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Interim Progress Report to Arrow International Ltd
and
The Carisbrook Stadium Trust

Dunedin Multi-purpose Stadium
ETFE Test Rig Evaluation – Turf Testing

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Executive Summary

This is an interim report that presents the findings to date from a trial that was commissioned to assess the effects of the proposed ethyltetrafluoroethylene (ETFE) roof material on turfgrass growth and light transmission properties in a stadium environment. The trial was conducted in a purpose-built ETFE test rig located in Dunedin.

The installation of an ETFE roof will remove undesirable elements of the Dunedin winter that would otherwise be present in a conventional stadium with solid-roofed stands (eg. frost and intense localised shading). It will also allow for much greater control of surface moisture conditions, so eliminating the risk of heavy rainfall and poor surface conditions before an important event. However, the overall effect of the ETFE material will also be to change the natural balance of light and temperature for turfgrass growth. Alteration of turf (and other) management practices will be required to deal with this.

Light levels transmitted through the ETFE will be the over-riding factor governing turfgrass performance in the proposed stadium. Measurements made on the ETFE used to build the test rig showed that the maximum transmission efficiency of photosynthetically active radiation at times of high sunlight availability was in the region of 75%, which is still sufficient for turfgrass growth and recovery, as demonstrated by the results to date of the spring and early summer artificial wear experiments described in this report.

However, during winter with low sun angles, it was predicted from the test rig and laboratory results that the transmission efficiency has the potential to reduce to 60% of photosynthetically active radiation available and could be even lower when other factors such as dew and localised shading from stadium structures are taken into consideration.

Using average monthly solar radiation data for Dunedin and published thresholds for turfgrass light requirements, it can be concluded that a reduction in transmission efficiency to 60% for a crucial period of the year (approx. middle of May to the end of July) will result in insufficient light being available for turfgrass growth and recovery during that period. The main reason for this conclusion is that natural light levels in Dunedin in winter are already close to the threshold for sufficient light for turfgrass growth and recovery.

It is concluded that a light transmission efficiency of at least 80% (along with a number of turf management strategies) will be required to avoid detrimental turfgrass conditions in winter, a value that must be considered as a key design parameter for the proposed stadium. The

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report outlines a number of ways in which an increase in light transmission can be achieved, some of which are already being worked on by the stadium design team. They include modifying the proposed roof to maximise sunlight interception, using a better grade of ETFE and investigating the use of supplementary lighting.

Cost estimates for recommendations given in the report range from an additional $35,000 per year for fertiliser and fungicide consumables to an additional $1.2M capital sum for a turf reinforcement system. Furthermore, if more detailed modelling of the stadium roof demonstrates the need for a supplementary lighting system, the capital cost of such a system must be justified.

Even with a transmission efficiency of 80%, the new stadium operator will still need to be mindful of the extent and type of use carried out and wherever possible, limit the amount of play during periods of low recovery potential, a management tool already used at the current Carisbrook Stadium.

If a transmission efficiency of at least 80% can be achieved through roof design modifications and if the turf management and other management strategies recommended in the report are implemented along with results of on-going research through the 2008 winter months using the ETFE test rig, we are confident at this stage that it will be possible to grow the grass successfully.

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Note

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1.0 Introduction

1.1 Background

The proposed new stadium at Dunedin is being designed with a permanent roof structure to be constructed out of ETFE (ethyltetrafluroethylene). This is the first time a fully enclosed stadium has been designed in this way. In the Masterplan & Feasibility Stage Outputs Report prepared by The New Stadium Development Consulting Team, it was identified that assessment of the proposed ETFE roof material would be required from a turfgrass growth and light transmission perspective during the concept stage of the project[1].

In early July 2007, Arrow International requested that Sports Surface Design & Management (SSDM) submit a formal proposal for six month research project to help determine whether an adequate turfgrass surface would be able to be maintained for sporting events within an enclosed ETFE environment (see Appendix 1 for terms of reference). SSDM is a specialist soils and turfgrass consulting division of Recreational Services Ltd from Auckland. SSDM's credentials to be able to conduct such work are given in Appendix 2.

A formal research proposal was submitted by SSDM on 12 July 2007, which was reviewed by HOK Sport Architecture. In this proposal, SSDM designed a comprehensive turf testing trial to be conducted over a six month period under a supplied mock-up of the proposed stadium roof (known as the ETFE test rig) in which artificial 'wear' would be applied to simulate the action of rugby-type stadium use.

The SSDM trial was designed to focus on three particular areas of interest:

- The ability of the proposed ETFE roofing material to allow sufficient photosynthetically active radiation to be transmitted through the roof to sustain a level of turfgrass growth required for sports events.

- How the 'wear tolerance' of turfgrass would change with time during the course of the trial within an enclosed ETFE environment when subjected to repetitive artificial wear events, such as would be expected during typical stadium operation.

[1] The New Stadium Development, Masterplan & Feasibility Stage Outputs, Section 2.3.12 Turf, p. 58.

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- How the recovery rate of turfgrass would change with time when grown within an enclosed ETFE environment after a significant artificial wear application had been made at different times during the course of the trial.

By the time of submission of the research proposal, SSDM had commenced liaison with the Otago Rugby Football Union (ORFU) Turf Manager in relation to the proposed trial design and its maintenance. This liaison was initiated as the ORFU Turf Manager would be maintaining the trial area in accordance with the testing methodology.

SSDM was informed on 15 August 2007 that it was the preferred turf consultant to carry out the turf testing and was subsequently invited to a start-up meeting in Dunedin on 22 August 2007 along with Alex York (HOK), Coryn Huddy (Turf Manager, ORFU), Grant McKenzie (Arrow International) and Dr Jock Allison (turf advisor to The Carisbrook Stadium Trust). Minor modifications to the ETFE test rig structure were discussed and agreed, as well as refinements to the proposed SSDM trial design, in particular the inclusion of more regular wear application and measurement of grass dry matter production (the latter in conjunction with AgResearch Grasslands). Baseline soil and turf measurements were made of the trial area, along with a demonstration of proposed testing gear.

SSDM submitted a final turf testing proposal in early September 2007, addressing the points raised in the start-up meeting, with the first major wear application commencing on 12 September 2007.

Important notes

1. Environmental design aspects for the proposed new stadium relating to humidity, temperature and ventilation control are being dealt with in a separate modelling exercise by others that is beyond the scope of this trial and are not covered in this report. For the purposes of this trial, the test rig was deliberately ventilated with a 500 mm air gap at the base of the rig to specifically reduce turfgrass management issues associated with high extremes of temperature and humidity (eg. disease). Although soil and air temperature levels were monitored during the course of the trial, along with relative humidity, the values recorded should not be taken as being representative of what might be experienced in a full size stadium.

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2. It was acknowledged by all parties that the preferred duration for the above trial was a full 12-month period in order to allow for light transmission evaluation and wear testing/turfgrass recovery during the critical winter growth period. However, fixed project timelines dictated that a verifiable report would be required by the end of summer 2008, ie. without a full year of wear testing being carried out, in particular during autumn and winter. Therefore a particularly important aspect of the SSDM trial design included the ability to capture sufficient light transmission data at low sun angles (relative to the horizon) in order to be able to predict light transmission during the winter period and its effects on turfgrass growth.

1.2 ETFE test rig

The ETFE test rig was designed by HOK sport architecture and associated consultants in June/July 2007, with construction commencing on 8 August and the rig being inflated on 13 August 2007. The test rig was located on an area within the current turf nursery at Carisbrook Stadium on which mature turf-type perennial ryegrass was growing in a sand-based rootzone. The type of turfgrass in the turf nursery would be similar to that proposed for the new stadium. After SSDM had been appointed to conduct the trial and had made an inspection during the start-up meeting on 22 August, minor modifications were made to the test rig (prevention of light and rainwater incursion). The finished test rig used for the turf testing trial is shown in Fig. 1.

Figure 1. ETFE test rig.

2.0 Trial Design and Management

2.1 Overview

The relatively small size of the test rig necessitated a very careful design in order to generate the maximum amount of information from the six month trial. A decision was taken by SSDM in their trial design to sacrifice plot replication in favour of more plot treatments, given that the effect of shade on turf wear in trials of this type is usually large. Replication would still be possible in the form of multiple measurements taken on individual plots, so it was considered that lack of plot replication would not be of great concern for this trial.

The SSDM trial was designed to assess turfgrass growth under a range of artificial wear treatments within the ETFE test rig (Fig. 2). An outside test area exposed to full sunlight was also used as the benchmark from which to compare results obtained within the ETFE test rig (see Appendix 3 for photo). Wear treatments that were applied within the ETFE test rig were also applied to the outside test area.

Figure 2. Artificial wear application machine – a modified petrol powered 20" Lawn Master mower fitted with studded rollers rotating at slightly different speeds. Extra weights were fitted on the front of the machine to increase grass-wearing effectiveness.

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2.2 Wear application

Wear treatments included a control treatment (no wear applied for the duration of the trial) and two principal types of wear treatment applied to two different plots within a test area three weeks after commencement of the trial and then every six weeks over the six month period (ie. wear applied at 3, 9, 15 and 21 weeks). The advantage of this staggered wear design was that it created a lead-in period prior to wear events taking place making it possible to assess the wear tolerance of turfgrass as it was exposed to an increasing duration of acclimatisation under the ETFE test rig.

Prior to each wear application, the two trial areas (outside area and ETFE test rig) were irrigated to produce standard soil moisture conditions conducive to a high wearing ability (ie. surface moist, but not saturated). A theta probe soil moisture sensor that gave instant readings of volumetric soil moisture content was used for this purpose.

The two principal types of wear treatment applied were:

2.2.1 Wear Treatment 1 (one-off intense wear and recovery)

A plot within each trial area was worn to approximately 50% ground cover and the number of passes required by the wear machine to achieve this loss of ground cover under the EFTE test rig and outside (uncovered) test area was recorded. After Wear Treatment 1 had been applied, the selected plots were managed to optimise grass recovery by over-seeding the plots and then measuring the rate of recovery of ground cover.

2.2.2 Wear Treatment 2 (on-going light wear)

A second plot within each trial area was worn with a number of passes of the wear machine to a level known to be able to be tolerated by the <u>outside</u> (uncovered) turf. The exact number of passes to be applied was determined by:

1. Firstly applying wear to the uncovered test area and wearing the plot to the point where the turf cover just started to deteriorate significantly and recording the number of passes carried out.

2. Then applying the same number of passes to the equivalent plot under the ETFE test rig and assessing the damage in terms of ground cover loss.

Wear was carried out as above on a fortnightly basis on Wear Treatment 2 plots in order to ascertain how the turfgrass behaved within an enclosed environment when subject to repetitive wear events, such as would be expected during a playing season where a maximum of two weeks may be available between wear events. After the wear treatment was carried out, each plot was monitored for grass recovery.

2.3 Trial maintenance

Day-to-day management of the trial was carried out by grounds staff of the Otago Rugby Football Union under the guidance of SSDM, with site visits and measurements being conducted on a monthly basis by SSDM staff.

How the two trial areas were managed from a maintenance point of view was standardised within reasonable limits, in particular with respect to grass cutting height and nutrient inputs. For both trial areas, nutrient inputs were based on best practice for growing turf in the closed roof Telsta Dome stadium in Melbourne. Irrigation inputs were based entirely on turfgrass water requirements as monitored regularly with a theta probe soil moisture meter, with irrigation applied using deep infrequent applications early in the morning in order to avoid leaving the surface wet for long periods of time. Disease prevention and control was assessed on a case-by-case basis (but has not been required on the trial area at the time of writing). All maintenance inputs and daily logs of plot and weather conditions were recorded on a customised Excel spreadsheet.

The basic maintenance inputs were:

- Mowing: trial areas were double cut three times a week at 25 mm cutting height with all clippings removed.

- After an initial correction for pH levels, the fertiliser programme was based on weekly background foliar applications over each trial area of nitrogen and potassium supplying the equivalent of 90 kg/N/ha and 111 kg/K/ha per year respectively; additional weekly applications of phosphorus dominant NPK foliar fertiliser (10-20-16) were also made to

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individual worn plots to boost recovery from wear on an as-required basis, supplying 2.7 kg/N/ha, 2.4 kg/P/ha and 3.6 kg/K/ha per application or double that amount, depending on the precise rate used (note: the same plots in both trial areas were always fertilised identically).

