THE DEVELOPMENT OF MOULD GROWTH IN A FABRIC STRUCTURE

IDENTIFICATION OF SOURCE AND CONTROL MEASURES

CASE STUDY : L. THOROGOOD

Floreat Forum Shopping Centre is a suburban centre located north of the city of Perth. The centre was constructed in the mid-1960's.

The original construction was typical of similar developments at that time comprising of two strips of single storey small shops either side of one major and two minor malls.

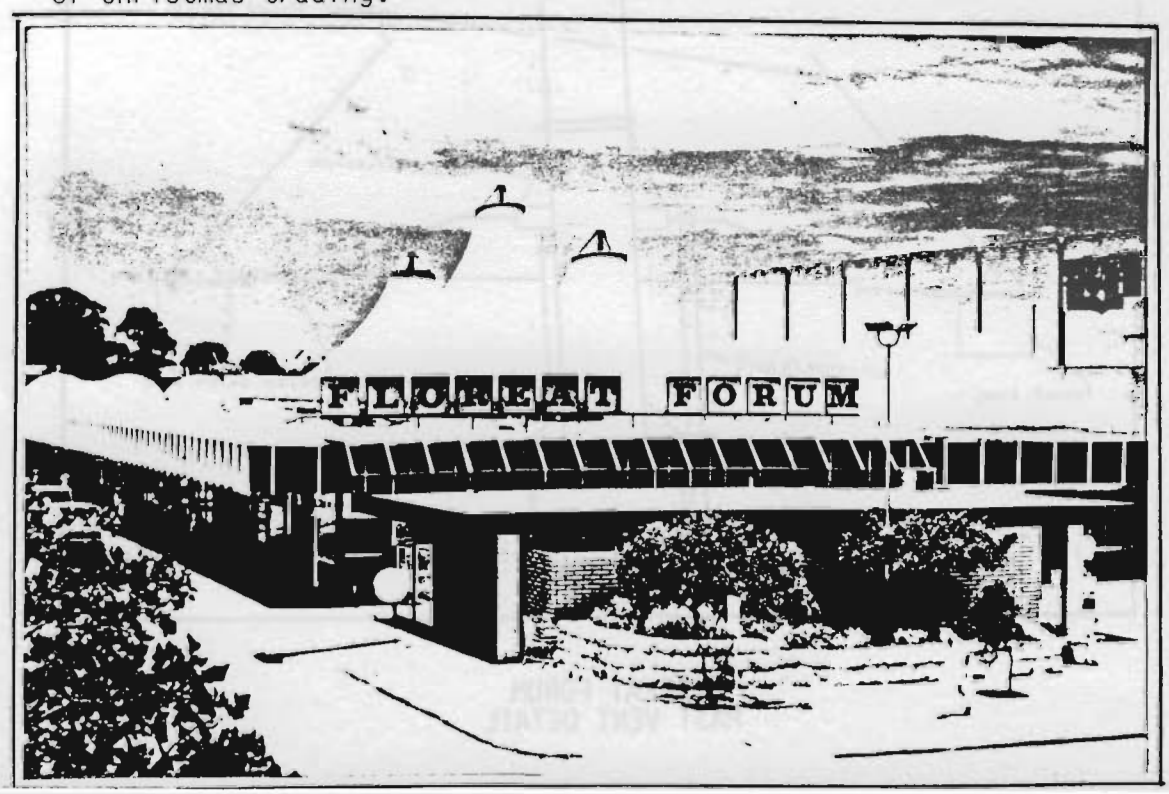
By the early 1980's the centre was trading at a low level, competitive activities of more recently established centres nearby were of concern to the owners.

It was decided that a major refurbishment should be undertaken. The open mall which was completely exposed to weather and which did not contribute to a cross flow of pedestrian traffic was identified as a key element in the redevelopment.

A decision was made to fully enclose the malls however it was considered that a low level roof of conventional construction would be too oppressive. A further consideration was the retention of existing palm trees which were a landmark in the centre.

Tensioned fabric structures were considered to be the most suitable form of construction to provide a spacious and natural environment while at the same time obtaining the benefit of energy savings resulting from natural daylighting.

