Hort Innovation

Final Report

Investigating the influence of green infrastructure on demountable building performance

Project leader:

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Delivery partner:

Queensland University of Technology

Project code:

GC16000

Project:

Investigating the influence of green infrastructure on demountable building performance GC16000

Disclaimer:

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Summary

Urban Heat Islands (UHIs) are problematic in subtropical climates and their impact is worse in extreme weather conditions. Green infrastructure such as green roofs and green walls can offer potential benefits. This includes; reducing heat impact on buildings, reducing use of air conditioning (thereby providing energy savings), reducing the effects of UHI (i.e. glare from surrounding structures) and improving employee health and well-being, reducing mental fatigue and promoting work productivity. Temporary accommodation or temporary work buildings can potentially benefit from green infrastructure through cooling the building, thereby reducing the need for air conditioning. However, to date, there is no evidence to suggest whether this is a viable solution.

This project is a collaboration among Lendlease (provided the site and demountable building), Grow Collective (designed and installed the green infrastructure), Queensland University of Technology (green infrastructure monitoring), Horticulture Innovation Australia (funding and project opportunity). The project was run from 1st February 2017 – 31st December 2017 after initial set-up delays.

The site chosen is the Lendlease site at RAAF Amberley Base located south-west of Brisbane CBD. Demountable buildings on site are used as offices with employees often spending over 12 hours per day working inside. Amberley is subject to extremely high temperatures. Every day during February 2017 recorded 30°C or higher with a maximum monthly temperature of 43.0°C and maximum monthly mean of 33.7°C (BoM, 2017).

The aim of this project is to measure the influence of green infrastructure on demountable building performance through pre- and post-installation surveys of Lendlease employees on base, pre- and post-installation microclimate data and acoustic monitoring. This project will provide industry with meaningful data to consider the appropriateness and viability of using green infrastructure to improve demountable building performance. This is not only limited to the construction industry, but can also span temporary accommodations, school buildings, post-disaster accommodation and community facilities. It is intended that the green infrastructure used in this project also be used for future studies, for example, to test their resilience in extreme weather conditions. Lastly, this project verified that a number of plants were able to grow in shallow inorganic systems both vertically and horizontally.

Keywords

Green infrastructure
Environmental monitoring
Building performance

Introduction

The project has finished and is completed on time as per the deliverables and achievement criteria. Temperature data was periodically collected every month except November (team was not available for a site visit) and condition and battery of the sensors were inspected. The final temperature data collection occurred on the 7th December 2017. After an initial failure, the acoustic sensors were deployed on the 7th December and on the final trip to Amberley on the 15th December, a week's worth of acoustic data was collected and subsequently analysed. Due to the large amount of data being collected and the departure of a previous research assistant hired to build the acoustic sensors, another research assistant was hired – Endrias Ergetu – who has rebuilt the acoustic sensors and completed the final analysis of all temperature and acoustic data.

The team was invited to present on the project's progress at the HIA urban greening research forum in Sydney on the 3rd November 2017 which Dr Agdas and Ms Thompson attended. The presentation showcased new progress photos taken from the site the week of the presentation and up to date temperature data analysis. The presentation was successful, and the research team was afterwards approached by many interested researchers commenting on the novelty of the project or offering opportunities for future research collaboration.

Final temperature data analysis is promising, and a more detailed comparison may provide further insight to the recorded data. Though only one week's worth of acoustic data was collected, the results look promising and the construction of the acoustic sensors was a success as they were built from scratch and programmed for data recording and saving purposes.

The project is now completed as is QUT's involvement. Grow Collective is interested in continuing temperature and acoustic monitoring for at least another six months. They aim to replicate the green infrastructure module design and conduct further testing for durability and suitability for various environments.