- Irrigation: applied using a soak hose to maintain a volumetric water content in the top 75 mm of the profile of between 35% (v/v) and 45% (v/v). Reseeded plots also received local syringing by hand twice daily to aid seed germination and initial establishment.

- Physical treatment: all plots were aerated using 8 mm mini-tines on a 50 mm by 130 mm spacing twice during October and November 2007; manual brushing/sweeping of all plots was carried out approximately weekly.

2.4 Principal measurements

To assess turfgrass performance and recovery, the following measurements were conducted:

Turfgrass: dry matter production and leaf moisture content, turfgrass fibre content, ground cover percentage and botanical composition, surface traction (grip), root growth, overall turfgrass quality.

Environmental: soil temperature, soil moisture content, relative humidity, air temperature, photosynthetically active radiation (PAR), spectroradiometer test on the ETFE.

Details of all measurements are shown in Table 1, with photographs of selected equipment shown in Appendix 3.

TABLE 1
Details of turfgrass and environmental measurements

Measurement	Description	Frequency of measurement
Botanical composition	Measured using an optical point quadrat (Laycock & Canaway, 1980) using 10 frames of 10 points measured in each plot.	Plots measured at the beginning and end of the trial for botanical composition. Also used on a monthly basis on control plots and all plots that had received wear for visual measurement of ground cover percentage.
Ground cover percentage	Measured using a capacitance probe (Stewart, 2000) that recorded the volume of leaf tissue between the probes and hence provided a quicker (but indirect) measurement of ground cover compared with the optical point quadrat. Measured on 10 locations per plot.	Measurements made on a fortnightly basis immediately after mowing, on control plots and all plots that had received wear.
Surface traction	Measured using the studded disc torque wrench apparatus of Canaway & Bell (1986). Complete separation of turf from the underlying soil was scored as a divot removed. Measured on five locations per plot.	Measurements made on a fortnightly basis on control plots and all plots that had or were about to receive wear.
Dry matter production and fibre analysis.	A sample of turfgrass clippings from each trial area was collected over a known surface area using a Toro GR 1000 pedestrian greens mower. The sample was weighed fresh, microwaved for one minute at high power to stop respiration and couriered to AgResearch Invermay for dry matter analysis after drying for 24 hours at 70^{o} C. A second bulk sample from the remaining trial area was also couriered for analysis of total fibre (neutral detergent fibre, NDF), and cellulose + lignin content (acid detergent fibre, ADF) using near infrared reflectance spectroscopy (NIRS).	Dry matter production was measured at each mowing event; fibre analysis was carried out on a monthly basis.
Volumetric soil moisture content	Measured using a Delta-T ML2 Theta Probe and HH2 Moisture Meter. Measured on five locations per plot.	Measurements made on control plots and all plots that were about to receive wear. Also used on a regular basis to manage irrigation application.
Root growth	Measured on 25 mm diameter cores taken to 100 mm depth. Soil was washed from the samples and root mass determined between 0-50 mm and 50-100 mm depths after drying at 70^{o}C for 24 hours. Measured on five locations per plot.	Measurements made at the beginning of the trial and thereafter on a monthly basis, on control plots only.
Soil temperature	Measured using a digital thermometer probe at a depth of 100 mm. Measured in a single location within each control plot.	Measured daily at 12 pm.
Surface temperature and humidity	Measured using a TFA 433 MHz Thermo Hygrometer humidity and temperature data logger and two remote sensors at near ground level (data logger and one remote sensor located in the ETFE test rig; one remote sensor located in the outside test area). Supplementary measurements of maximum and minimum temperature were also measured in the same locations using conventional mercury thermometers positioned approx. 1.2 m above ground level.	Readings were taken by the datalogger every 4 hours, 24 hours per day. Maximum and minimum temperatures were measured daily at 12 pm.
Turfgrass fineness, uniformity, overall quality	Assessed subjectively using a standard 1-9 scale. One assessment was made per plot.	Assessments made on a monthly basis immediately after mowing, on control plots and all plots that had received wear.
Photosynthetically active radiation (PAR)	Measured over a sunrise to sunset period using a LI-COR LI-250A light meter and LI-190 quantum sensor. Positioning and location of the sensor varied according to nature of PAR information required.	Measurements made monthly over a four month period at half hour or one hour intervals.
Spectral transmission	Measured over the 300-1100 nm wavelength under a single or double layer of ETFE in full sun, blue sky and light overcast conditions using a LI-COR LI1800 portable spectroradiometer fitted with a cosine receptor.	One-off laboratory measurement carried out by Lincoln University.

3.0 Trial Progress – Light Transmission

3.1 Light quality (laboratory measurements)

Laboratory-based spectroradiometer tests were conducted on the ETFE material under full sun, blue sky and light overcast conditions over the spectral wavelength of 300-1100 nm. Measurements were made through a single layer of ETFE and a double layer, as well as in unobstructed light. Spectral absorption graphs are shown in Appendix 4.

Although the two layer measurements did not reflect precisely the 'pillow' structure of the ETFE in situ in a stadium design, the results nevertheless showed that light transmission percentages and the quality of light transmitted were in general agreement with those claimed by the manufacturers. That is to say, there were no detrimental absorption peaks in the spectral wavelength required for plant photosynthesis (400-700 nm) and the smooth percentage transmission lines recorded confirmed that the ETFE material caused a reduction in transmission of approximately 10% per layer when light was shining at a low incident angle (ie. beam perpendicular to the ETFE surface) through the material (Appendix 4). Thus, a <u>maximum</u> transmission efficiency of 80% can be anticipated on this grade of ETFE. In practice, this value has the potential to be reduced depending on the angle of incidence of the sun, localised shade effects from the structure holding up the ETFE material and other miscellaneous effects (eg. dew). Field measurements provided more information in this regard (see next section).

3.2 Light quantity (field measurements under ETFE rig)

Field measurements of transmission of photosynthetically active radiation (PAR) carried out on 10/10/07 (weather conditions: full sun with intermittent light cloud) under the ETFE test rig showed the following results:

- The amount of PAR transmitted through the ETFE test rig averaged approximately 75% of unobstructed PAR over the course of daylight hours from sunrise to sunset (Fig. 3).

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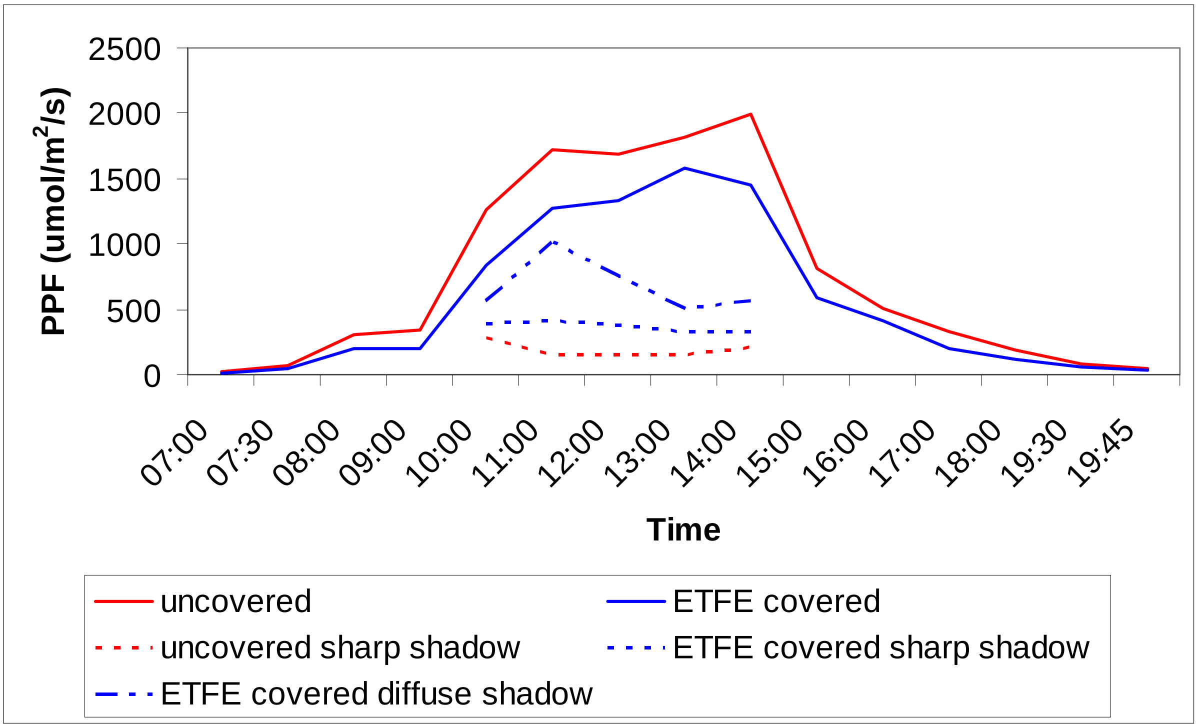

Figure 3. Levels of photosynthetic photon flux density (PPF) measured on 10/10/07 in the ETFE test rig (covered) and the adjacent outside test area (uncovered). The ETFE transmitted approximately 75% of the photosynthetically active radiation (PAR) received during the course of the day (note: full sunlight is approximately 2000 µmol/m^2/s).

- The above value is in general agreement with the laboratory data in Section 3.1, with the extra 5% loss from 80% to 75% averaged over the course of the day most likely arising from the effect of early morning dew, localised shade and higher transmission losses at high incident angles (ie. low sun angles relative to the horizon) (Fig. 4). In this respect, the following transmission percentages were also recorded on 10/10/07:

    - Transmission of PAR through the dew-covered ETFE test rig was under 60% of unobstructed PAR (ie. transmission losses of 40%). During the middle part of the day when dew had burnt off, transmission percentages were typically 80%, in agreement with the laboratory measurements (Section 3.1).
    - Transmission of PAR in a ‘sharp’ shadow under the ETFE test rig was typically between 17% and 45% of unobstructed PAR depending on the time of day the measurement was taken (ie. transmission losses of between 55% and 83%).
    - Transmission of PAR in a ‘diffuse’ shadow under the ETFE test rig was typically between 25% and 59% of unobstructed PAR depending on the time of day the measurement was taken (ie. transmission loss of between 41% and 75%).

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- Given that dew will be present at certain times of the year and that a significant quantity of shadows will be formed by the roofing lattice and surrounding stands, it is important that these additional light transmission losses are taken into account in the design of the stadium roof.

The difference between a 'sharp' shadow and a 'diffuse' shadow is shown in Fig. 5.

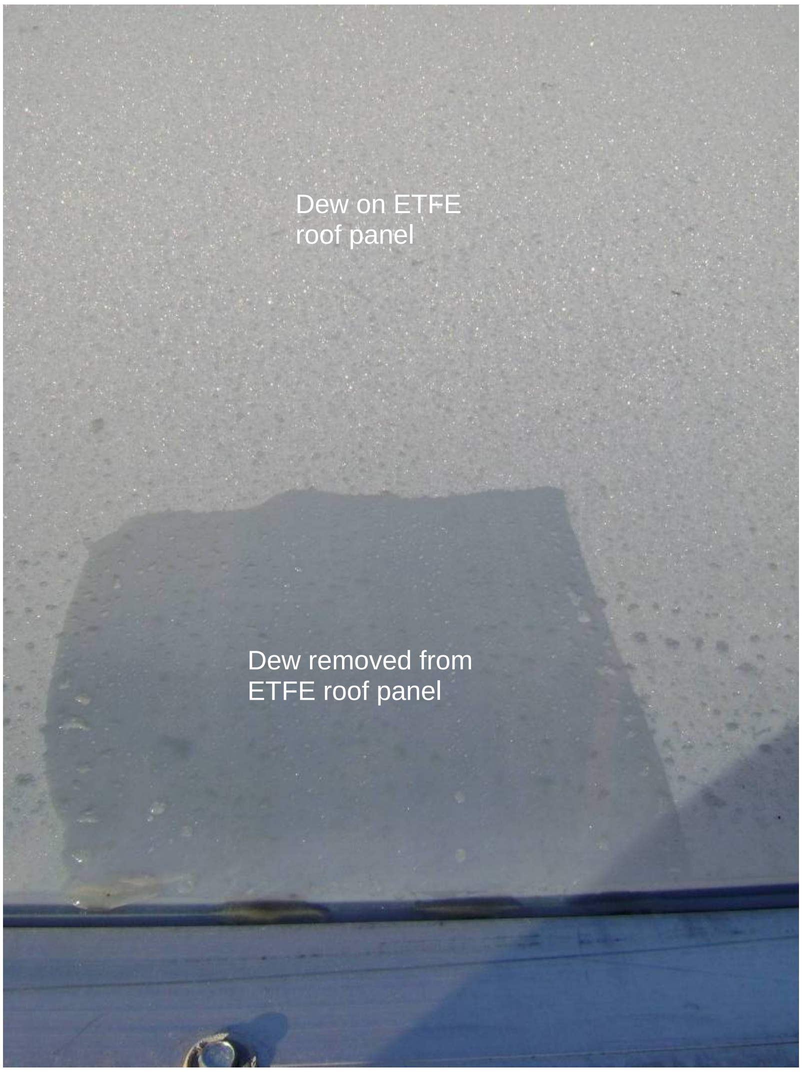

Figure 4. The presence of dew on the ETFE reduced light transmission through the material significantly. The effect will not be of great consequence in early summer, but will have significant implications during autumn, winter and spring at low sun elevations. Transmission percentages were less than 60% through the dew-covered ETFE test rig.