Demolition commenced at the site in June 1984. Construction including enclosure and landscaping of the malls, refitting of shopfronts was completed in November 1984 coinciding with the start of Christmas trading.



DESIGN

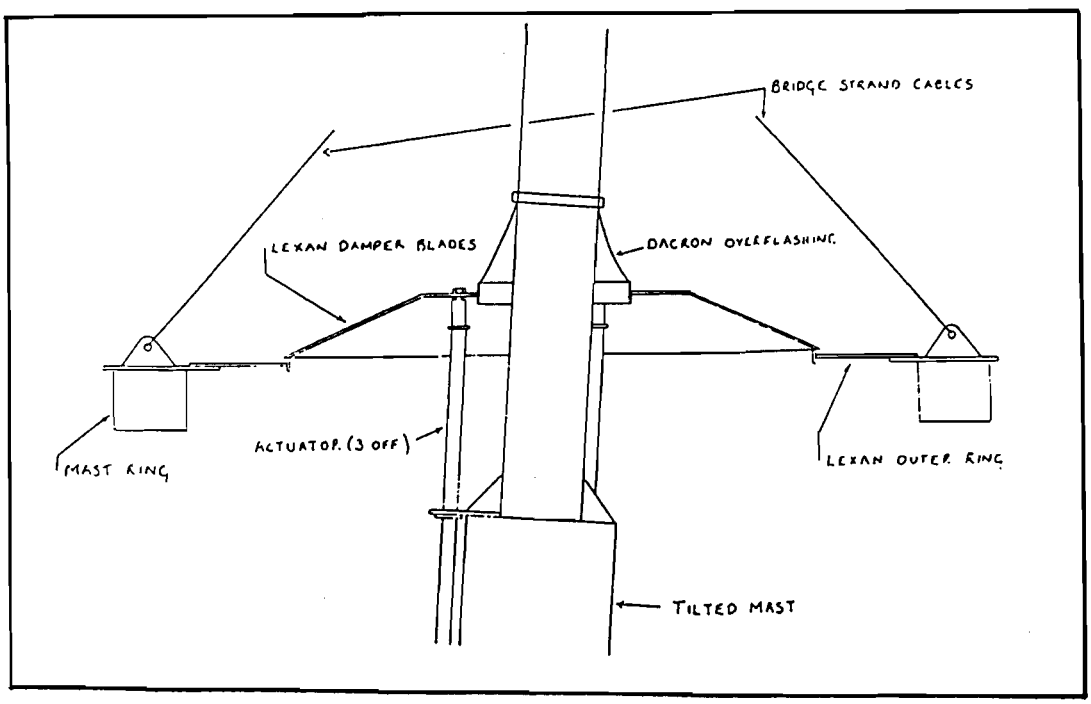
The Main Mall covers and area of 66.6m x 18.1m. To accommodate the three clusters of palm trees a series of three assymetrical linked fabric cones were designed. The membrane springing line is a new 1m deep steel truss located above the original metal deck roof. The roof drains into the original gutters which are located within the boundary of the fabric structure.

To avoid the need for sprinkler protection the truss was left exposed to provide a 1m air gap between the existing metaldeck roof and the new membrane roof.

The membrane is supported by three tubular inclined masts, the heights of which are 18.6m, 15.m and 14.6m from ground. At mast-top fabric is attached to 3.0m diameter steel rings which are fixed to the mast by 29mm dia. bridge strand cables. The steel rings are in the horizontal plane.

Analysis by the project mechanical consultant confirmed that thermal performance characteristics of the selected fabric for the membrane were such that comfort levels could be maintained in the mall using spill air from the existing stores. No additional air conditioning was required.

The consultant designed a flat acrylic cap to each of the steel rings for weather protection. The acrylic caps were originally conceived as being capable of automatic operation in conjunction with rain sensors. The principle of the design of the vents was that they would be open in summer months to allow natural venting of radiant heat by stratification. In winter months the vents would be closed to reduce loss of heat.