Methodology

Pre- and post-installation surveys

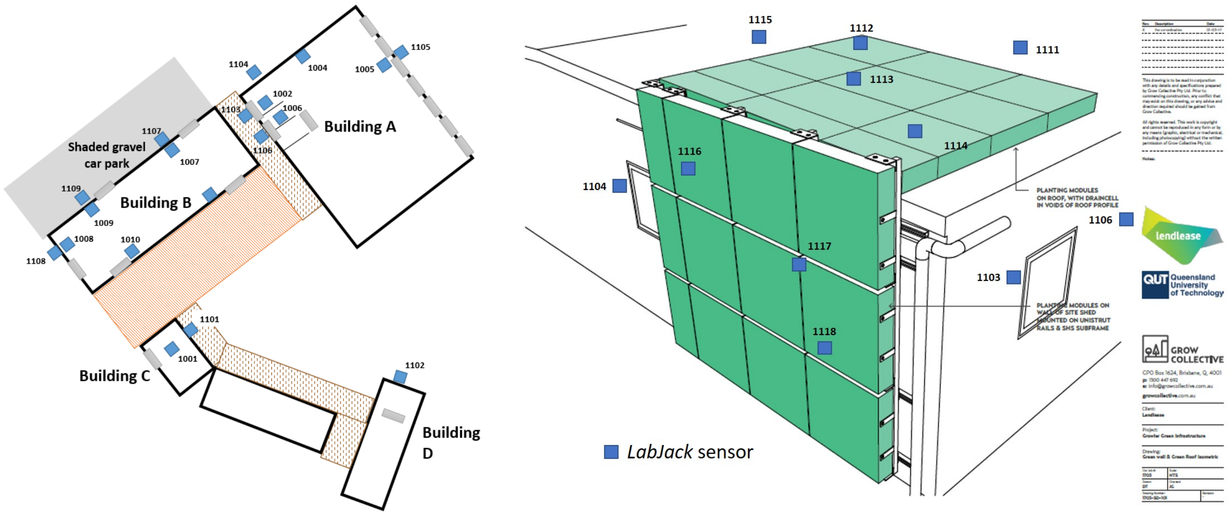
A pre-installation staff survey, aimed at capturing staff perceptions on the value of green infrastructure initiatives in building performance improvement was created in the earlier stages of this project. The survey was designed to capture occupant experience prior to the installation of the green roof and wall. It was distributed in March 2017 and ran for two weeks. In total, ten Lendlease employees completed the survey with a response rate of 71.4%. The survey was designed to provide a baseline in structuring of questions as well as gauging the response for the post-installation survey. A follow up, post-installation survey was created and disseminated two months after the green roof and wall installation. It was decided that the questions would require changing as to ask important and relevant questions reflected in the literature. The survey comprised 18 statements (rather than questions, Appendix 1) and the participants were asked to rate their level of agreement on a Likert scale of 1 to 7—Strongly disagree (1) to Strongly agree (7). The 18 statements were categorised underneath themes consistent in the literature, 'Health and well-being', 'Environmental perception', 'Environmental aesthetics' and a fourth category 'Opinion of green roof and wall' for employees to express their opinion on the installed green infrastructure. The estimated completion time was one minute. The link was emailed to the Lendlease contact at Amberley for dissemination to employees in an email following QUT ethics procedure.

Microclimate monitoring

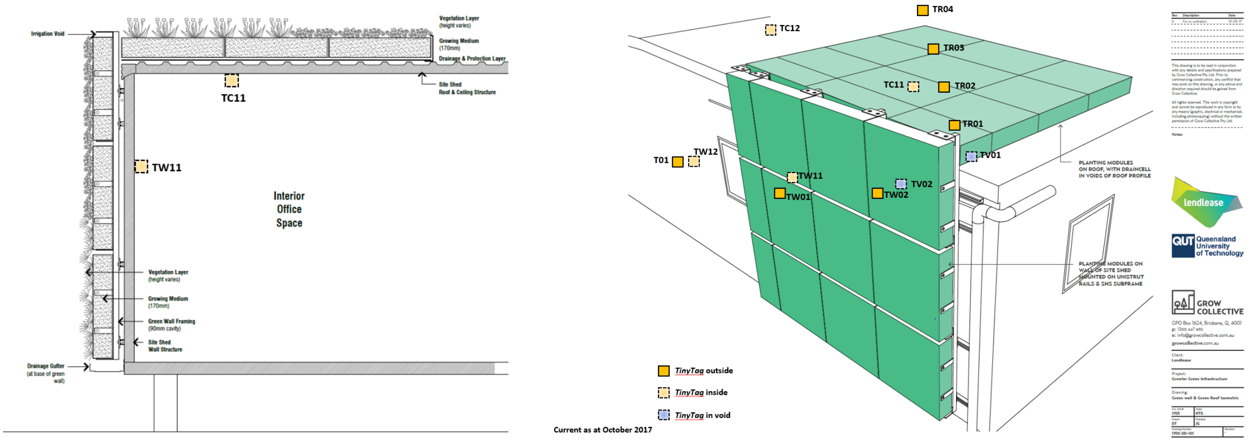
Original temperature sensors (*LabJacks*) were deployed in February 2017, approximately three months prior to green infrastructure installation (Figures 1a, b). However, by July all outdoor sensors had failed, subject to one or more issues: water leakage, condensation, ice, rust, battery failure and USB failure. Following this, new sensors (*TinyTags*) were deployed two weeks later that have proved to be sturdier and have been able to withstand environmental conditions. The downside was that QUT only had 13 of the new sensors and as such could only monitor one demountable building with comparisons inside and outside (Figures 2a, b).

