LP130100731: Mimicking natural ecosystems to improve green roof performance

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Melbourne Water

Inner Melbourne Action Plan
'Making Melbourne More Liveable'

LP130100731 Aims:

1. Assess whether ecosystem mimicry can improve green roof stormwater retention and water quality.
2. Determine how species diversity affects green roof performance.
3. Develop new green roof substrates to improve water and nutrient retention
4. Validate experimental findings on a full-scale green roof
5. Model green roof thermal and hydrology performance with different substrate and plant combinations under different rainfall and climate scenarios.

We have 4 months left on the grant

Students

Zhanna Grebenshchykova, (Uni of Bordeaux internship) *The nutrient removal performance of vegetated roofs: quantification of an optimal fertilisation regime* (Experiment 2)

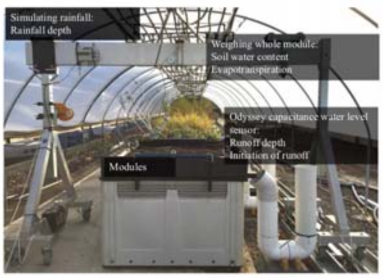
Andrew Pianella (PhD) - The thermal performance of green roofs in South-East Aust

Zheng Zhang (PhD) - Improving green roof hydrologic performance by increasing functional diversity

Joerg Werdin (PhD) - Can biochar improve green roof hydrological performance in hot and dry climates?

Influence of plant composition and water use strategies on green roof stormwater retention

- Evaluated how plant water use strategies influenced evapotranspitation (ET) and stormwater retention;
- ET and retention were greatest in plants with high water use and drought tolerance
- Plant roots reduced retention and soil water content due to preferential flow;
- Preferential flow overwhelmed the influence of water use strategies.



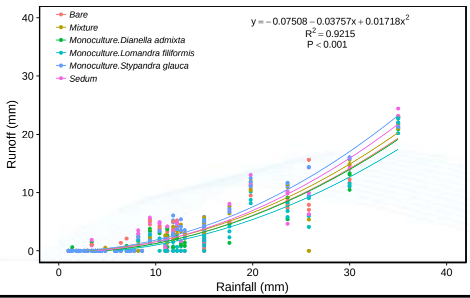
Summary

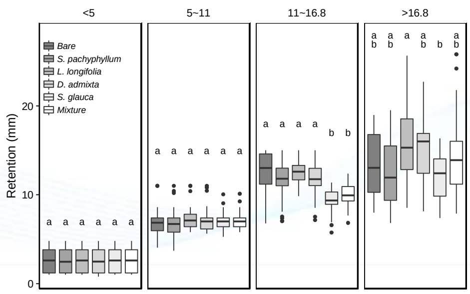
Water use strategies	Conservative	Plastic	Plastic	Plastic

Preferential flow	**No**	**No**	**No**	**Yes**
Water use	**Low**	**High**	**High**	**Limited**
Retention	**Medium**	**High**	**High**	**Low**

Rainfall Retention

- Rainfall event size is the main driver of retention
- 100 mm deep green roof retained 84-95% annual stormwater because Melbourne has lots of small rainfall events
- Plant species:
    - have no influence on retention performance in small events
    - Influence retention via available storage before rainfall





R-values of Green roof substrates - 10 cm deep, no plants

Andrew Pianella

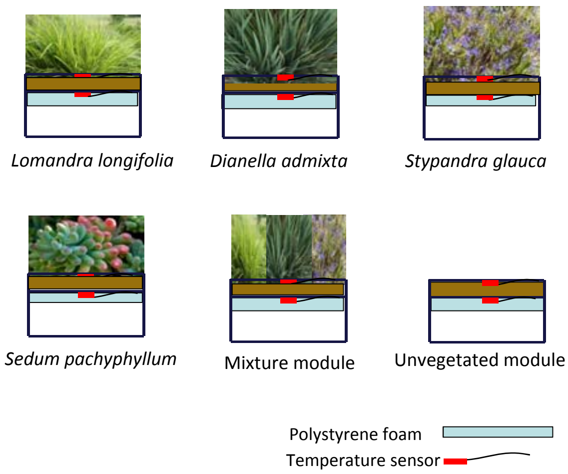
	SCORIA			BOTTOM-ASH			ROOFTILE		
R-values [Km^2W^{-1}]	Dry	Moist	Wet	Dry	Moist	Wet	Dry	Moist	Wet
Transient	**0.805**	**0.332**	**0.293**	**0.801**	**0.449**	**0.228**	**0.506**	**0.203**	**0.149**
Steady-state	**0.735**	**0.295**	**0.236**	**0.691**	**0.336**	**0.192**	**0.471**	**0.198**	**0.129**