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Figure 5. Light conditions at 10:00 NZDT on 10/10/07 showing the difference between ‘sharp’ and ‘diffuse’ shadows in the ETFE test rig (bottom photo). The outside test area is shown in the top photo.

- Overall, the total amount of PAR received in the test rig on 10/10/07 under spring sunlight conditions with intermittent cloud coverage was approximately 24 mol/day of PAR (assumes a ‘cap’ of 1000 µmol/m^2/s for a cool season grass during late spring growth conditions – ie. values measured above 1000 µmol/m^2/s cannot be utilised by the plant as it is at ‘light saturation’). A value of 24 mol/day PAR is 4 mol/day above the definition of reduced light by Rogers et al. (1997)[2]. On average, any situation where the turf

[2] Reduced light is defined as an amount of light which is below the level of light required for maximum photosynthesis.

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receives less than one third of the full sunlight available is considered to be in a reduced light situation (ie. less than 20 mol/day received over at least an eight hour day).

- Outside the test rig, the equivalent value of total amount of PAR received was 28 mol/day.

Field measurements of light transmission carried out on 11/10/07 (weather conditions: light drizzle, full cloud cover all day) under the ETFE test rig showed the following results:

- The amount of PAR transmitted through the ETFE test rig ranged between 65% and 76% of unobstructed PAR over the course of daylight hours from sunrise to sunset.

- Within the ETFE test rig, PAR values over the course of the day never exceeded 341 µmol/m^2/s compared with 463 µmol/m^2/s for the outside test area. A value of 300-400 µmol/m^2/s over an eight hour period is the minimum amount of light required to achieve a reasonable plant recovery at times of low growth (eg. winter). A value of below 100-200 µmol/m^2/s is considered an insufficient amount of light (ie. below light compensation point[3]).

- The values measured under full overcast conditions on 11/10/07 can be considered a reduced light situation, representative of the worst winter light conditions that would still achieve reasonable plant recovery for turf subject to sporting traffic.

3.3 Light quantity at low angles

As winter approaches, maximum sun elevations decrease to just less than 21° in Dunedin. Data from Hutchins (2007) have indicated that light perpendicular to the ETFE has a transmission of 90% (81% for two layers) but that this declines to about 85% transmission (72% for two layers) for incident angles of 45° (midday at the equinoxes in Dunedin) and drops rapidly below 75% transmission (56% for two layers) at incident angles greater than 60° (ie. less than 30° angle of elevation of the sun from the horizon). In other words, transmission through the ETFE decreases markedly at low sun elevations.

[3] Defined as the level of light energy needed for a plant to produce an amount of photosynthate equal to the amount it uses for respiration.

A secondary light study was therefore carried out on 7-8 November 2007 to measure the percentage transmission rates *in situ* at low sun elevations in the early morning in order to make predictions about winter light levels and their likely effect on turfgrass performance. In this study, the light sensor was held perpendicular to the sun's beam with the sensor being located specifically under the roof.

Light measurements made through the roof of the ETFE test rig showed that there was a significant linear relationship between the percentage of PAR transmitted through two layers of ETFE in the roof panel and low angles of sun elevation (Fig. 6). The light readings taken within the ETFE test rig confirm that transmission of low elevation sunlight through the 2-layer roof pillow will be reduced, the implications of which are discussed in Section 3.4. Thus, during winter, the transmission of light through the roof pillows of ETFE will be strongly affected by the slope of the roof relative to the sun elevation and aspect.

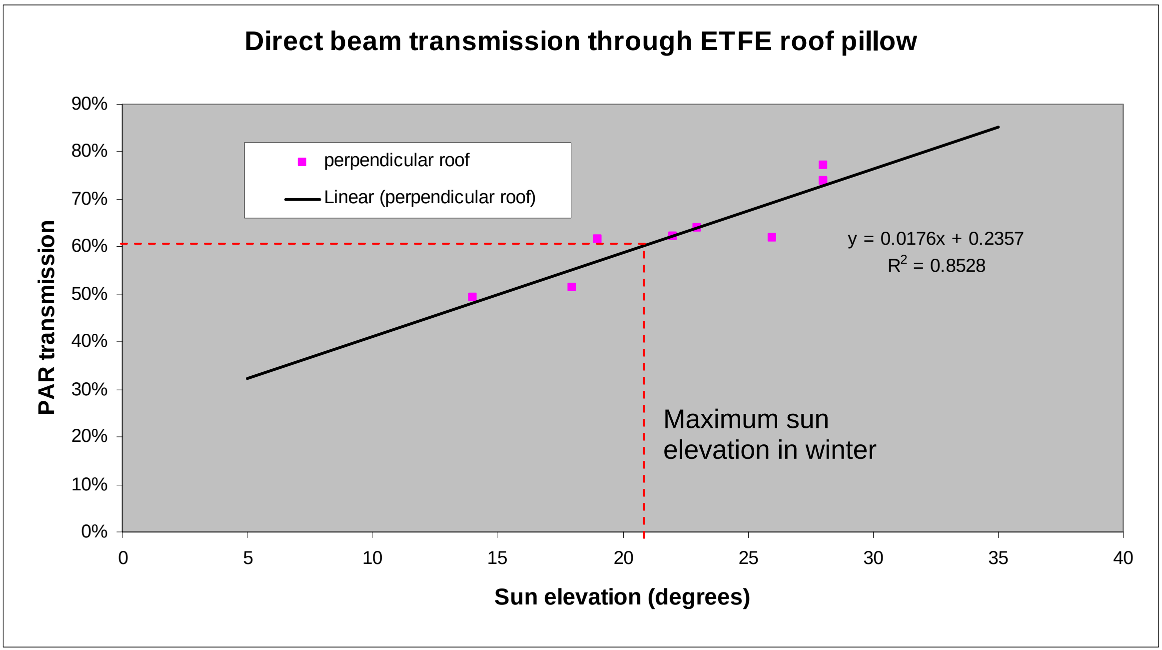

Figure 6. Relationship between the percentage transmission of PAR and the angle of elevation of the sun through the roof of the ETFE test rig. At maximum winter sun elevations of 21^{o} in Dunedin, only approximately 60% of PAR will be transmitted through the roof.

3.4 Prediction of winter PAR levels and effect on turfgrass growth

Solar radiation data from the NIWA CliFlo database for Dunedin Musselburgh EWS in conjunction with the field data from the ETFE test rig were used to predict typical winter PAR

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levels likely to pass through an ETFE pillow (note: terms and conditions for the use of NIWA data are attached in Appendix 5). Three different models of transmitted PAR were evaluated:

1. A daily mean of 80% of the PAR is transmitted through two layers of ETFE (the best case scenario based on studies in the ETFE test rig).
2. A daily mean of 60% of the PAR is transmitted through two layers of EFTE (the worst case scenario based on studies in the ETFE test rig).
3. There is 80% PAR transmission in March decreasing to 60% PAR transmission by June and returning to 80% PAR transmission in September (a reasonable scenario based on studies in the ETFE test rig).

In the modelling approach above, it has been assumed that the sun elevation will have little additional effect on transmission in March or late September but will have a substantial effect by the end of June depending on the slope and aspect of the ETFE roof relative to the daily path of direct solar radiation. Further, it has been assumed that transmission will be through a large, double layered ETFE with a 10° slope towards the midday sun and that the sides are relatively low in height compared to the length and width of the sloping roof and that the sides are made of ETFE. No allowance has been made for shading of low elevation light or for changing incident angles during the day, nor have the contributions of direct and diffuse light been separated. Most light reaching the turf surface would therefore come through the roof except for some sidelight coming from less than about 5 degrees above the horizon.

Fig. 7 shows a solar radiation scale (MJ/m^2/day) and a PAR scale (PPF, moles/m^2/day) and then plots the effect of the three models of transmitted PAR through the ETFE. Note that there are approximately 2 moles of photosynthetically active photons per MJ of solar radiation. The points to note from Fig. 7 that are crucially important for this project are as follows:

- The threshold level for reduced light (20 moles/m^2/day) for turfgrass growth and performance shown on the graph is taken from Rogers *et al*. (1997). At a reduced light level, turgrass will continue to exhibit characteristics associated with 'normal-appearing' turfgrass but its growth habit and morphology will be different from turfgrass grown under full sunlight (eg. higher plant cell elongation) – these characteristics were observed in early spring under the ETFE test rig (see Section 4.0). Rogers *et al.* (1997) noted that the actual level of light to be considered as reduced light depends on a combination of

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factors including turfgrass species, temperature, moisture, CO_2 levels, plant carbohydrate and nutrient levels etc.

- The threshold level for insufficient light for turfgrass growth and performance is 6 moles/m^2/day over an eight hour photoperiod for cool season turfgrass (Rogers *et al*. 1997) and is also shown on the graph in Fig. 7. It is defined as the amount of light which is below the compensation point of the turfgrass (ie. respiration exceeds photosynthesis). In practice, the exact photosynthetic compensation point changes with temperature (the lower the temperature, the lower the compensation point), but eventually turfgrass will cease growing and die under prolonged conditions of insufficient light. The precise time it takes for the turf to die will depend largely on the carbohydrate reserves in the turfgrass plant, the amount of use the turfgrass receives and the length of time exposed under insufficient light.

- The Telstra Dome in Melbourne has set 10 moles/m^2/day as their minimum PAR for acceptable turfgrass growth and recovery for all areas of the arena (Darby, 2007), but it is important to note that this stadium has a usage schedule much higher than the proposed new stadium is likely to receive. This PAR level represents a level similar to a European spring/autumn, a value which is being replicated through the Northern Hemisphere winter in venues using artificial lighting systems to gain some extra winter growth in shaded areas. Telstra Dome will only be able to achieve this target level by the use of supplementary lighting. ‘Normal’ PAR levels in the Telstra Dome in May/June are significantly below 10 moles/m^2/day over large sections of the field.

- The average unobstructed PAR for the month of June in Dunedin is approximately 7.5 moles/m^2/day (Fig. 7). This value is less than the target level set by the Telstra Dome. Unobstructed PAR only reaches a value of 10 moles/m^2/day by mid August in Dunedin. So, in the middle of winter in Dunedin, natural light levels are only just above what is required for turfgrass growth. With these low natural light levels, a conventional stadium with a solid roof over its grandstands would incur significant localised shading issues and subsequent turfgrass management difficulties. Even where significant localised shading issues could be avoided (eg. with an ETFE roof), Dunedin would still need supplementary lighting to reach the 10 moles/m^2/day target. Current experience at Carisbrook during June and July suggests that the low natural light levels in winter, combined with significant frost and shade, have a major effect on booking events at the stadium, with typically no more than two captains’ runs and two games in June and a test match and club match in July (Huddy, pers. comm.).