The new data was compared with the previously collected data and analysed with regard to seasonal and temperature changes and how that has affected temperatures outside and inside the demountable buildings. The final trip to collect temperature data was undertaken on the 7th December 2017 and the final trip to collect the acoustic data (sensors were only deployed on the 7th December) was on the 15th December 2017. This concludes QUT's involvement and access on to the site. Both temperature and acoustic sensors have been left on site with the aim for Grow Collective to take over data collection.

Plant growth on the green roof and green wall was highly successful. Species were chosen by Grow Collective that could grow in shallow inorganic systems, both vertically and horizontally under dry and extreme weather conditions. Species included *Aloe vera*, *Rosmarinus officinalis*, *Philodendron xanadu*, *Aptenia cordifolia*, *Russellia equisetiformis*, *Pennisetum* sp., *Jasminum* and *Metrosideros sp*. At the research forum in Sydney, QUT showcased the first set of progress photos from the site from July to October 2017 (Figures 3a,b and 4a,b).



Figures 1a (left) and **1b** (right). Original sensor deployment plan.



Figures 2a (left) and **2b** (right). Updated and final sensor deployment plan.

Figures 3a (left) and **3b** (right). Green roof growth from July 2017 – October 2017.

Figures 4a (left) and **4b** (right). Green wall growth from July 2017 – October 2017.

<u>Acoustic monitoring</u>

Acoustic monitoring at the site was not included in the original project design but was discussed. After the deployment of the second round of temperature sensors, it was decided that acoustic monitoring could provide insightful data. Planes flying overhead at Amberley are loud and this project provided an opportunity to assess the impact of green infrastructure in dampening the noise generated. The acoustic sensors were built at QUT and the first set were deployed in the two small rooms in demountable building A (manager's room (covered by green infrastructure) and meeting room). The sensors worked; however failed in collecting data that was readable, thereby prompting a sensor redesign. The research assistant who originally designed the sensors left the project and a new research assistant was appointed to redesign the sensors. Furthermore, QUT researchers were unable to visit the site during November for acoustic sensor deployment. These instances contributed to the overall delay in the deployment of acoustic sensors. The sensors were programmed to measure sound level at a frequency of 10 times per second (10Hz). These measurements were then averaged and recorded on a minute-by-minute basis. Sensors also retained the highest recorded measurement over the course of each minute to compare any possible dampening effect of intense sounds (Figure 12).

Outputs

A formal dissemination workshop has not been completed, however project results have been discussed separately with Grow Collective and Lendlease employees. Further, Ms Thompson and Dr Agdas were invited to present at the HIA National urban greening research forum in Sydney on the 3rd November in which recent results were disseminated. The presentation was 15 minutes long with an accompanying PowerPoint presentation which outlined:

- A background of the project and what the potential benefits of green infrastructure are.
- Who the project is in collaboration with including funding organisations
- The overall aim/s of the project
- Map and outline of the Lendlease demountable buildings on the site at Amberley
- Progress growth photos of the green roof and the green wall from July 2017 to October 2017
- Methods, sensor deployment and placement on the demountable buildings
- Initial temperature results from 10th July to 6th October 2017 comparing different outdoor temperature sensors to the recorded BoM temperatures.
- Outline of the pre- and post-installation surveys and summary of the results
- Acoustic monitoring deployment plan
- Future research directions

The response to the presentation in Sydney was overwhelmingly positive. Many individuals approached the team offering potential research collaboration or asked for more information about the project and results. A final report will be sent to both Grow Collective and Lendlease employees if interested and if the organisations express further interest, QUT will host a formal dissemination workshop in 2018 to discuss results.