- Scoria substrate has the lowest thermal conductivity
- R-values of scoria and bottom ash higher than most green roof substrates studied overseas.
- Data used in green roof thermal models.

Pianella et al (2016) Steady-state and transient thermal measurements of green roof substrates. Energy and Buildings 131, 123-131

Effects of plant selection on substrate temperature

- Four monoculture modules
- Mixed and unvegetated modules
- Three replicates
- Rainfall is controlled
- Scoria substrate



Pianella, A., Zhang Z., Farrell, C., Aye, L., Chen, Z., Williams, N.S.G. (In prep) Effects of plant selection on green roof substrate temperature.

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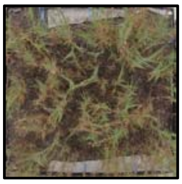
Effects of plant selection on substrate temperature



Stypandra Glauca

LAI ≈ 1 ± 0.1
h ≈ 65-75 cm
ρ_{vis} ≈ 7% ± 2.5
ρ_{IR} ≈ 26-39%

Lomandra longifolia

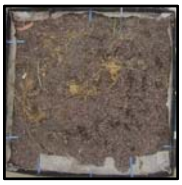
LAI ≈ 3.3 ± 1
h ≈ 35-45 cm
ρ_{vis} ≈ 12.5% ± 2
ρ_{IR} ≈ 23-54%

Sedum pachyphyllum

LAI ≈ 2.5
h ≈ 15-18 cm
ρ_{vis} ≈ 10% ± 2
ρ_{IR} ≈ 11-38%

Dianella admixta

LAI ≈ 0.8 ± 0.1
h ≈ 15-18 cm
ρ_{vis} ≈ 9% ± 1
ρ_{IR} ≈ 27-46%



Unvegetated

ρ_{vis} ≈ 6% ± 1
ρ_{IR} ≈ 10-18%

Mixture

LAI ≈ 1.3 ± 0.1
h ≈ 7-80 cm
ρ_{vis} ≈ 8.5% ± 2
ρ_{IR} ≈ 29-41%

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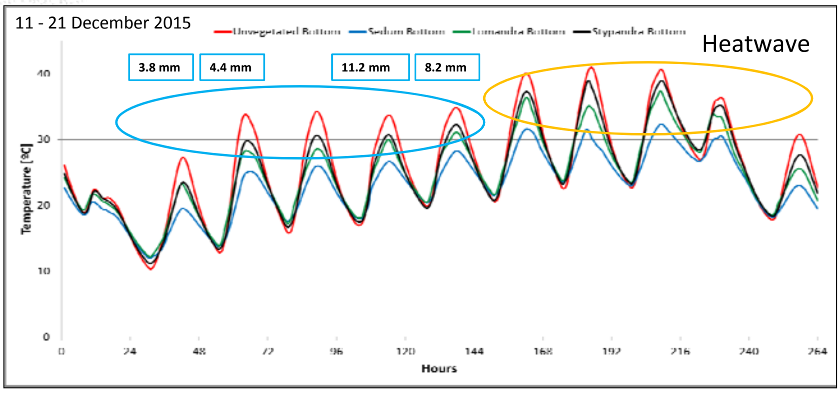
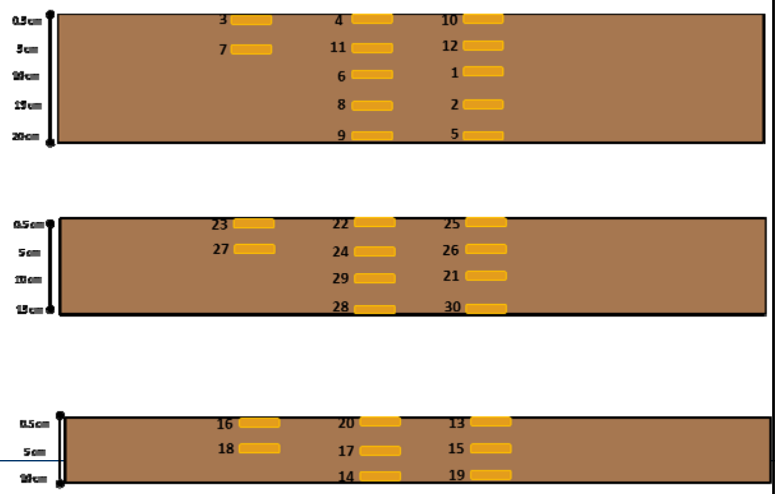
Results: Bottom Temperature Swings

