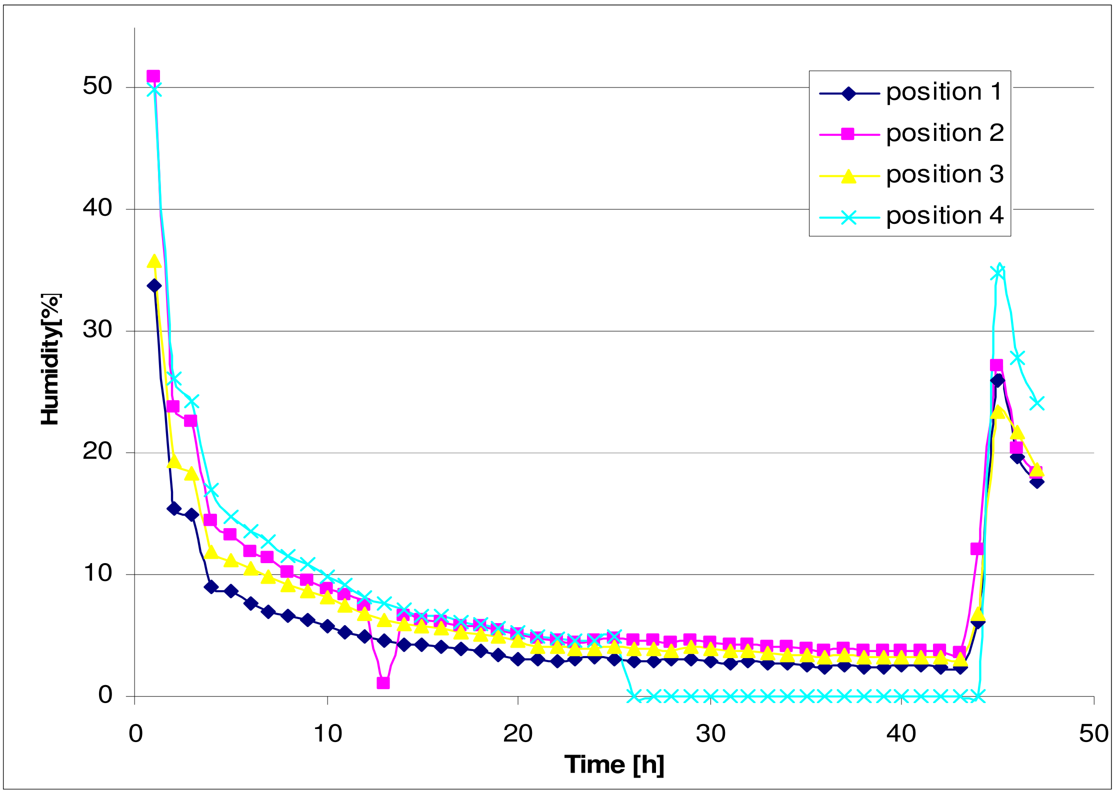

Figure 7: Humidity levels during drying process (sensors locations as indicated in Figure 3).

The humidity measurement results (Figure 7) demonstrate that after 20 hours of drying in the chamber the humidity level within the drying chamber is at 5% and remains at a similar level until the drying is completed and the heat turned off.

4.3. Weight changes

Table 1: Wall Panels - weight change and percentage difference.

Wall Panels	Weight [kg]		
	Laboratory Air Cured	Saturated	Dry 42h
LX + B (London Brick/Breeze Block)	250	266.5	253
		+6.6%	**-5.4%**
L + C (Medium Brick/Concrete Block)	269	286	270
		+6.3%	**-5.9%**
R (Double Victorian Brick)	371	387	373
		+4.3%	**-3.8%**

Table 2: Individual Bricks and Stone Sample - weight change and percentage difference.