Dissemination methods have included informal dissemination of temperature results to Grow Collective and Lendlease employees and Ms Thompson and Dr Agdas' presentation at the HIA urban greening research forum in Sydney on the 3rd November. The research team plans to write and disseminate two journal articles:

- Journal article 1: Potential energy savings due to green infrastructure
- Journal article 2: Financial viability of green infrastructure modules over their life cycle (i.e. cost of installation, maintenance versus energy savings).

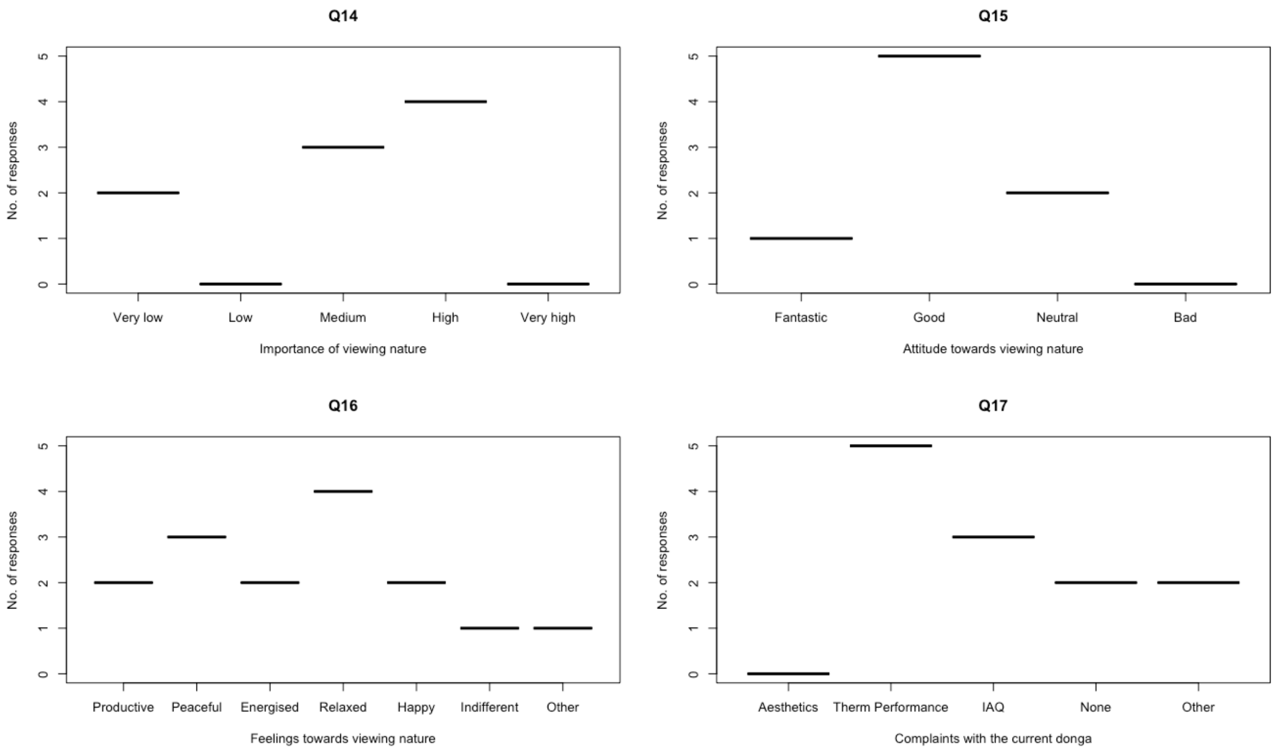
Outcomes

<u>Pre- and post-installation surveys</u>

Pre-installation

In total, ten Lendlease employees completed the survey with a response rate of 71.4%. Some questions were allowed to be skipped, so number of responses per question varies. Background questions were asked such as gender, age, previous work on a construction site with dongas, the average number of hours worked per week, how long employees had been working on site and how long participants spend on site and in dongas daily. A final question about their feelings towards the donga air conditioning were measured using 'Likert-like' point scales. The limited results indicated staff perceptions as highly variable and susceptible to personal biases rather than the objective assessment of the value of green infrastructure.