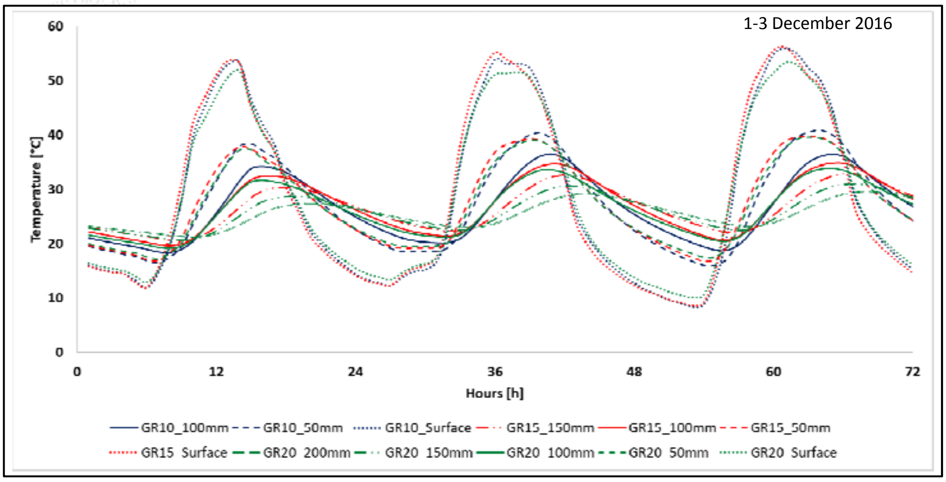


- Unvegetated modules have the greatest temperature variations;
- *Stypandra* has a performance similar to unvegetated modules due to scarce coverage.
- In this period, *Sedum* offers better insulation than *Lomandra* due to wetter substrate. However, annually *Lomandra* performs the best.