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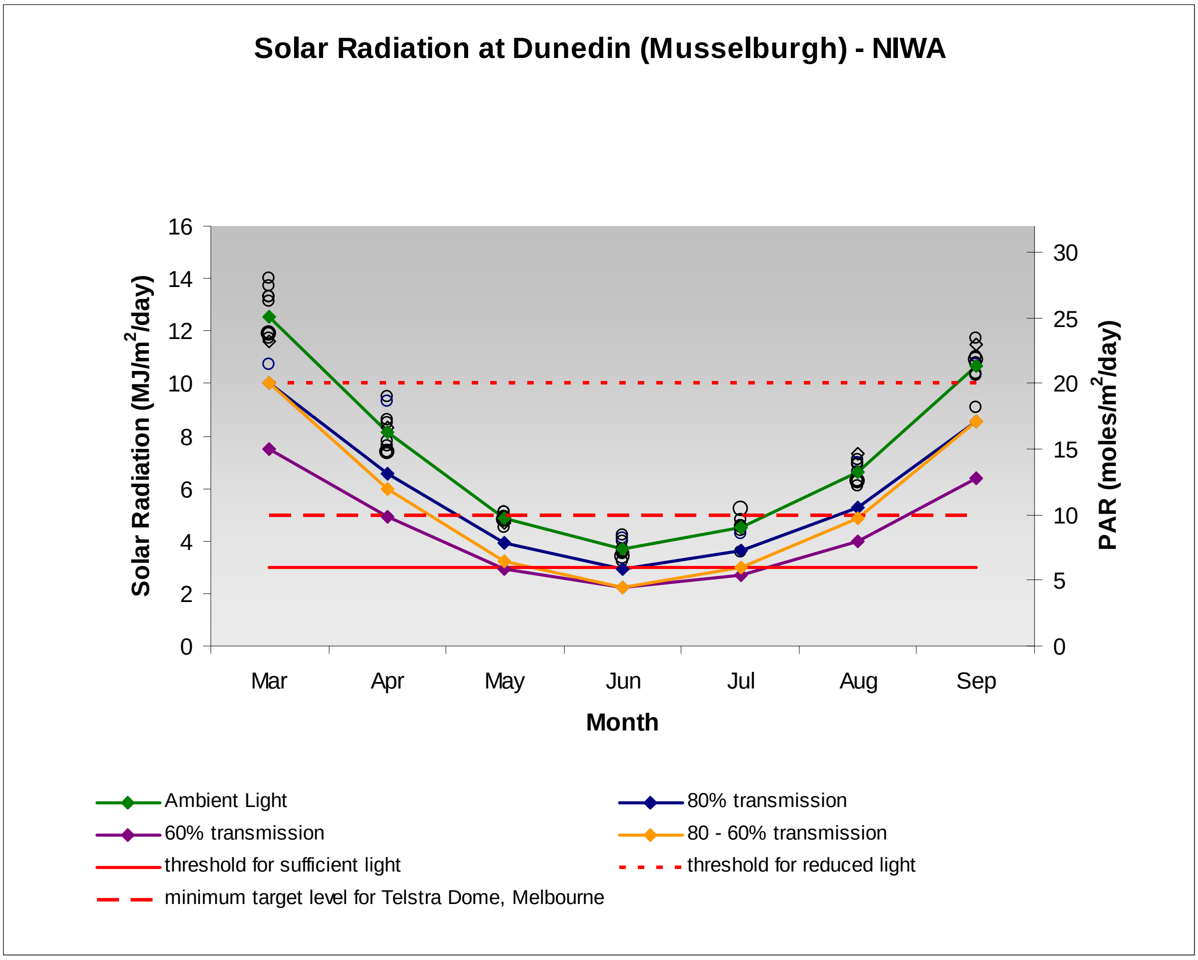

Figure 7. Average solar radiation and PAR levels Dunedin and predicted levels of PAR transmission through ETFE under three modelling scenarios (source of data for ambient light solar radiation: NIWA)

- Even without knowledge of how low sun elevations and solid structures in the proposed stadium will affect transmission of sunlight to the turf, as a result of the low natural light levels in Dunedin in winter and in the absence of a supplementary lighting system, it is predicted from the test rig that the entire turf surface of the proposed stadium with an ETFE roof will receive less than sufficient light for adequate turfgrass growth and recovery after sporting events for at least a two month period during winter. This situation is different from a conventional stadium where seriously low light levels affect only large sections of the turf surface but the middle of the field still receives full sunlight (see Fig. 8). With a conventional stadium, these large sections of the turf surface 'thin out' very badly during winter and in many cases require complete turf replacement. With an ETFE roof, the intensity of localised shading would be virtually eliminated and instead 'diluted' over the whole field, but the intention should be to manage the surface so that the playing surface doesn't require large scale turf replacement – a number of strategies are given in Section 6.0 as to how this might be achieved.

- Finally, the light environment under one ETFE pillow and the small ratio of roof dimensions with respect to the side height of the test rig may not be a good test for low sun angle measurements relative to the very large ratio of roof width and length with respect to the end heights of the proposed stadium. More rigorous models which account for the effects of changing incident angles during the daily course of solar angle changes and which give scenarios for varying levels of direct and diffuse radiation will give a better indication of the potentially available light for ETFE covered winter turf in the Dunedin environment, but it is unlikely the conclusions in the last point above will change significantly.

Figure 8. Typical shade and frost problems on the current Carisbrook surface (July 2007).

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4.0 Trial Progress – Wear Testing

4.1 Turfgrass dry matter production

To date here has been a greater total amount of turfgrass dry matter production (ie. leaf growth) in the ETFE test rig than in the outside test area (Fig. 9). Most of this increased growth occurred in September in response to increased soil and air temperatures within the ETFE test rig in conjunction with the reduced light level (see Fig. 7).

The results to date do not suggest that extra leaf production has been at the expense of root growth and wear tolerance but measurements are on-going. It is important to note that extra leaf growth does not necessarily translate to better surface playing quality conditions and increased wear tolerance of turfgrass: the increased dry matter production in the ETFE test rig was also mirrored by an increase in leaf succulence (ie. higher leaf moisture content) of the turfgrass compared with the outside test area. An increase in leaf succulence can result in more damage (bruising) being caused to turfgrass leaves under playing conditions, increasing the likelihood of a disease taking hold. The solution to this problem is to ensure that temperature control inside the stadium is balanced in relation to the amount of available photosynthetically active light. In practice, this may actually involve preventing temperatures from rising too high through the use of carefully designed ventilation.

As a result of the early spring growth in the ETFE test rig, irrigation and nutrient inputs were scaled back in October and the turfgrass growth rate between the two trial areas became virtually identical by the end of that month.

Total fibre content analysis (ie. lignin, cellulose and hemicellulose content) of turfgrass leaves from each trial area has remained the same to date (data not shown). A lower fibre content would be expected to be associated with a reduced wear tolerance.

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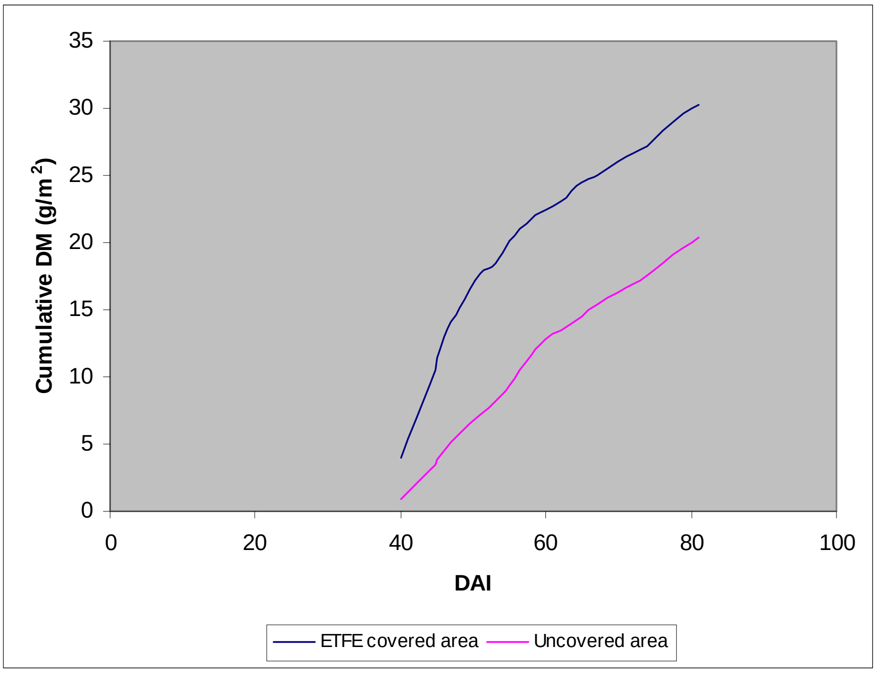

Figure 9. Cumulative dry matter (DM) production over the course of the trial to date (DAI = days after installation of ETFE test rig). The rapid initial growth under the ETFE test rig was controlled through careful turf management. Currently the rate of dry matter production under the ETFE test rig is almost identical to the uncovered area, as are actual dry matter values.

Actual dry matter figures clearly show the initial response of the turfgrass to being covered with the ETFE rig and the effect of management to control this growth (see Appendix 6). At certain times during the year, management practices must be targeted towards slowing down the rate of turfgrass growth.

4.2 Root growth

Typically during warmer weather, cool-season turfgrasses direct carbohydrates produced by photosynthesis into leaf growth and the generation of above ground biomass. Cooler temperatures encourage root development, vital for wear tolerance.

Results to date have shown a reduction in root mass at depth under the ETFE test rig (Fig. 10). Although the results in the test rig were not significantly different from the uncovered area, there was an emerging root growth differential at a time of peak grass growth and development. We anticipate the situation will be exacerbated with more time under the ETFE test rig. This result has implications for whether a turf reinforcing product should be used in the design of the playing surface.

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Figure 10. Soil cores for root analysis taken from the control plot in the uncovered area (left) and the control plot in the ETFE covered area (right) three months after the ETFE test rig was installed. Root mass in the 50-100 mm section was not significantly greater from the uncovered area but a root growth differential between the two trial areas was seen to be emerging.

4.3 Wear application and ground cover loss

Ground cover and wear application results to date have shown the following:

- There have been no differences between the two test areas in terms of the number of passes of the artificial wear machine required to wear the ground cover percentage to 50% (Wear Treatment 1). In other words, wear tolerance of turfgrass in the two test areas has been the same to date.

- Under spring conditions, it took an identical amount of time (55 days) for heavily worn plots in both trial areas (Wear Treatment 1) to reach full ground cover following destruction of ground cover to 50% by the wear machine (Fig. 11). <u>This demonstrates that grass recovery under the ETFE test rig has been able to match the recovery of turfgrass on the uncovered area</u>.

- Under spring conditions when regular light wear was applied (Wear Treatment 2), there was no difference in loss and recovery of ground cover between the two trial areas,

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although it should be noted that ground cover has been deteriorating progressively and equally under light wear in both trial areas.

Figure 11. Ground cover recovery 55 days after a heavy wear application (Wear Treatment 1) in spring under the ETFE test rig (left) and the uncovered area (right).

- Fig. 12 shows the ground cover percentage for the ETFE test rig expressed as a fraction of the ground cover percentage for the uncovered area following wear application in spring. A ratio of 1.0 indicates no difference between the two trial areas; a ratio of less than 1.0 indicates that the ETFE test rig is performing worse than the uncovered area; a

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ratio above 1.0 indicates that the ETFE test rig is performing better than the uncovered area. In Fig.12 there were no significant differences between the two trial areas for each wear treatment. In other words, under the application of artificial wear in spring, changes in ground cover under the ETFE rig were not significantly different from the outside test area, a good result for this component of the trial.