FLOREAT FORUM
MAST VENT DETAIL

The Minor Mall membranes cover an area of 30.5m x 6.2m and are enclosed by six groyne vaults which are 3.2m above the springing line of the fabric. Unlike the Main Mall, the membranes of the Minor Malls provide a weatherproof, sealed enclosure to the space below. Similar to the Main Mall, no new air conditioning was added, spill air from the shops being sufficient to maintain comfort levels.

The South Mall membranes cover an area of 24.4m x 3.2m and are 2.0m above the springing line of the fabric. The membrane forms a weatherproof, sealed enclosure to the space below.

On completion of construction the internal surfaces of the membranes were cleaned first with water, then with a cleaning agent to the manufacturer's recommendation.

DEVELOPMENT OF MOULD GROWTH

1986

In mid May 1986 nineteen months after completion the first indication of mould growth was noted on the underside of the Main Mall cones.

The growth was first noted as dispersed and pinhead size principally on the western side of the building and concentrated at the lower perimeter of the cones where the fabric is less than 30° to the horizontal.

By mid July the incidence of mould increased rapidly and individual spores spread up to 3mm in diameter.

Contamination was greater on the western side and growth had also developed in the upper portions of the cone.

There was no evidence of growth in either the Minor Mall or the South Mall.

The entire internal surface of the Main Mall membrane was cleaned and all mould removed in August 1986. The fabric assumed its original appearance without evidence of staining.

No further growth was noted through Spring, Summer and Autumn months

1987

Conditions in the malls were closely observed from April 1987.

In late May, 1987 a similar pattern to the previous year occurred in the Main Mall. Minor contamination was also noted in the South Mall and several spots also noted in the Minor Mall. In both the South and Minor Malls contamination occurred only at the ridge line of the vaults where the fabric slope was horizontal.

Analysis of mould samples was undertaken on 7th July, 1987 by R.L. Weston of ANALABS, Western Australia. (Fig. 1).

In summary test results indicated:

- The underside of the Main Mall membranes were saturated with condensation on a majority of mornings
- The underside of the Minor Mall and South Mall membranes evidenced only a slight surface film.
- The condensation in the Main Mall was free running and formed beads suspended from the membrane in the perimeter when fabric slope is less than 30° to the horizontal
- The east side of the structure which sees the full morning sun was essentially dry by midday
- The original roof gutters which are inside the line of the membrane roof were not upgraded and contained casual water from Winter rainfall
- On cold Winter mornings a heavy mist developed in parkland near the western boundary and 'rolled' across the centre and the Mall through exposed truss
- Palms were watered at random and had grown rapidly by 2m-3m. In some cases the fronds were in contact with the upper portion of the membrane.
- The growth was most severe in the areas of the structure which did not dry quickly.
- Conditions in the South Mall and Minor Mall differed as follows:

  1. No significant planting
  2. No internal gutter
  3. Roof sealed at the perimeter
  4. No fabric slope less than 30° except at the ridge (The limited growth that occurred in the structures was at the ridge)

The following conclusions were reached:

- The mould was not generated by plant spores
- A warm, moist environment was created in the Main Mall which caused the growth of mould.
- Radiant heat captured by internal finishes during daytime was released at night and contained in the top ½ of the cone structures
- Moisture was added to the internal environment from the following sources:

  Plant respiration
  Casual water in gutter
  Increased Humidity from winter rainfall and morning mists

Advice from ANALABS indicated that when conditions to sustain mould growth are removed or changed (e.g. summer conditions) individual spores die and will not regenerate. Mould in subsequent periods is new and not related to previous occurrences.

The membranes were cleaned on August 16 1987 and a programme of corrective action taken as follows:

1. Top vents to be opened on winter evening to allow exhaust of stratified warm air
2. Internal gutters to be cleaned and as necessary replaced
3. Removal of 50% of palms and controlled watering of the remaining palms
4. Daily monitoring of effect vent operation on level of condensation to be undertaken for eighteen months (Fig. 2)
5. Two areas each 150mm x 150mm were left uncleaned. No condensation was detected from October 1987 to May 10, 1988.