Temperature variation with green roof thickness

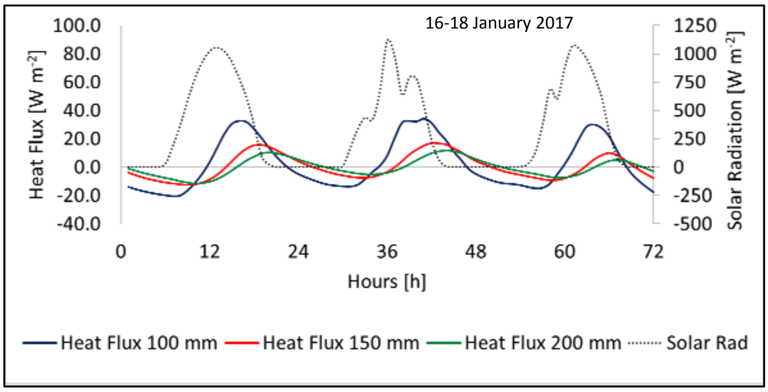


Temperature variation with green roof thickness



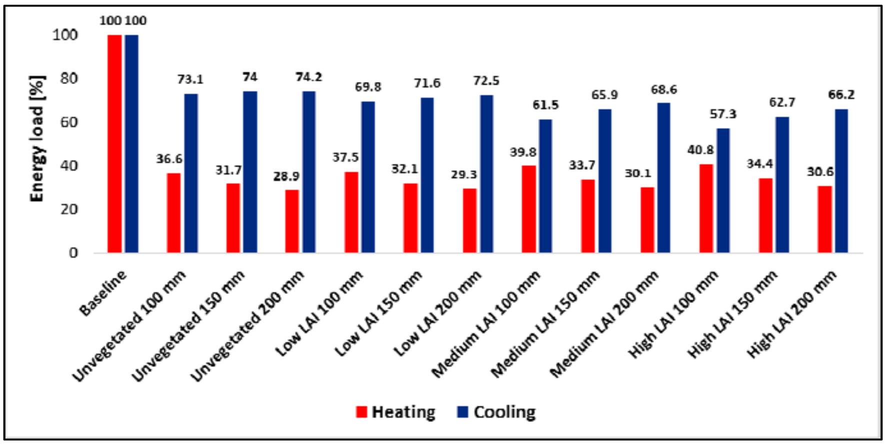
Substrate thermal profiles across the three experimental green roofs does not vary significantly in the top 50-80 mm

Heat flux through the roof



- Peak heat fluxes of 34, 17, 12 W m^{-2} for the 100, 150 and 200 mm thick green roofs respectively.
- Time delay of 3.5 , 5 and 7 hours for the 100, 150 and 200 mm thick green roofs respectively.

Potential Annual Building Energy Savings



Energy simulations for 1-storey brick commercial building with concrete roof and set indoor temperature (21 C heating, 24 C cooling).

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Energy Conclusions

- David Sailor's green roof model has been modified and updated to South-East Australia weather to provide more realistic simulations;
- R values of substrates are low. Scoria is the highest of those tested
- Selecting high albedo and cover plants will improve thermal performance
- Green roofs consistently reduce and delay peak heat fluxes into the building with increasing substrate thickness.
- Scoria substrate and *Lomandra longifolia* in a 150 mm green roof provide the best green roof thermal performance in Melbourne of the combinations we tested.
- Potential energy savings: 65% heating and 35% cooling.

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Can biochar improve green roof hydrological performance ?

Joerg's PhD structure

Chapter 1
Literature synthesis

Chapter 2
Biochar properties

Chapter 3
Biochar – substrate - plant interaction

Chapter 4
Irrigation / Water quality

Research question chapter 2:
Can wood anatomical structure be used as a predictor for the water holding properties of biochar?

Wood biochar and its water holding properties

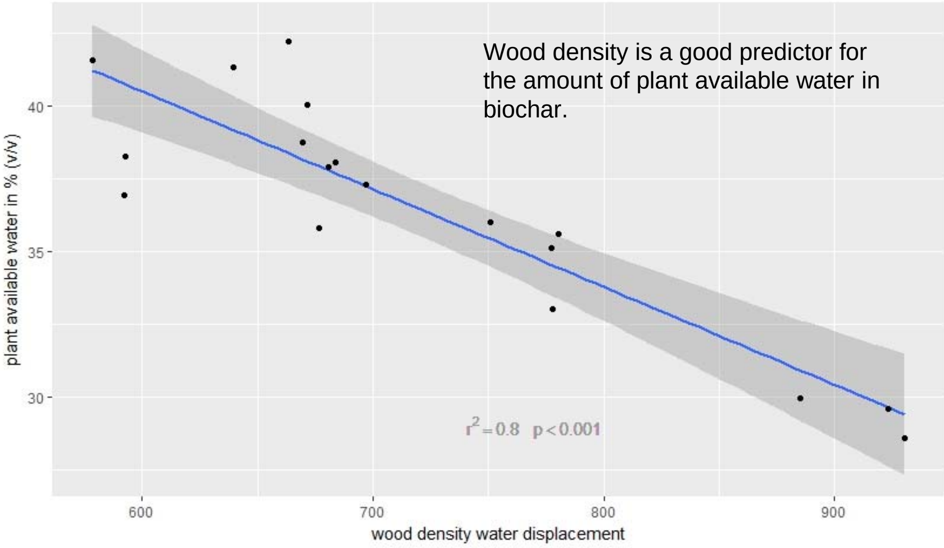
Research question	Experiment	Data	Output
Can wood anatomical structure be used as a predictor for the water holding properties of biochar?	Wood anatomical structure in relation to biochar water holding properties. 18 x wood species 3 x Replicates Total 57 Samples 18 x biochar types 3 x Replicates Total 57 Samples	Wood density- and anatomical structure (Silviscan and water displacement) biochar water holding capacity (WHC), matric suction curve, plant available water (PAW), field capacity (FC), bulk density (BD)	Paper / Geoderma or Science of the Total Environment