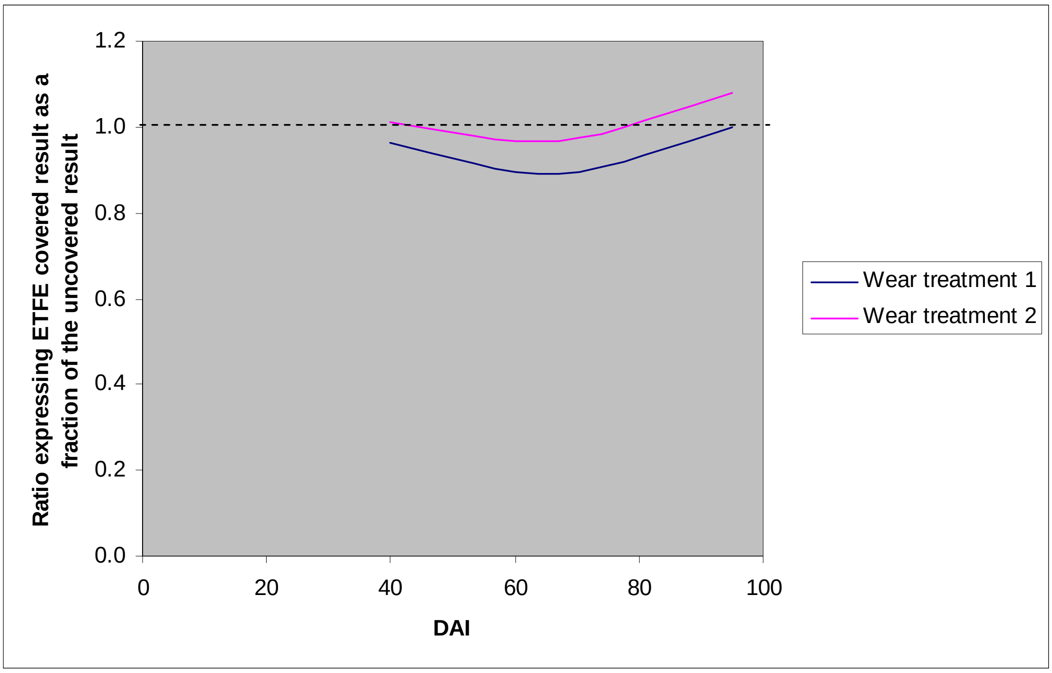

Figure 12. Ground cover results expressed as a ratio of ETFE to uncovered for the high wear application in spring (Wear Treatment 1) and on-going light wear application in spring (Wear Treatment 2). The dotted line indicates no difference in ground cover percentage between the ETFE test rig and the uncovered area; a ratio of less than 1.0 indicates that the ETFE test rig is performing worse than the uncovered area; a ratio above 1.0 indicates that the ETFE test rig is performing better than the uncovered area. In the above graph there are no significant differences between the two trial areas for each wear treatment. (DAI = days after installation of ETFE test rig)

4.4 Surface traction

Surface traction measurements were used in this trial as way of assessing whether an area of turfgrass contained sufficient player 'grip' prior to wear taking place. The equipment used was developed specifically for this purpose and is used as an international standard test method for evaluation of sports surfaces[4].

[4] BS 7044: Section 2.2 (1990). Artificial Sports Surfaces. Part 2. Methods of Test. Section 2.2 Methods for determination of person/surface interaction. British Standards Institution, London, 8 pp.

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The same data analysis as used for ground cover was applied to the traction results, ie. a ratio of 1.0 indicates no difference in traction between the two trial areas; a ratio of less than 1.0 indicates that the ETFE test rig has worse traction than the uncovered area; a ratio above 1.0 indicates that the ETFE test rig has better traction than the uncovered area.

Results to date have shown that all traction values measured in the trial exceeded minimum values required for a rugby playing surface (data not shown). Furthermore, there has been no significant difference in traction results between the two trial areas for each wear treatment (Fig. 13). This is again a good result.

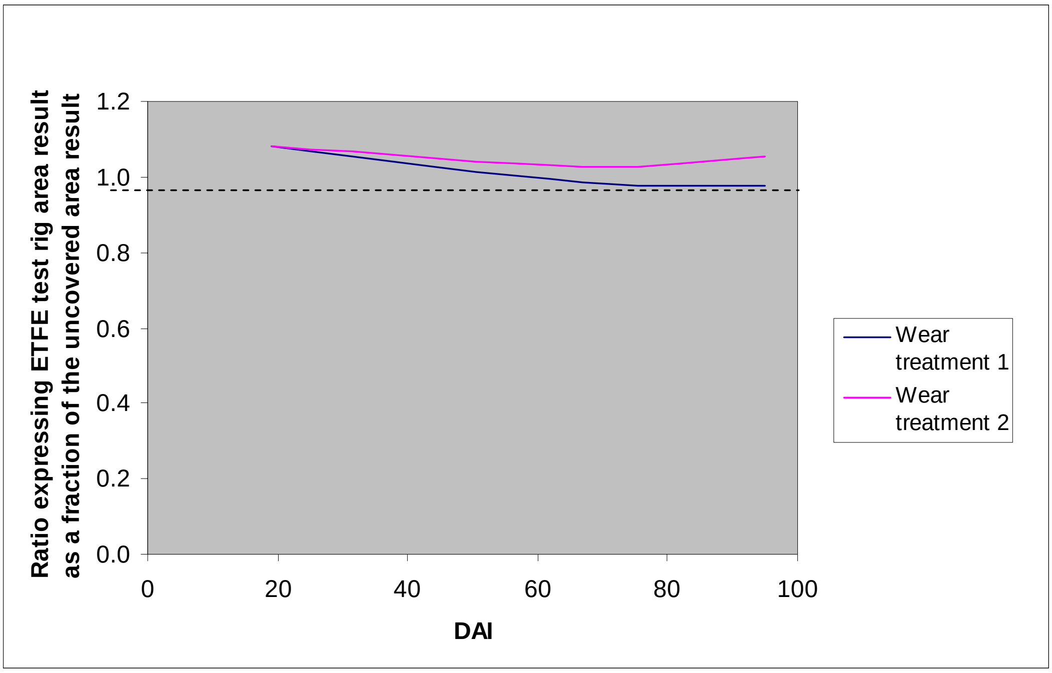

Figure 13. Surface traction results expressed as a ratio of ETFE to uncovered for the high wear application in spring (Wear Treatment 1) and on-going light wear application in spring (Wear Treatment 2). The dotted line indicates no difference in surface traction between the ETFE test rig and the uncovered area; a ratio of less than 1.0 indicates that the ETFE test rig is performing worse than the uncovered area; a ratio above 1.0 indicates that the ETFE test rig is performing better than the uncovered area. In the above graph there are no significant differences between the two trial areas for each wear treatment. (DAI = days after installation of ETFE test rig)

4.5 Temperature

4.5.1 Surface temperature (minimum and maximum daily values)

Figs. 14 and 15 show the results of four recording locations; three within the ETFE test rig and one outside for maximum and minimum temperature. In all cases, the temperatures

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outside were significantly lower (P>0.05) than temperatures measured in all three positions in the ETFE test rig.

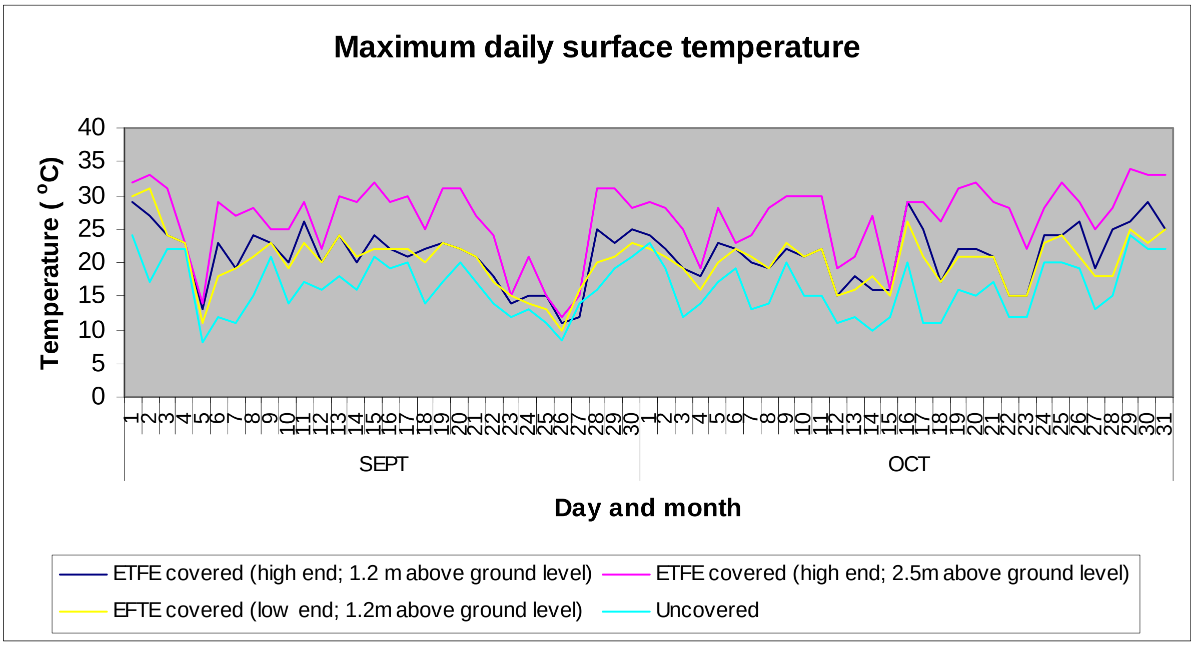

Figure 14. Maximum daily temperature readings.

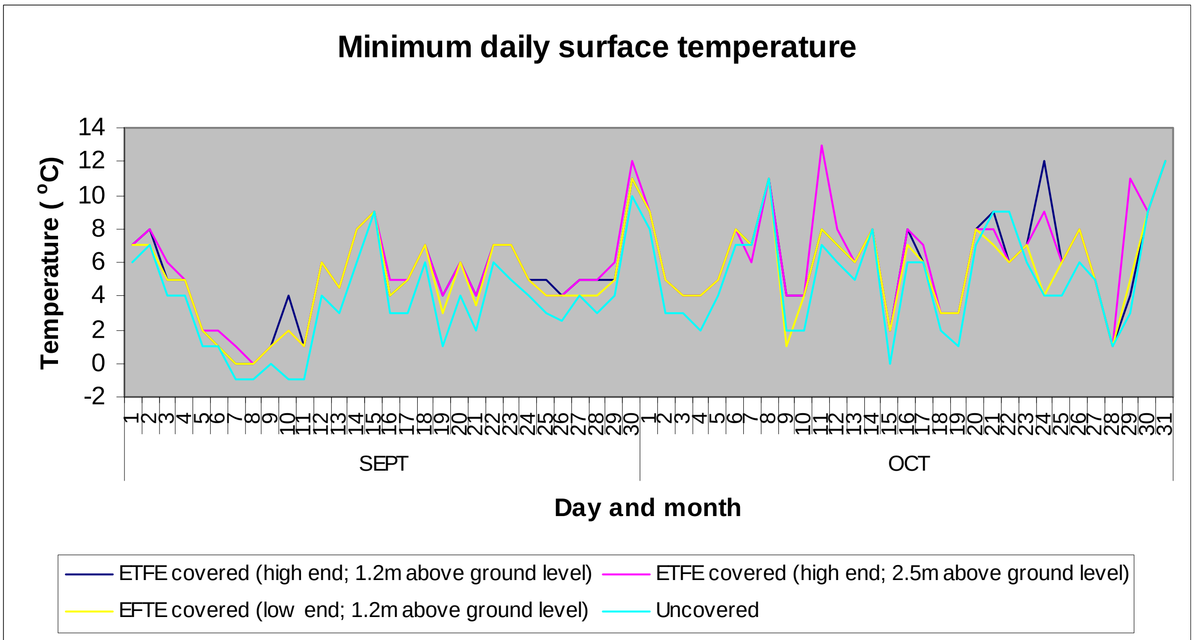

Figure 15. Minimum daily temperature readings.

4.5.2 Soil temperature

Soil temperatures at 100 mm depth were significantly higher (P>0.05) under the ETFE test rig compared with the uncovered area, although all values measured to date have been within the optimum 10-18°C range for root development for perennial ryegrass at times of peak growth. However, it should be noted that where high soil temperatures are coupled with high air temperatures, shoot growth will be favoured over root growth. Research on cool season turfgrass has shown that on high air temperature days (>35°C), reducing soil temperature by as little as 3°C can have a beneficial effect on turf quality and root growth (Xu and Huang, 2001).