1988

During the latter part of May 1988 rainy weather prevailed. Condensation was recorded on eleven of thirty days between May 10 and June 8. It is noted that during rainy periods Centre Management preferred not to open the vents. When open there was no effective weather protection and rainwater fell onto the tiled floor surface below.

It was also revealed that the design of the vents was providing difficulties:

- The 1.8mØ acrylic discs were not sufficiently reinforced and 'fluttered' in moderate wind.
- The vents frequently jammed as a result of the inclined mast angle relative to the horizontal plane of the mast ring and vent cap.

Consequently the vents were left closed throughout weekends and whenever rain threatened - the period of highest humidity.

On Thursday June 9, 1988 the first signs of mould were noted in the Main Mall. No growth occurred in the Minor Mall nor in the South Mall. The mould had increased on Friday June 10.

The mould was generally in early stages in a light film of condensation. These occurrences were typified by a concentrated dark spot in suspension in the condensate which could be readily removed with a cloth.

The two 150mm x 150mm control areas of mould left from the previous year remained unchanged. Mould did not regenerate from the uncleaned areas confirming ANALABS' prediction.

Vents were closed over the weekend of June 11/12 1988. On June 13 a further increase in mould was noted. Although there was no apparent linkage between the individual spores it was noted that the growth approximately doubled each day.

At this stage mould was generally limited to the lower boundary on the east side and not visually objectionable from ground. The growth was accessible from the old roof without recourse to special equipment. Cleaning of the affected areas was undertaken on June 20. Again all traces of mould were removed, no staining occurred and the fabric was restored to its original appearance. No noticeble regrowth occurred.

The following further action was recommended:

1. A flexible membrane be attached to the outside of the Western side of the truss to prevent ingress of mist from parklands.
2. Fixed cones with permanent venting capacity be attached to each top ring and the original vents removed.

1989

The side flap was installed in May 1989, however the new cones had not been installed at last inspection on June 13, 1988.

A minimal amount of mould was noted on June 11, 1989. Inspection will be ongoing through 1989/1990 and a summary of results prepared in December 1989.

CLEANING METHOD

Material of construction of the membranes is Teflon coated fibreglass.

The fabric will not permanently stain. At each cleaning approximately 60% of the dark spores which had not spread were removed by wiping with a soft moist cloth. Those spores which had generated into larger grey spots proved more difficult to remove and 'EXIT MOULD' was applied and the area then washed with water. The total membrane surface was then cleaned with a chemical to the manufacturer's recommendation. A caution is necessary, that cleaning materials which are suitable to one fabric may be harmful to others. Care must be taken in establishing the appropriate cleaning materials for individual classes of fabric.

Access to the membrane surface was obtained by use of a 60ft man hoist.

OTHER OCCURRENCES

CHEMFAB has installed approximately 40 fabric structures. Other than Floreat Forum, intermittent mould growth has occurred in two other structures. Both of these installations are in residential applications. The first in Victoria having a conical profile, the second in Queensland being a small 6m diameter dome.

The Victorian structure is located on an exposed site on a hilltop and experiences cold windy conditions during Winter.

The Queensland structure is located adjacent to a river and experiences relatively high levels of humidity.

In neither installation is venting or air conditioning provided.

DUST COLLECTION

A related visual problem experienced in all fabric structures is collection of dust on their internal surface over a period of two or three years, the extent of which will depend on usage patterns of the area below.

Condensation in enclosed structures may often cause the dust to be concentrated and over a long term present an appearance similar to mould, however provided that condensation is not present in significant volume mould growth does not appear to develop.

The atrium roof at Jupiter's Casino in Broadbeach, Queensland, constructed in 1985 evidenced a blotchy effect after three years. On close inspection during cleaning in 1988 massive contamination by nicotine and other airborne pollutants was evident. This pollution had contaminated not only the membrane but also aluminium and structural steelwork.

A membrane structure performs the function of glazing. Similar to other glazing materials such as glass or polycarbonate a planned maintenance (cleaning) programme is necessary.

A design requirement frequently overlooked or disregarded is the need to provide access into the building by high reach equipment for general maintenance including cleaning. This requirement should be highlighted by the membrane designer/ manufacturer during the design development process.