Masonry Samples	Weight [kg]		
	Oven 24h dry (110 ºC)	Saturated	Dry 42h
LX (London Brick)	11.44	13.8	11.6
		+20.6%	**-19.2%**
L (Medium Brick)	12.21	14.73	12.4
		+20.6%	**-19.1%**
R (Victorian Brick)	21.38	23.43	21.62
		+9.6%	**-8.5%**
S (Sandstone)	-	63.4	63
			-0.6%

Table 3: Timber Elements - weight change and percentage difference.

Timber Element	Weight [kg]		
	Laboratory Air Cured	Saturated	Dry 42h
Hardwood External Door	24.10	25.34	23.36
		+5.1%	**-8.2%**
Internal Pine Door	26.77	28.10	26.68
		+5.0%	**-5.3%**
Timber Floor	15.04	17.74	14.75
		+18.0%	**-19.9%**
Plasterboard Panel	14.51	19.96	14.41
		+37.6%	**-38.2%**
Skirting Board	1.79	2.20	1.73
		+22.9%	**-26.3%**
Wooden Chair	3.11	4.29	2.94
		+37.9%	**-43.4%**

The weight measurement results (Tables 1 to 3) demonstrate that the applied drying method has been effective in removing the additional water due to saturation and returning the samples to a moisture state similar to the original condition.

4.4. Shrinkage tests

Determination of the shrinkage strain in wall panels and timber doors has been made using Demec equipment in accordance with the British Standard - BS 1881-206:2006. The strain in the wall panels was measured of the locations shown in Figure 8. Figure 9 gives a schematically view of the strain monitoring locations on the doors.

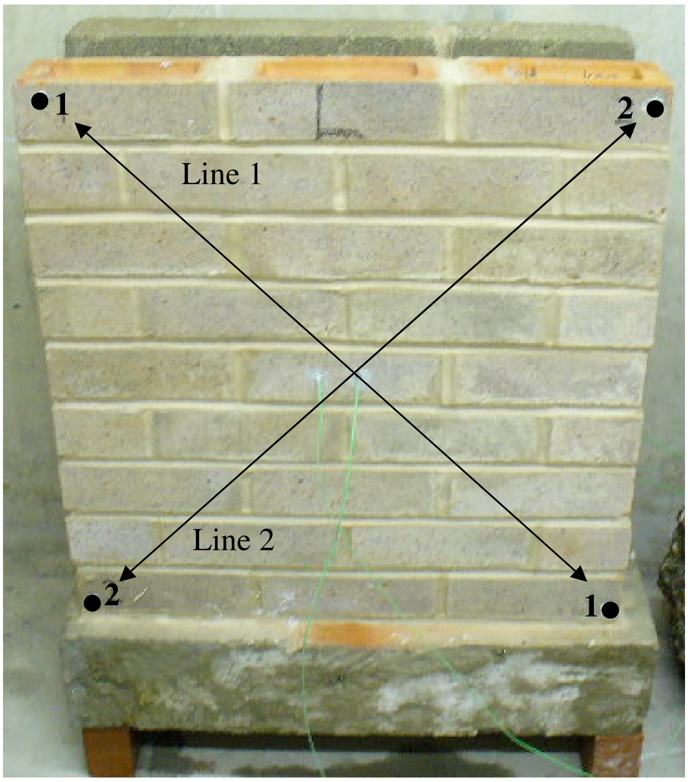

Figure 8: Strain monitoring locations on wall panel

a) b)