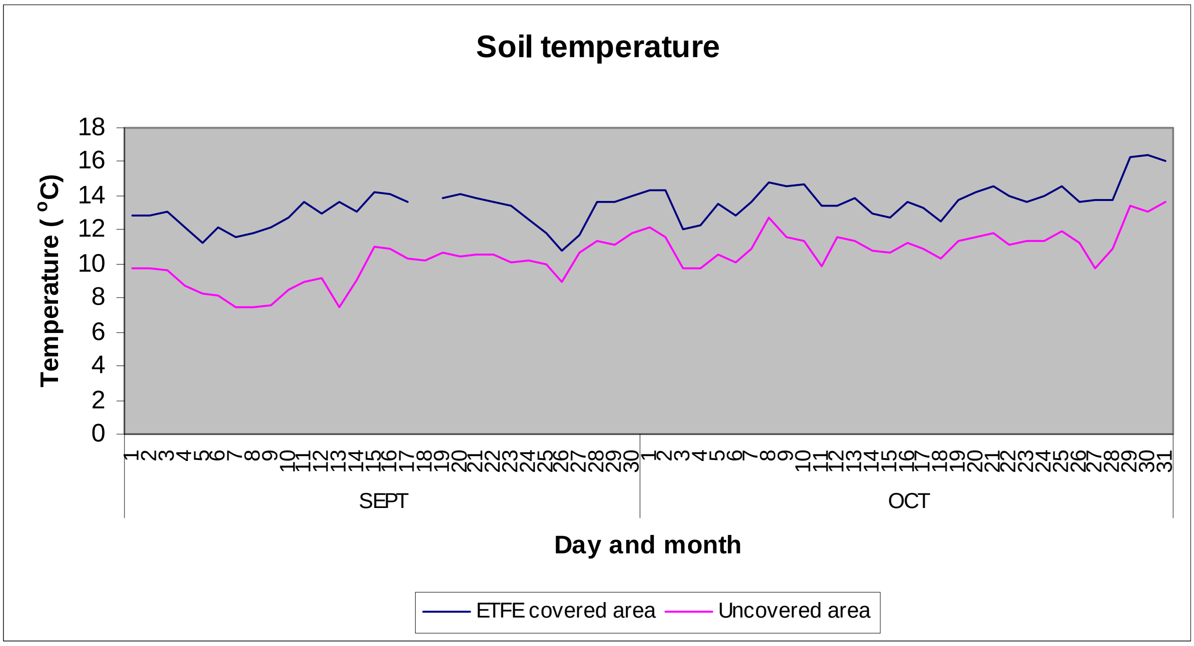

Figure 16. Soil temperature fluctuations under the ETFE test rig and outside, recorded at 100 mm depth.

4.6 Humidity

Humidity readings in the uncovered test area were significantly lower (P>0.05) than those obtained from within the ETFE test rig, but it is considered that the humidity readings observed within the ETFE test rig would not result in poor turfgrass performance (Fig. 17).

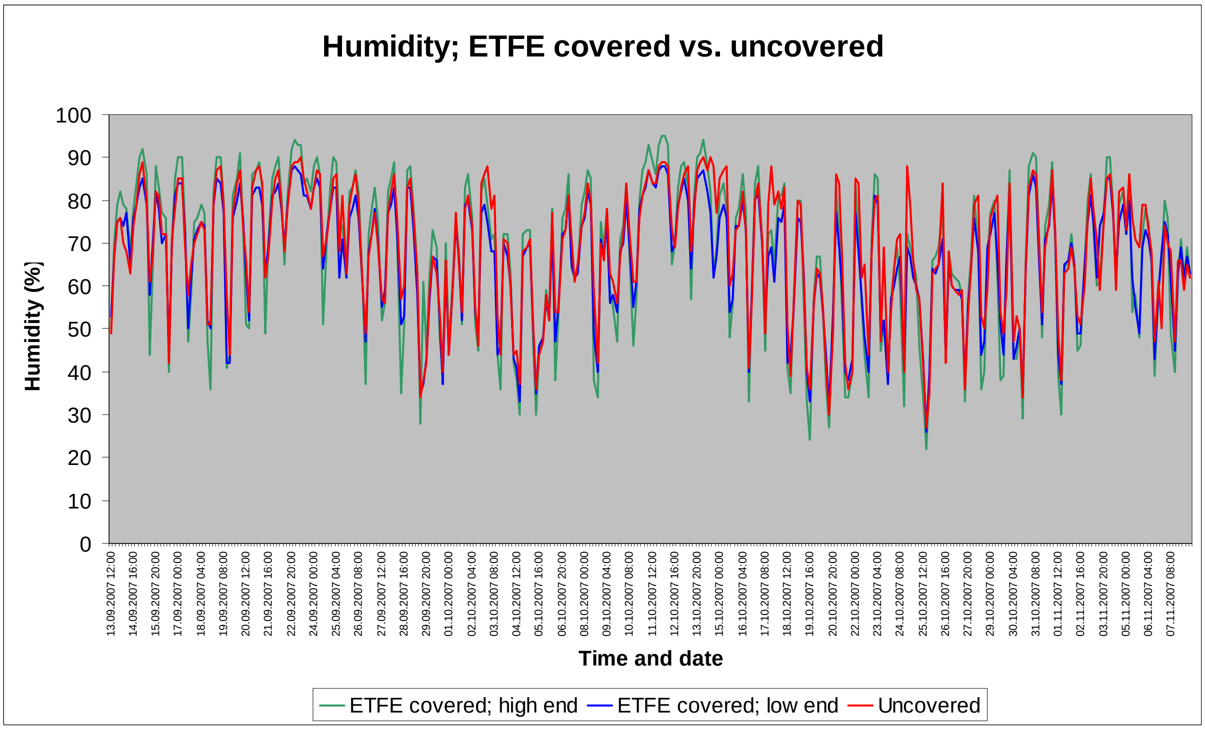

Figure 17. Humidity fluctuations at ground level within the ETFE test rig at two locations and in the uncovered area.

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5.0 Summary and Conclusions

5.1 Light quality and quantity

On the basis of the light quality and light transmission results carried out in the ETFE test rig, the following conclusions are made:

- The effect of the ETFE material is to cause a reduction in the quantity of light transmitted but not a deleterious effect on the balance (quality) of the photosynthetic wavelength transmitted.

- With the current ETFE material in the test rig, a maximum transmission efficiency of 80% of photosynthetically active radiation (PAR) can be anticipated in situations of high elevations of full sun (~35^o+ from the horizon). This value is in general agreement with those claimed by the manufacturers.

- Averaged over the course of a full day, the maximum transmission efficiency at times of non-limiting sunlight (ie. September to March) is likely to be reduced to 75% as a result of early morning dew, localised shade and higher transmission losses at low sun angles relative to the horizon.

- A 25% reduction in PAR transmission during late spring and through the summer months is of little consequence on sunny days and probably of minor consequence on moderate overcast days in terms of turfgrass growth and recovery (this conclusion is backed up by the turfgrass wear test results in Section 4.0).

- The effect of dew in isolation of other effects is to reduce light transmission efficiency by 20% (eg. from 80% to 60%). This reduction will have the greatest effect in winter when transmission is predicted to be only 60% in the absence of dew. Thus every available opportunity should be taken to increase transmission rates of light through the ETFE (eg. by washing dew off the roof before sunrise and by taking advantage of any improvements in ETFE technology). Further work should be carried out to determine the likelihood of dew forming on an ETFE roof 40+ m above a turf surface.

- The efficiency of light transmission at low sun elevations is of greatest concern. A sun elevation of 21^o (the approximate mid winter sun elevation in Dunedin) has the potential

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to reduce the transmission efficiency to less than 60%. This level of reduction of light transmission during the winter months will prevent any possibility of adequate turfgrass recovery after events held during this period under basic turf management techniques (ie. no turf replacement), even though a proposed roof would remove other growth and usage retarding effects such as frost and excessive surface moisture arising from rainfall and limited evapotranspiration. Nevertheless, there are methods that can be implemented to increase the transmission efficiency and amount of photosynthetically active light, the three most practical options being: 1) to use a better grade of ETFE foil (preliminary assessment of 'matt' ETFE foil suggests a significant improvement in transmission[5]); 2) to modify the design of the roof for better interception of available winter sunlight; and 3) to use supplementary lighting to boost levels above.

- The 9-10^{o} slope of the proposed roof of the new stadium will mitigate some of the low transmission at low sun elevation angles but only around midday. The problem would be exacerbated in the winter afternoons in a non east-west orientation. Tilting the roof, while favouring light transmission in the direction of tilt, will reduce low sun angle transmission from the other direction. The net effect cannot be easily predicted from this trial but the gains and losses may well cancel each other out. More work is required to optimise the slope/curvature design of the roof with respect to light transmission efficiency, particularly during the winter months, using fully integrated hemisphere modelling software.

- The above conclusions apply mainly to bright sun and this only occurs at roughly one third of the daylight hours. It is important though because total PAR under full sun averages about three times the PAR under overcast conditions.

- In summary, we believe that under the current design and ETFE material, the system will transmit at best only 60-70% of the global radiation to the sports turf surface during the critical winter period when the sun fails to rise above 25 degrees above the horizon (10 weeks - mid May to end July). It would be prudent to work with these figures until we acquire more light transmission values at low sun angles and a better model of roof and side wall light transmission on the actual stadium design.

- Finally, it should be noted that the ETFE material being proposed to construct the roof of the new stadium is understood to be '250 super clear ETFE' compared with the '250 clear ETFE' that has been used to construct the test rig. The difference in light transmission

[5] Hutchins & Dvorjetski (2002).

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between the two products is understood to be approximately 4%, which means that slightly better light transmission can be anticipated in the actual stadium than was measured in the ETFE test rig and under the sample tested by Lincoln University. Use of the ‘matt’ ETFE described earlier may be an even better choice.

5.2 Turfgrass growth

Average monthly solar radiation data for Dunedin, coupled with data from the ETFE test rig and known published thresholds for sufficient light and reduced light for cool season turfgrass growth and recovery, show that there will be three specific growth periods:

Growth period	ETFE covered	Uncovered[1]
Maximum turfgrass growth and recovery from wear possible[2]	End of September to middle of March	Middle of September to early April
Reduced turfgrass growth and recovery possible	Middle of March to middle of May and end of July to end of September	Early April to middle of September
Insufficient light available for turfgrass growth and recovery[3]	Middle of May to end of July	None

<u>Notes</u>

[1] Assumes no shading caused by covered grandstands. In practice, approximately 25% of the playing surface area will typically receive significant shading issues during winter (see Fig. 8) when no turfgrass growth and recovery is possible (ie. insufficient light available for turfgrass growth and recovery).

[2] Assumes that internal temperature and humidity levels within the proposed stadium can be moderated by ventilation to avoid extremes.

[3] This is defined as the period of time below critical light levels for turfgrass growth and recovery.

It can be concluded from the reduced growth and recovery period in the trial (end of July to end of September for the ETFE test rig) that the ETFE has the potential to tilt turfgrass shoot growth out of balance in favour of excessive leaf production, but that it is also possible to bring this back into balance when optimum light levels for photosynthesis are reached in October. Excessive leaf production at reduced light levels will cause a reduction in wear tolerance and although no differences in wear tolerance between the ETFE test area and the uncovered test area were recorded during the early part of this trial, this result could be in part because of the very mature state of turfgrass used in the trial. This situation would be different for turf that was sown and matured in a reduced-light environment.

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There are indications from the maximum turfgrass growth and recovery period in the trial (end of September to middle of March) that the ETFE has the potential to tilt turfgrass root growth out of balance in favour of reduced rooting depth. This result is most likely related to elevated temperatures (ie. the turf becomes ‘lazy’). Higher temperatures will always favour shoot over root growth and over time will lead to reduction in root mass at depth. An emerging differential in root depth between the two trial areas will have implications in terms of the need for a turf reinforcing system.

The final stadium design will therefore need to provide a means of controlling surface temperature. Cool-season turfgrass cannot tolerate very high temperatures and although readings at the hottest time of the year are still to be taken, maximum values approaching 35°C have already been observed (although such high temperatures would not be expected at ground level in the actual stadium). Measures will have to be incorporated into the final stadium design to enable the internal environment of the stadium to be manipulated to ensure robust turfgrass performance during times of high temperatures.

By the time the current wear testing trial is complete, field data from the ETFE test rig will be available for only two of the three growth periods in relation to light availability (maximum turfgrass growth period and reduced turfgrass growth period), with no turfgrass performance data available for the crucial winter period. This is a limitation of the current trial, created by the tight decision making timetable for this project. Nevertheless, the analysis of light transmission data, coupled with known boundary conditions and first principles, allows a professional opinion to be formed about winter growth as articulated in Section 5.1 and below.

In terms of predicting the turfgrass performance when insufficient light is available, some temperature elevation under the ETFE roof can be expected in winter, plus there will be an absence of frost and excessive surface moisture. This situation should offset some of the effects of low light via quicker leaf emergence and recovery of canopy cover, and greater photosynthetic response. Nevertheless, the downside of this is that higher respiration will occur during the long nights and negate some or all of the temperature induced photosynthetic benefits. Furthermore, an increase in temperature at a time of insufficient light conditions has the potential to have an adverse effect on plant growth; if the temperature increases too much it will cause turfgrass plants to utilise carbohydrate reserves for growth, exhibit weak elongated leaves and a reduced tolerance to wear. Therefore temperature control within the proposed stadium should not be determined in isolation of available light levels.