It is a reflection on the attitudes of a segment of the Australian building owners' industry that ongoing maintenance is all too frequently neglected. Notable examples are:

The Sydney Opera House
The Sydney Eastern Suburbs Railway

In many cases the problem is compounded by selection of materials that are maintenance intensive. There is probably no such thing as a maintenance free construction. Membrane structures present a low maintenance option, however the fact that minimal maintenance is required frequently puts the structure at the bottom of the list for sensible preventative maintenance.

MOULD GROWTH - CONCLUSIONS

Fabric structures respond differently to most traditional materials structurally, mechanically and acoustically.

While emphasis is given to structural considerations the fabric structure industry possesses little expertise in mechanical or acoustical engineering.

Similarly, while several architects have designed a number of fabric structures the majority of installations represent the architect's first exposure to the technology.

It is incumbent on the fabric structure industry in the long term that its individual members acquaint themselves with the full technical considerations of their product and draw these to the designers' attention.

All too often the mechanical engineer assumes a lesser role in the preliminary design process. With fabric structures the emphasis of disciplines differs from other building forms.

The industry should seek and encourage more active participation of mechanical consultants in the design process. With appropriate mechanical design input fabric structures provide specific performance benefits.

Given a full appreciation of the response of fabric structures the mechanical engineering profession can avoid problems of mould growth and assist in recognizing their advantages to the fullest.

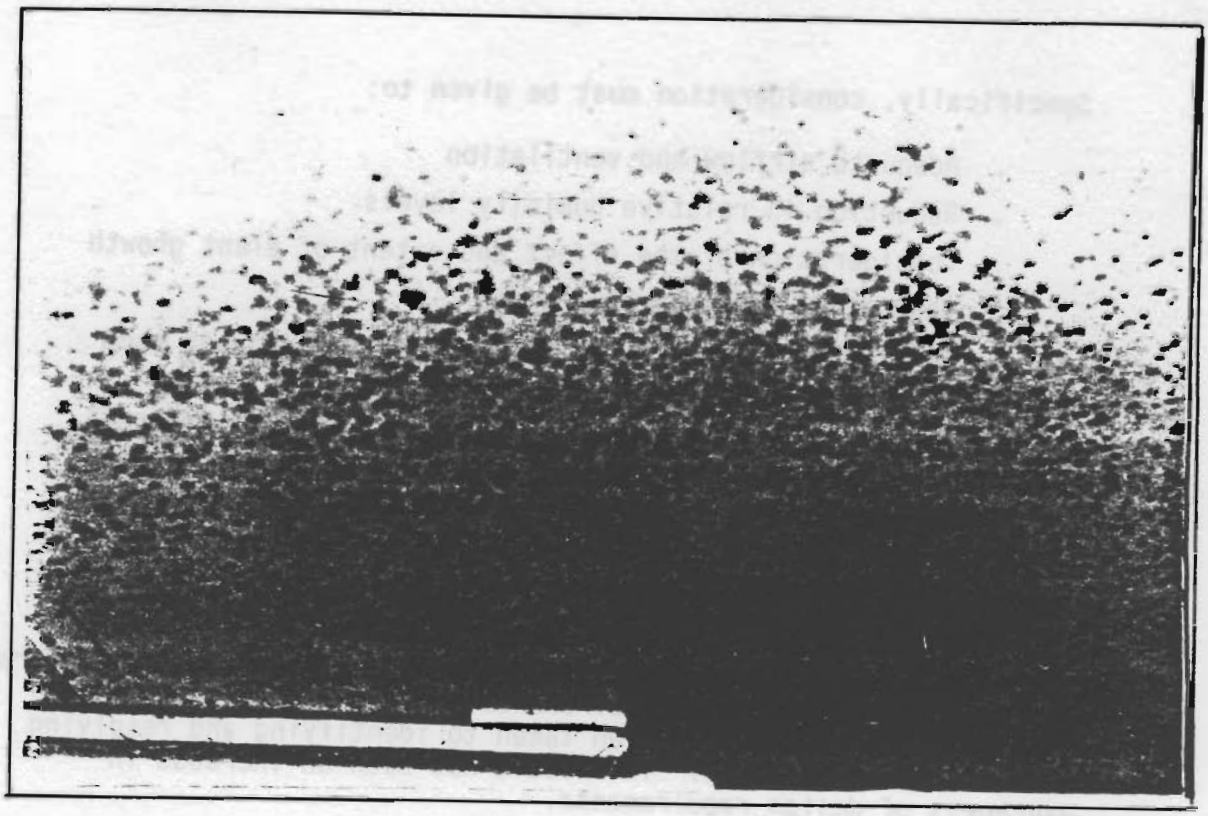
Specifically, consideration must be given to:

- Adequate airflow and ventilation
- Reduction in relative humidity levels
- Consideration of the effect and extent of plant growth
- Controlled watering programmes
- Particular attention to high 'cone' profiles and when slope is less than 30'
- Provision of adequate access for intermittent internal cleaning
- Informal monitoring of the building owner's maintenance programme by the fabricator/builder and provision of recommendations and assistance in respect of access and cleaning methods.

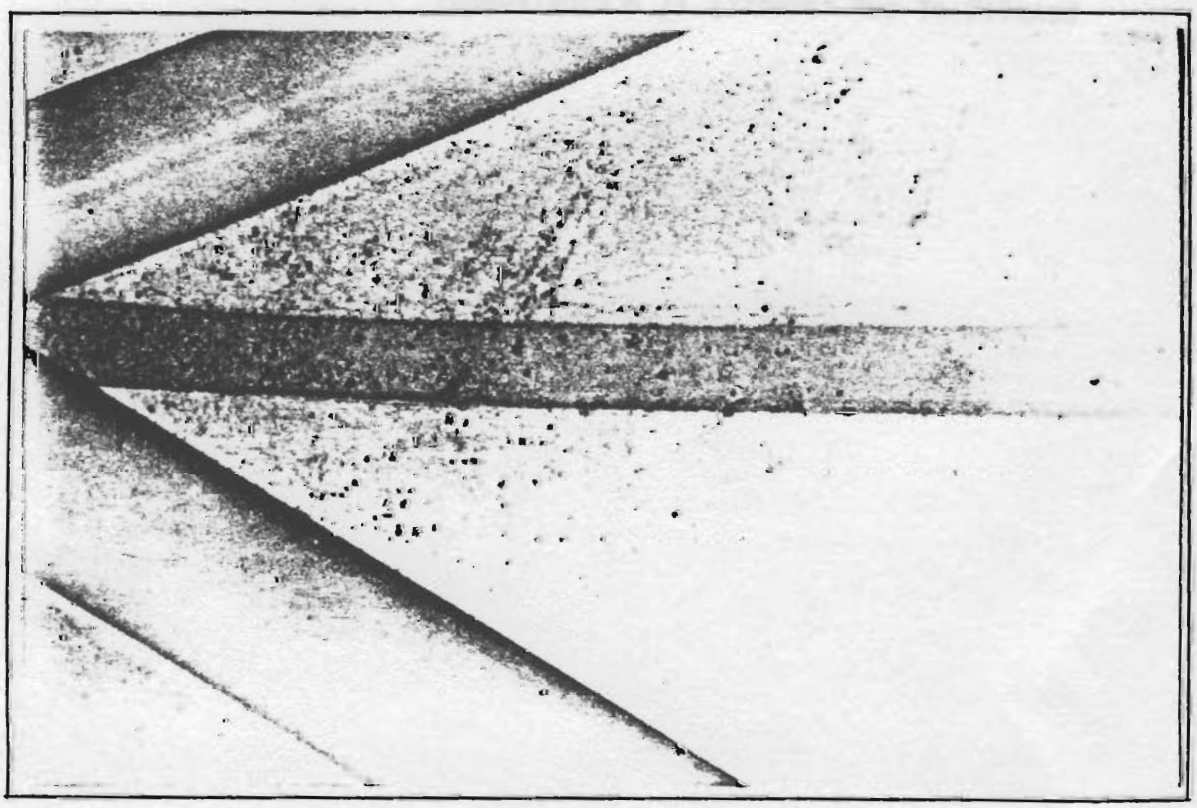
At Floreat Forum both Centre Management and the building owners are attentive to maintenance requirements within the Centre. A constructive approach has been taken to identifying and resolving the problem that exists. The result has been an increase in awareness of design requirements.