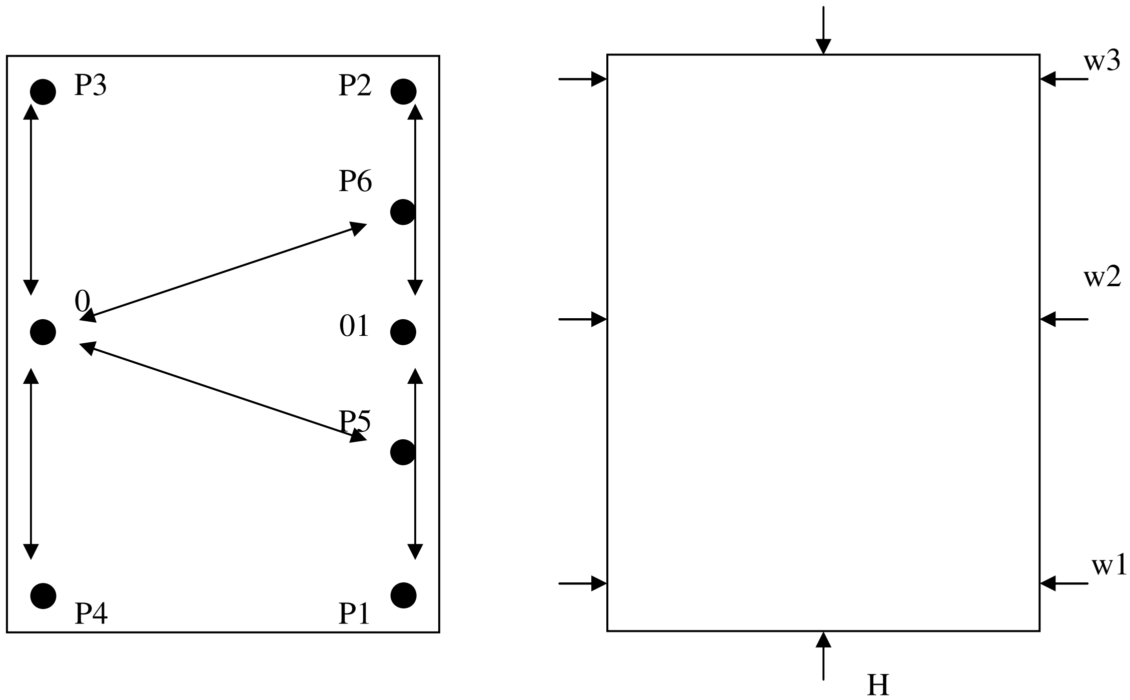

Figure 9: a) Demec point locations on door panels, b) Locations of dimension measurements.

The difference in the shrinkage strain after the wetting and drying process gives the differential shrinkage strain set up in the wall panels and doors providing an estimate of the risk of tensile cracking and warping process in those elements.

Tables 4 to 6 show the values of strain in the different locations on the wall panels during the drying procedure.

Table 4: Differential microstrain in wall panels during drying.

Wall Panel	Line	Differential strain (microstrain)		
		Wet - Lab. air cured	Dry 42h - Lab. air cured	Cooled 24h - Lab. air cured
LX	1	53.7	225.54	75.18
	2	59.07	207.64	69.81
B	1	136.04	198.69	76.97
	2	132.46	186.16	75.18
L	1	39.38	196.9	239.86
	2	48.33	211.22	-114.56
C	1	229.12	241.65	112.77
	2	202.27	248.81	114.56
R side A	1	1.79	263.13	51.91
	2	23.27	313.25	80.55
R side B	1	28.64	-37.59	73.39
	2	23.27	289.98	94.87

Table 5: Differential microstrain in doors during drying.

Timber Element	Location	Differential strain (microstrain)	
		Wet - Lab. air cured	Dry 42h - Lab. air cured
Hardwood External Door	0-P1	349.05	-315.04
	0-P2	252.39	-309.67
	01-P3	250.60	-293.56
	01-P4	298.93	-298.93
	0-P5	773.28	out of range
	0-P6	1161.71	out of range
Internal Pine Door	0-P1	159.31	272.08
	0-P2	30.43	42.96
	01-P3	87.71	-21.48
	01-P4	277.45	-59.07
	0-P5	766.12	492.25
	0-P6	193.32	152.15

Table 6: Dimensional measurements.