Overall, in the absence of being able to increase the ETFE roof's low light transmission properties at low sun angles in winter and/or in the absence of installing supplementary lighting, the presence of the ETFE roof is not going to make it any easier to grow turfgrass. Nor will the ETFE roof increase the amount and type of use that can be sustained during the winter period. This is because the roof will spread the shading problem over the whole field instead of confining it to a fixed position at the northern end of the field, particularly during the winter months in Dunedin. Thus, instead of knowing that a fixed location of a shaded area of a field in a conventional stadium will definitely require turf replacement, there is the uncertainty that the weather conditions in any particular year may tip the light balance so that the entire field requires turf replacement in an ETFE-covered stadium. The boundary conditions established by this trial for light transmission and the management recommendations given in Section 6.0 offer ways in which the risk of above situation occurring can be reduced.

The period from the middle of May to the end of July is going to have to be managed as critically as it is in the current Carisbrook Stadium, if not more so. The challenges will change – instead of having to deal with frost, a perpetually wet surface and intense shade in the northern portion of the ground, the turf management challenges under ETFE will be to deal with potential turfgrass diseases, to maximise light interception, to prevent on-going thinning of turf, to minimise surface damage and avoid having to re-turf areas of the field.

In conclusion, our professional opinion is that we remain cautiously optimistic about this project. Based on the testing carried out to date, we believe that while there will be winter issues to overcome, it will be possible to grow the grass successfully, subject to the recommendations given in the next section (in particular increasing the amount of light that is transmitted through the proposed roof). Further research is still required to optimise the design of the proposed ETFE roof in relation to the results of this trial, to finalise the design detail of the stadium environment in general to ensure that temperatures match available light levels, to finalise the best type of turfgrass to use (trials are already underway) and finally to determine the best turf management practices that will be required to maximise turfgrass performance.

6.0 Recommendations and Management Implications

The key to success for this project from a turfgrass perspective will be two-fold:

1. To be able to moderate the environment in the proposed stadium, in particular to avoid soil and air temperatures and humidity levels that are beyond the optimum for cool season turfgrass growth in the summer and to allow adequate ventilation across the turf surface.

2. To maximise the quantity of photosynthetically active light in the proposed stadium during the winter months, particularly during the late autumn and winter period in order to take advantage of the warmer temperatures that are likely to be created by the enclosed stadium. It should not be discounted that supplementary lighting may be the only way to achieve this. Further modelling on the final stadium design will determine this.

The following turf management strategies are recommended. These strategies will be required regardless of whether supplementary lighting will be available for this project or not:

- In addition to the CFD modelling being carried out for environmental control (temperature, ventilation and humidity), feed the results from this trial in the ECOTECT software (or other appropriate software) to predict how light transmission to the actual turf surface in the proposed stadium will be affected by the final roof design, in particular taking into account the shape, location and orientation of the ETFE roof and side pillows. This work is already underway.

- Continue with the turf testing under the ETFE test rig, in particular assessing the performance of turf varieties currently established in the turf nursery when transplanted into the ETFE test rig, monitoring turf performance during the 2008 winter period and refining turf management techniques in the ETFE test rig for maximum turfgrass performance.

- Design a stadium environmental and ventilation control system that provides appropriate temperatures for turfgrass growth at different times of the year in relation to the amount of available light, in particular to prevent turfgrass growing below its light compensation point. Do not over-design the stadium for spectator comfort at the expense of agronomic performance.

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- Design the stadium surface with an above-ground turf reinforcing system that mitigates the effect of shallow root development and which also has the capability for turf replacement, but manage the surface with the intent of minimising turf replacement at all times.

- Design the stadium surface so that the perimeter of the field is bordered by an IRB approved artificial turf surface, so reducing the amount of maintenance and other traffic that will travel over the natural turf surface.

- Evaluate the need for a stadium roof with a washing system to remove early morning dew and so maximise light transmission at critical times of the year.

- Apply best practice for management of turf in shaded stadia, including but not necessarily limited to: automated environmental monitoring, strict usage control, highly customised fertiliser applications, constant grass clippings removal, light weight turf maintenance machinery (including the option of pedestrian mowing), preventative fungicide application, individual head control in irrigation sprinklers, use of growth regulators, and selection of best performing turfgrass for growing under reduced light.

- Use the above best practice after damage from wear events so that the canopy reaches full ground cover re-establishment quickly and is able to capture as much photosynthetically active light as possible without wasting valuable light falling on a bare playing surface.

- Use the above best practice to ensure that the playing surface goes into the winter playing period with the strongest possible turfgrass cover – recovery during the winter period will be limited to non-existent without the use of supplementary lighting or unless natural light transmission rates can be increased to 80% or more during winter.

- Carefully control the events management schedule, particularly during the first season of use, and regularly review the schedule as more experience is gained on how best to manage the surface.

- Do not allow any form of repetitive training and non revenue generating use on the playing surface.

- Only programme non-sport events on the playing surface such as concerts if there is sufficient time to guarantee turfgrass recovery before the next event (eg. outside the months of March to September inclusive).

Cost estimates for some aspects of the above recommendations are shown in Table 2.

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TABLE 2
Cost estimates for potential additional turf requirements

Potential capital item	**Detail**	**Estimated additional cost ($, ex-GST)**
Irrigation system	State of the art valve-in-head irrigation system	$100,000 above a conventional block-type system
Turf reinforcement	An above-ground turf reinforcing system with capability for turf replacement	$1.2M/ha for the reinforcing product and grow-in off-site[1]
Turf nursery	Establish a 2000 m^2 turf nursery for reinforced turf	$360,000 includes reinforcing product and machinery purchase
Artificial lighting	-Lighting rigs to supply up to 160 $\mu mol/m^2/s$ of PAR. -Upgrade of electricity supply, switch boards and other infrastructure -Secure storage -Shipping and customs charges -Equipment to transport the rigs	$2.5M - $4M depending on the area to be illuminated at any time[2]

Potential maintenance item	**Detail**	**Estimated additional annual cost over current practice ($, ex-GST)**
Mowing	Removal of all clippings	Already being carried out
Fertiliser	Foliar fertiliser application	Additional $25,000
Fungicides	Preventative fungicide applications	Additional $10,000
Physical treatments	No more frequent than current	Already being carried out
Scarifying	No more frequent than current	Already being carried out
Top dressing	No more frequent than current	Already being carried out
Turf replacement	- Attempt to minimise turf replacement at all costs (wholescale re-turfing will be hugely expensive); therefore suggest re-turfing at a level no more frequent than current – may still be required to replace linesman's runs, logo areas etc. -Turf replacement with reinforced turf from turf nursery.	$60,000[1]
Operation of light rigs	-On going electricity use -Replacement bulbs every 10,000 hours -Employment of two additional part-time staff specifically for rig deployment	$200,000-300,000

Notes
1. No fees for transporting turf to the stadium are included.
2. Figures based on those released by the Telstra Dome (Darby, 2007). Note that these costs may be able to be reduced significantly if it is a viable option to install a permanent lighting rig in the roof structure.

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Appendix 1 – Request for Proposal for Turf Trial

The following information was provided to Sports Surface Design & Management by Arrow International on 3/7/07 in their request for a proposal for the turf trial:

Background

This development will be a first in the world for a sports stadium where turf is grown under an ETFE fixed roof. Predominately events such as Super 14, NPC and test rugby will be played on the pitch in the new stadium. There will be other events such as rock concerts and international soccer that will utilise the stadium but these would only be once or twice a year each.

A key issue for the new stadium is the performance or regrowth / recovery rate of the turf especially during the winter months.

The turf performance is a significant issue for the Dunedin City Council. DCC will be looking for a verifiable report that confirms the ability of the turf to recover and allow for the use the new stadium is intended for.

Proposal requirements

The proposal will need to include advice of any issues following the completion of testing and the outlining of turf management strategies required to overcome these issues.

The proposal will need to allow for the following:

- All time in wear testing, measuring, recording and analysing of information throughout testing period - 6 months
- Preparation and submission of verifiable report at the end of the testing period
- Any costs from other parties required to facilitate all or any of the above two bullet points
- All travel costs and disbursements

The proposal will need to be submitted by Wednesday 11th July 2007.

ETFE test rig

The ETFE test rig will be constructed at the back of the existing Carisbrook Stadium. Completion of the ETFE test rig is set down for the week of 23 July 07. The agreed watering and maintenance regime for the ETFE test rig shall be reviewed and agreed with ORFU Turf Manager. A proposed wear testing regime is enclosed for review. Testing duration is noted at 12 months. However it has always been the intention to carry out the trial over six months. Single phase power is available in the test rig. Other requirements are to be advised.

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Appendix 2 – Background Information on Sports Surface Design & Management

Sports Surface Design & Management has two dedicated full-time sports surface consultants with significant experience of working with natural and artificial turf in the local authority environment.

Position	**Senior Manager**
Name	Dr Richard Gibbs
Years practical experience	21
Years with company	3.5
Previous employment	1991-2003 Scientific Services Manager, New Zealand Sports Turf Institute, Palmerston North, NZ 1990-1991 Senior Lecturer, Lancashire College of Agriculture & Horticulture (Course Manager of National Diploma in Sports Ground Management and Turf Science), UK 1986-1990 Sports Turf Research Scientist, (Sports Council sponsored researcher), University College of Wales, Aberystwyth, UK
Qualifications and training	1982-1986 PhD Soil Science, Lincoln College, Cant., NZ 1978-1981 BSc Agricultural Chemistry (1st Class Hons), Leeds University, UK
Professional membership	❑ Member, New Zealand Soil Science Society ❑ Member, International Turfgrass Society ❑ Member, Sport Science New Zealand ❑ Member, NZ Sports Field Forum ❑ Member, Sports Turf Research Institute, Bingley, UK ❑ Member, New Zealand Recreation Association
Professional appointments	2007-Present Vice Chairman, Sports Field Forum NZ Inc. 2005-Present Vice President, International Turfgrass Society 2004-Present Executive Committee Member, Sports Field Forum NZ Inc. 2002-Present Editorial Board Member, Journal of Turfgrass and Sports Surface Science 2001-Present Director, International Turfgrass Society 1999-Present Honorary Research Associate, Massey University, Palmerston North 1993-Present Co-editor, International Turfgrass Society Journal

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Recognised achievements	❑ Yorkshire Agricultural Society Medal Holder, 1981 ❑ Commonwealth Scholar, Lincoln College, 1982-1986 ❑ MacMillan Brown Agricultural Research Scholarship, Lincoln College, 1985 ❑ Published over 120 popular articles on turf management and related subjects ❑ Co-ordinator of and/or principal researcher of 68 research projects since 1991. ❑ Published 31 refereed, or peer-reviewed, scientific papers on sports turf. ❑ Supervisor of three Honours students, two Masters Students and one PhD student from Massey University. ❑ Member of the international panel that reviewed the 1993 and 2004 United States Golf Association Green Section recommendations for a method of putting green construction. ❑ Co-author, Natural Science for Sport and Amenity; Science and Practice, CAB International, May 1994.
Focus and commitment	Richard takes overall leadership of and responsibility for projects assigned to Sports Surface Design & Management in terms of scope of work, methodology, quality control, sub-contractor and sub-participant engagement, budgeting and reporting. It is estimated that approximately 50% of Richard's time is allocated to any individual project. In terms of the specialist technical areas that Richard contributes to assigned projects, these include feasibility studies, strategic decision making, drainage/profile design, project management, rootzone and growing media suitability testing, agronomic consultancy/training, product and desktop research, sports surface evaluation and performance assessment. In more general terms, Richard's commitment to the NZ turf industry and to councils in particular is reflected by his position on the executive of the NZ Sports Field Forum, where he has been responsible for writing the organisation's business plan, making submissions to ERMA on herbicide use and organising the Best Sports Field Competition. All these activities have been carried out either at cost, or for no fee. Richard also regularly presents talks at the biannual NZ Turf Conference & Trade Show and is a frequent contributor of articles to popular turf management magazines.