The owner's confidence in fabric structures has not diminished with a second installation presently underway at Warringah Mall in Sydney.

The assistance of Mr Tony Higgins of The Hammerson Group of Companies, his patience and consent to publish this paper to the benefit of our industry is acknowledged.



FLOREAT FORUM - MAIN MALL
JULY 7, 1987



FLOREAT FORUM - SOUTH MALL
JULY 7, 1987

FIGURE 1

ANALABS
A division of Macdonald Hamilton & Co. Pty. Ltd.
Perth Head Office.
52 Murray Road Welshpool, Western Australia 6106.
Tel: (09) 458 7999 Telex: Analab AA92560.
P.O. Box 210 Bentley, W.A. 6102.

RLW:mt

27th July 1987

The Manager
Chemfab Pty Ltd
80 Mount Street
NORTH SYDNEY NSW 2000

ATTENTION : Mr L. Thorogood

OUR REF : 1000.0.01.52876

Dear Sir

RE : Floreat Forum Shopping Centre

On the 7th July 1987 an inspection was made of the roofing fabric at the above location by Mr A. Barton, A.I.M.L.S., M.A.S.M., F.A.I.H.S. The meeting involved yourself, Mr Barton and the Centre Manager.

Samples of the dark circular stains present on the West Side of the Main Mall were collected for direct microscopy and culture.

Microscopy revealed that fungal mycelium were present in large numbers. After 3 days culturing at 30°C fungal colonies appeared on the culture medium. Provisional identification indicates that this fungus is CLADOSPORIUM species, a fungal species frequently found in the soil and in the air.

TREATMENT

The safest and most effective immediate treatment is to wash the roof with a chlorine based or equivalent domestic cleaner.

Mr Barton Reports that over 200 fungicides have been reviewed seeking one that is long lasting and compatible with the Chemfab fabric. Although Chemfab is resistant to the majority of these fungicides the investigations indicate that all the fungicidal disinfectants have a limiting factor to their use in these circumstances. They are either water soluble and therefore leach away, breakdown in sunlight, stain fabrics or are toxic for humans and not recommended where food is sold.

It is possible that the manufactureres of the Chemfab material have experienced this problem in other countries and therefore can make long term recommendations. The expense of testing various fungicides for this one project is not considered an economic exercise especially when the results may not provide a permanent solution.

cont'd/....

In the event that the manufacturers can recommend a long acting fungicide we would be pleased to test it against the isolated fungus.

As with many microbial biodeterioration problems the simplest and more economic approach is to modify the design. In this instance consideration should be given to reducing the humidity at roof level by modifying the existing roof to limit rain water gaining access to the Chemfab inner surface or by improving ventilation.

Please advise me if we can be of further assistance in this matter.

Yours faithfully
ANALABS - A Division of Macdonald
Hamilton & Co Pty Ltd.