Species and results

Species	Radial fibre lumen diameter (µm)	Wood density Silviscan (kg/m^3)	Wood density water displacement (Kg/m^3)	Dry bulk density biochar (kg/m^3)	Water holding capacity (% v/v)	Plant available water (% v/v)
E. cypellocarpa	11.0	629.5	671.6	159.1	44.2	40.0
E. delegatensis	11.3	526.1	593.1	157.7	43.6	38.3
E. dives	11.1	545.9	697.0	189.8	43.2	37.3
E. globoidea	10.6	654.9	780.6	190.7	41.5	35.6
E. leucoxylon	10.6	726.6	777.5	210.4	40.4	35.1
E. macrorhyncha	10.7	615.6	680.9	178.2	42.8	37.9
E. melliodora	10.2	684.2	750.8	280.9	44.0	36.0
E. microcarpa	9.8	823.3	885.2	322.9	38.0	30.0
E. muelleriana	10.8	626.4	669.5	179.5	43.5	38.8
E. nitens	10.9	612.8	639.6	186.0	47.4	41.3
E. obliqua	11.2	611.9	676.9	158.6	40.8	35.8
E. pauciflora	10.5	521.2	578.7	140.3	44.5	41.6
E. polyanthemos	10.4	685.2	777.6	249.2	39.0	33.0
E. polybractea	9.9	881.2	930.1	294.3	35.5	28.6
E. radiata	10.8	526.7	663.7	195.6	47.8	42.2
E. regnans	11.4	553.8	592.2	158.7	41.6	36.9
E. tricarpa	9.9	852.4	923.0	304.8	36.9	29.6
E. viminalis	10.7	666.3	684.0	189.7	44.2	38.1

***Table 1** Summary table of measurements taken for each of the different Eucalyptus species and their corresponding biochar type*

Wood biochar and its water holding properties



Academic Outputs

1. Clarke, R. E., A. Pianella, B. Shabani, and G. Rosengarten. 2017. Steady-state thermal measurement of moist granular earthen materials. Journal of Building Physics **41:101-119.**
2. Pianella, A., L. Aye, Z. Chen, and N. S. Williams. 2017. Substrate depth, vegetation and irrigation affect green roof thermal performance in a mediterranean type climate. Sustainability (Switzerland) **9.**
3. Pianella, A., R. E. Clarke, N. S. G. Williams, Z. Chen, and L. Aye. 2016. Steady-state and transient thermal measurements of green roof substrates. Energy and Buildings **131:123-131.**
4. Szota, C., T. D. Fletcher, C. Desbois, J. P. Rayner, N. S. Williams, and C. Farrell. 2017. Laboratory tests of substrate physical properties may not represent the retention capacity of green roof substrates in situ. Water (Switzerland) **9.**
5. Szota, C., C. Farrell, N. S. G. Williams, S. K. Arndt, and T. D. Fletcher. 2017. Drought-avoiding plants with low water use can achieve high rainfall retention without jeopardising survival on green roofs. Science of the Total Environment **603-604:340-351.**
6. Zhang, Z., C. Szota, T. D. Fletcher, N. S. G. Williams, J. Werdin, and C. Farrell. 2018. Influence of plant composition and water use strategies on green roof stormwater retention. Science of the Total Environment **625:775-781.**

Plus three published conference proceedings

Recommendations for Industry

- Need to consider the effect of plant roots on water retention
- R values of substrates are small
  - No additional benefit deeper than 15 cm
- Energy savings
  - Up to 65% heating
  - Up to 35% for cooling
- The plants are very important: shade, albedo
- Biochar is a new useful substrate component