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<table>
<tr><th>Position</th><th colspan="2">Sports Surfaces Consultant</th></tr>
<tr><td>Name</td><td colspan="2">Dr Marke Anthony Jennings-Temple</td></tr>
<tr><td>Years practical experience</td><td colspan="2">6</td></tr>
<tr><td>Years with company</td><td colspan="2">1.5</td></tr>
<tr><td rowspan="2">Previous (relevant) employment</td><td>Oct 2001-Dec 2005</td><td>Research Engineer, Cranfield University, Silsoe, UK. Research title: Linking the soil moisture status of winter sport rootzones to measures of playing quality</td></tr>
<tr><td>July 2001-Sept 2001</td><td>TurfTrax Ground Management Systems, Bedfordshire, UK</td></tr>
<tr><td rowspan="3">Qualifications and training</td><td>2001-2005</td><td>EngD (Doctor of Engineering), Cranfield University at Silsoe, UK</td></tr>
<tr><td>1999-2000</td><td>MSc Water Management (soil and water), Cranfield University at Silsoe, UK</td></tr>
<tr><td>1994-1997</td><td>BSc (Hons) Agriculture and Forestry, Bangor University, Wales</td></tr>
<tr><td>Focus and commitment</td><td colspan="2">Marke is answerable to Richard for all work carried out on projects assigned to Sports Surface Design & Management. It is estimated that a minimum of 50% of Marke's time will be allocated to any individual project.

In terms of the specialist technical areas that Marke contributes to assigned projects, these include feasibility studies, strategic decision making, resource consent application, site evaluation, research and development, computer programming, sports surface evaluation and performance assessment.</td></tr>
</table>

Appendix 3 – Photographs of Selected Equipment

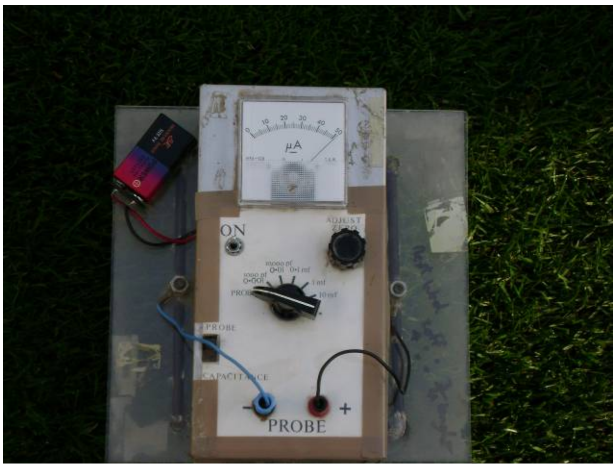
Turfgrass dry matter production measurement

Quantum sensor and light meter

Theta probe and moisture meter

Temperature/humidity datalogger

Studded disc/torque wrench traction tester

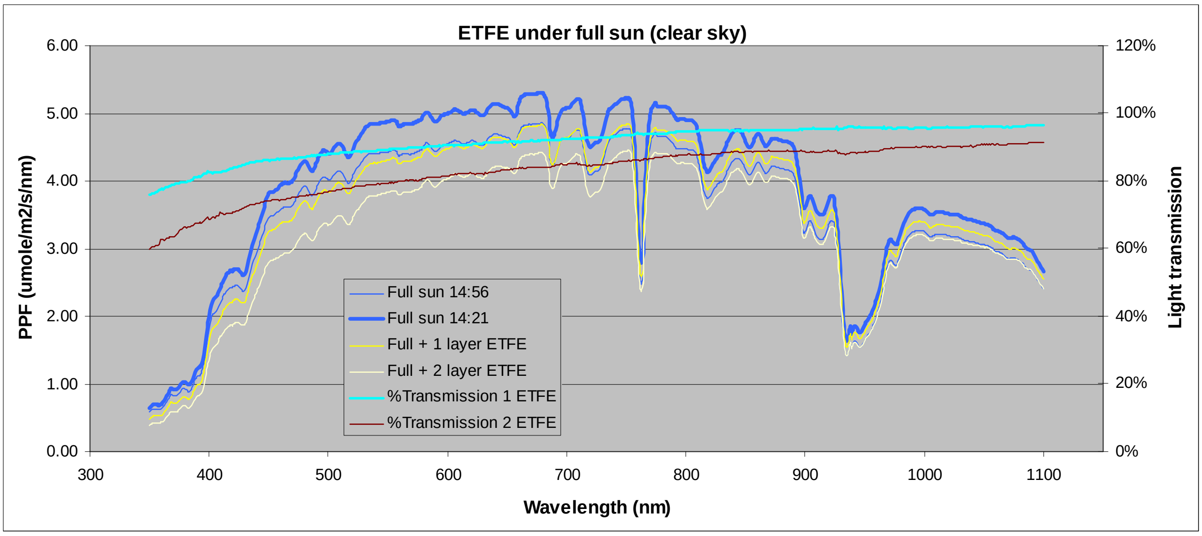


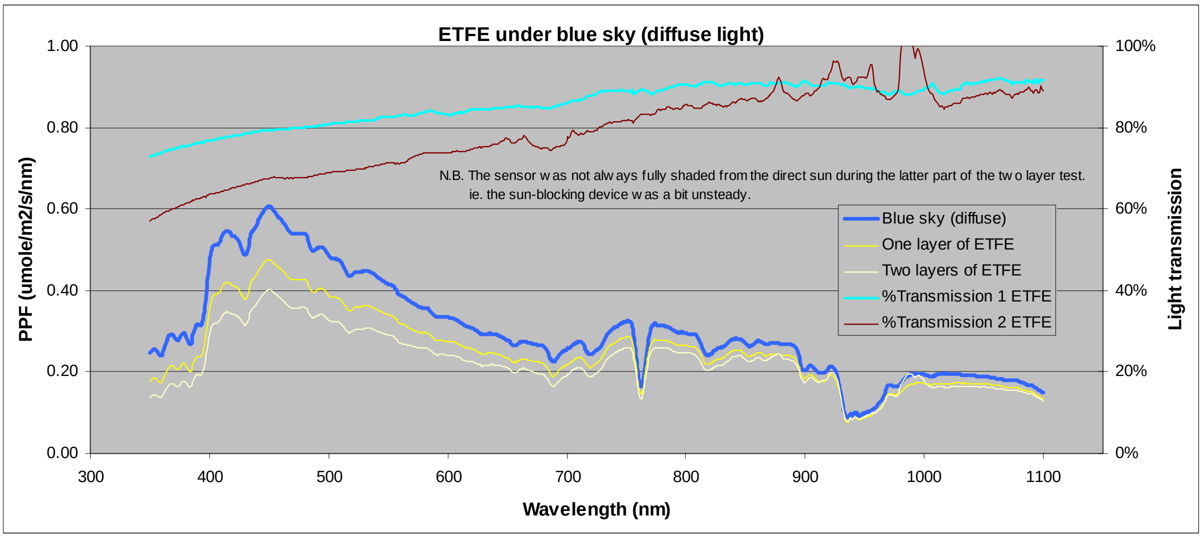
Capacitance probe

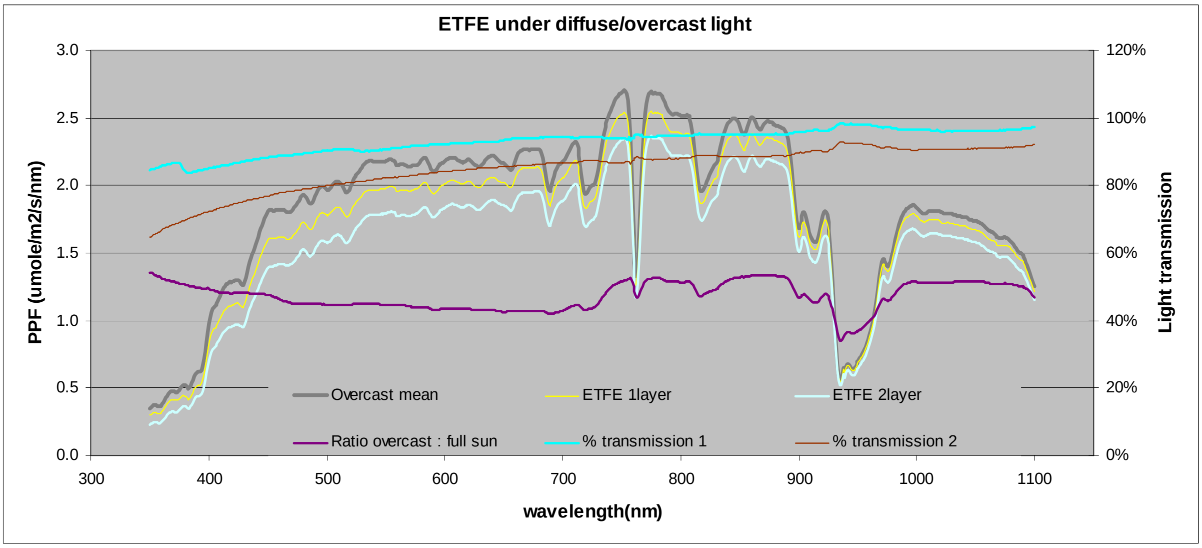
Optical point quadrat

Outside test area

Appendix 4 – Spectral Absorption Graphs







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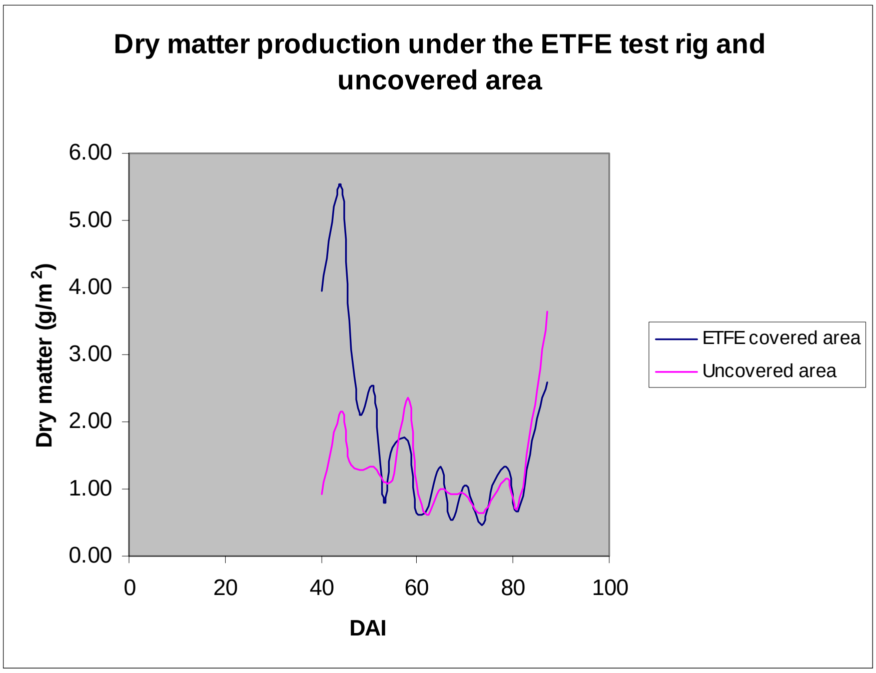
Appendix 6 – Dry Matter Production



Note: DAI = days after installation of ETFE test rig.

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Appendix 7 - References

Canaway, P.M. & Bell, M.J. (1986). Technical note. An apparatus for measuring traction and friction on natural and artificial playing surfaces. J. Sports Turf Res. Inst. 62: 211-214.

Darby, G. (2007). Dome sees a new light. Australian Turfgrass Management 9(6): 12-16.

Hutchins, M.G. (2007). The angle dependent optical properties of Vector special projects Texlon foil sample 50. Solar Energy Materials Research Laboratory Report No. 06/257, SEMRL, Oxford, May 2007.

Hutchins, M.G. & Dvorjetski, D. (2002). The optical properties of Vector special projects Matt and Super Transparent ETFE foils. Solar Energy Materials Research Laboratory Report No. 02/210, SEMRL, Oxford, March 2002.

Laycock, R.W. & Canaway, P.M. (1980). A new optical point quadrat frame for the estimation of ground cover in close mown turf. J. Sports Turf Res. Inst. 56: 91-92.

Rogers, J.N., Stier, J.C., Rieke, P.E. and Crum, J.R. (1997). Method for growing turfgrass indoors under reduced light conditions. United States Patent 5617671.

Stewart, A. (2000). Winter wear tolerance of turf ryegrass. NZ Turf Management Journal, May 2000, pp. 18-20.

Xu, Q. & Huang, B. (2001). Lowering soil temperatures improves creeping bentgrass growth under heat stress. Crop Sci. 41: 1878-1883.

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