R.L. Weston - Grad Dip Chem. A.R.A.C.I. C. Chem M.R.S.C.
CHARTERED CHEMIST

FLOREAT FORUM SHOPPING CENTRE

MONTHLY MOISTURE MONITORING REPORT

READING IDEALLY TO BE TAKEN
AT 9.00A.M. DAILY

MONTH OF APRIL, 1988

DATE	DAY	TIME	SW CORNER			SE CORNER			VENTS	
			DRY	MOIST	WET	DRY	MOIST	WET	OPEN	CLOSED
1-4-88	Friday									
2-4-88	Saturday	9.00	✓			✓			CLOSED	
3-4-88	Sunday									
4-4-88	Monday									
5-4-88	Tuesday	9.00	✓			✓			CLOSED	
6-4-88	Wednesday									
7-4-88	Thursday	9.00	✓			✓			9am to 5pm	
8-4-88	Friday	9.15	✓			✓			9am to 8.30pm	
9-4-88	Saturday	9.00	✓			✓			9am to 5pm	
10-4-88	Sunday								9am to 12.30	
11-4-88	Monday	9.00	✓			✓			CLOSED	
12-4-88	Tuesday	9.00	✓			✓			9am to 5pm	
13-4-88	Wednesday	12.00	✓			✓			9am to 5pm	
14-4-88	Thursday	9.00	✓			✓			9am to 5pm	
15-4-88	Friday	9.00	✓			✓			9am to 5pm	
16-4-88	Saturday	9.00	✓			✓			9am to 5pm	
17-4-88	Sunday								9am to 1pm	
18-4-88	Monday	9.00	✓			✓			CLOSED	
19-4-88	Tuesday	9.00	✓			✓			8am to 4.15pm	
20-4-88	Wednesday	9.00	✓			✓			7am to 4pm	
21-4-88	Thursday	11.30	✓			✓			11.15am - 5.30pm	
22-4-88	Friday	9.00	✓			✓			9am to 4pm	
23-4-88	Saturday	9.00	✓			✓			9am to 5pm	
24-4-88	Sunday								9am to 11am	
25-4-88	Monday	HOLIDAY							CLOSED	
26-4-88	Tuesday	10.00	✓			✓			CLOSED	
27-4-88	Wednesday	9.00	✓			✓			10am to 4pm	
28-4-88	Thursday								CLOSED	
29-4-88	Friday	9.00	✓			✓			CLOSED	
30-4-88	Saturday	9.00	✓			✓			CLOSED	
31-4-88	Sunday								9am to 12.30p	

SIGNED _____ TITLE MAINT _____

FLOREAT FORUM SHOPPING CENTRE

MONTHLY MOISTURE MONITORING REPORT

READING IDEALLY TO BE TAKEN
AT 9.00A.M. DAILY

MONTH OF MAY, 1988

DATE	DAY	TIME	SW CORNER DRY	SW CORNER MOIST	SW CORNER WET	SE CORNER DRY	SE CORNER MOIST	SE CORNER WET	VENTS OPEN CLOSED
1-5-88	Sunday								
2-5-88	Monday	9.00	✓			✓			CLOSED
3-5-88	Tuesday	9.00	✓			✓			10am to 2pm
4-5-88	Wednesday								9am to 4.30p
5-5-88	Thursday	9.00	✓			✓			CLOSED
6-5-88	Friday	9.30	✓			✓			10am to 5.30p
7-5-88	Saturday	9.00	✓			✓			9am to 5pm
8-5-88	Sunday								CLOSED
9-5-88	Monday	9.00	✓			✓			CLOSED
10-5-88	Tuesday	9.00			✓			✓	10am to 3.30p
11-5-88	Wednesday	9.00	✓			✓			9am to 5pm
12-5-88	Thursday								CLOSED
13-5-88	Friday	9.00			✓			✓	CLOSED
14-5-88	Saturday	9.00			✓			✓	CLOSED
15-5-88	Sunday								CLOSED
16-5-88	Monday	9.00			✓			✓	CLOSED
17-5-88	Tuesday	9.00			✓			✓	9am to 2.30p
18-5-88	Wednesday	9.00	✓			✓			1pm to 4pm
19-5-88	Thursday	9.00	✓			✓			9am to 4pm
20-5-88	Friday								CLOSED
21-5-88	Saturday	9.00	✓			✓			CLOSED
22-5-88	Sunday								10am to 12pm
23-5-88	Monday	9.00	✓			✓			CLOSED
24-5-88	Tuesday								CLOSED
25-5-88	Wednesday	8.30			✓			✓	CLOSED
26-5-88	Thursday	9.00	✓			✓			9am to 12pm
27-5-88	Friday	9.00	✓			✓			CLOSED
28-5-88	Saturday	9.00	✓			✓			9am to 2pm
29-5-88	Sunday								9am to 12pm
30-5-88	Monday	9.00			✓			✓	CLOSED
31-5-88	Tuesday	9.00	✓			✓			CLOSED

SIGNED _____

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