Timber Element	Location	Width/Height [mm]		
		Laboratory air cured	Saturated	Dry 42h
Hardwood External Door	W1	842	844	843
	W2	845	846	842
	W3	839	840	838
	H	1982	1985	1980
Internal Pine Door	W1	808	808	809
	W2	810	812	812
	W3	812	812	812
	H	2031	2033	2033

The strain during the drying process shows the shrinkage that occurs as the materials dry out.

The maximum of differential strain in the wall panels has been observed between the laboratory air cured and immediately after drying. These results can be largely explained by the thermal extension of wall panels and after cooling the differential strain level was reduced to approximately 100 microstrains. This level of microstrain should not be sufficient to cause a significant risk of tensile cracking in the wall panels and no such cracking was observed during the visual inspections.

Shrinkage test results for the timber elements indicated that during the wetting and drying process these elements, as would be expected, are more susceptible to warping and cracking than the masonry.

4.5. Visual examination

Figure 10: Wall panel LX view after drying process - no visible damage

Figure 11: Wall panel L view after drying process - no visible damage

Figure 12: Wall panel R view after drying process - no visible damage

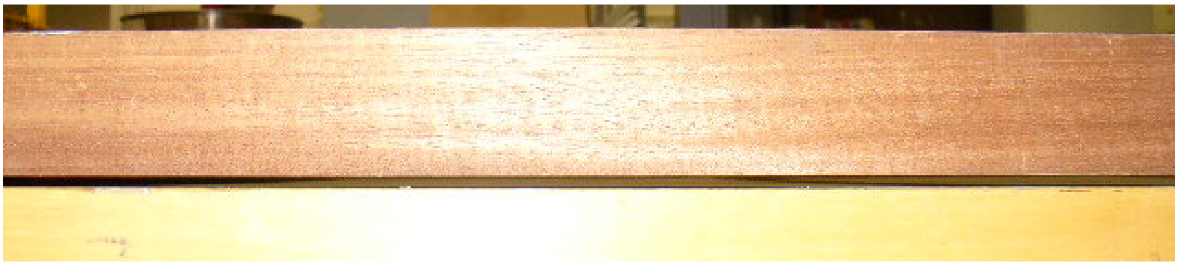

Figure 13: Hardwood external door - distortion 6mm over 1800 mm, after drying

Figure 14: Internal pine door - distortion 12 mm over 1800 mm, and delamination of painted hardboard facing after drying

Figure 15: Plaster board panel - distortion after water saturation

The surface of the masonry wall panels after drying process showed no visible damage. The other specimens did show degrees of distortion and other damage, most notably the plasterboard which distorted during the wetting process (see Figure 15) and the internal door from which the hardboard facing partly lifted. Other than these examples, the other levels of distortion may be considered tolerable.

5. Conclusions

The independent testing & evaluation programme carried out to demonstrate the performance of the *Dryair "Moisture Flush"* process (high temperature, high volume, pressurised system) has shown the system to be capable of returning a range of saturated construction materials and components to dry condition with minimal overall change in dimension and limited risk of cracking or other damage.

The test results and evaluation by CIM found that:

- The *Dryair "Moisture Flush"* process was extremely effective in removing water from a wide range of common construction materials that had been saturated to simulate elements of a flood affected structure within a short period of time.

- A constant and equal distribution of heat and humidity was achieved in the test chamber during the period of the evaluation. This assisted in ensuring a rapid & effective drying with minimal distortion due to thermal and humidity differentials.

- No measurable or observable permanent damage was recorded for the masonry wall panels during the wetting and drying exercise. Similarly, the sandstone sample was not adversely affected by the drying process.

- The more absorbent and moisture sensitive materials did show varying levels of marginal distortion as a result of wetting and drying although these were generally within acceptable limits with the exception of the plasterboard, which distorted upon wetting, and the interior door where the hardboard facing to one side became partly detached, again during the wetting phase.

- The monitoring of temperature and relative humidity during the drying process appears to be a simple and effective method of monitoring the progress of the drying process for most practical applications of building or structural drying.