Other responses to questions have been graphically represented in Figures 5a – d.



Figures 5a – d. Graphically represented survey results for questions 14 – 17. **a)** Q14. Importance of viewing nature, **b)** Q15. Attitude towards viewing nature, **c)** Q16. Feelings towards viewing nature, **d)** Q17. Complaints with current donga.

Post-installation

To date only six out of 30 potential participants completed the survey. This number is insufficient, and Participant 5 was omitted from the analysis due to every question being answered with a score of '1'. These limited results are shown in Table 1 and are summarised.

Table 1 Comparison of post-installation survey responses from six participants. Participant 5 was omitted from analysis. Numbers were coloured to emphasise positive responses to questions. <4 = red, 4 = grey, >4 = green.

Participant	Statement Categories and Numbers																	
	Health and Well-being							Environmental Perception			Environmental Aesthetics			Opinion of green roof and wall				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	1	1	1	1	1	1	1	1	1	1	2	2	5	4	3	2	2	4
2	6	6	6	6	6	3	7	6	6	6	6	6	2	7	7	6	7	7
3	6	6	6	6	6	2	6	6	6	6	7	7	2	7	7	5	7	6
4	6	6	4	5	5	4	5	5	5	5	6	6	3	5	5	5	5	5
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	5	6	6	5	5	3	5	6	6	6	6	6	4	5	4	5	5	5

<u>Health and well-being</u>

- 4 out of 5 participants agreed that when stressed, being in nature can help them relax.
- 4 out of 5 participants disagreed that being in nature when not stressed sometimes makes them too relaxed, unproductive or unmotivated

<u>Environmental perception</u>

- 4 out of 5 participants agreed that they care about having a view of nature from their desk, it's important to them and they actively seek to spend their break in or viewing nature

<u>Environmental aesthetics</u>

- 4 out of 5 participants agreed that they prefer a window near their desk with a view of nature
- 3 out of 5 participants disagreed with the statement that viewing a lively urban setting can be more stimulating than an unspectacular natural setting

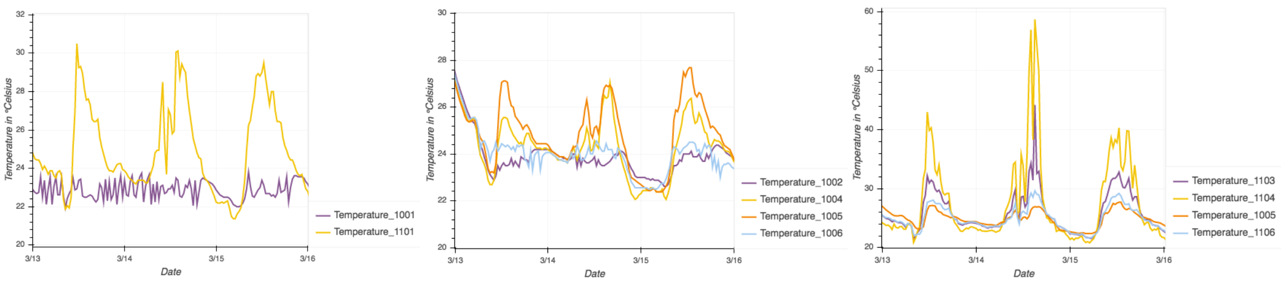
<u>Opinion of green roof and wall</u>

- 4 out of 5 participants like the green roof and wall
- 3 out of 5 participants think installing the green roof and wall was a good idea
- 4 out of 5 participants think it's worth investing money into installing green roofs and walls on demountable buildings
- 4 out of 5 participants think the green roof and wall makes the demountable building more visually appealing
- 4 out of 5 participants think the green roof and wall helps with glare off the building

<u>Microclimate monitoring</u>

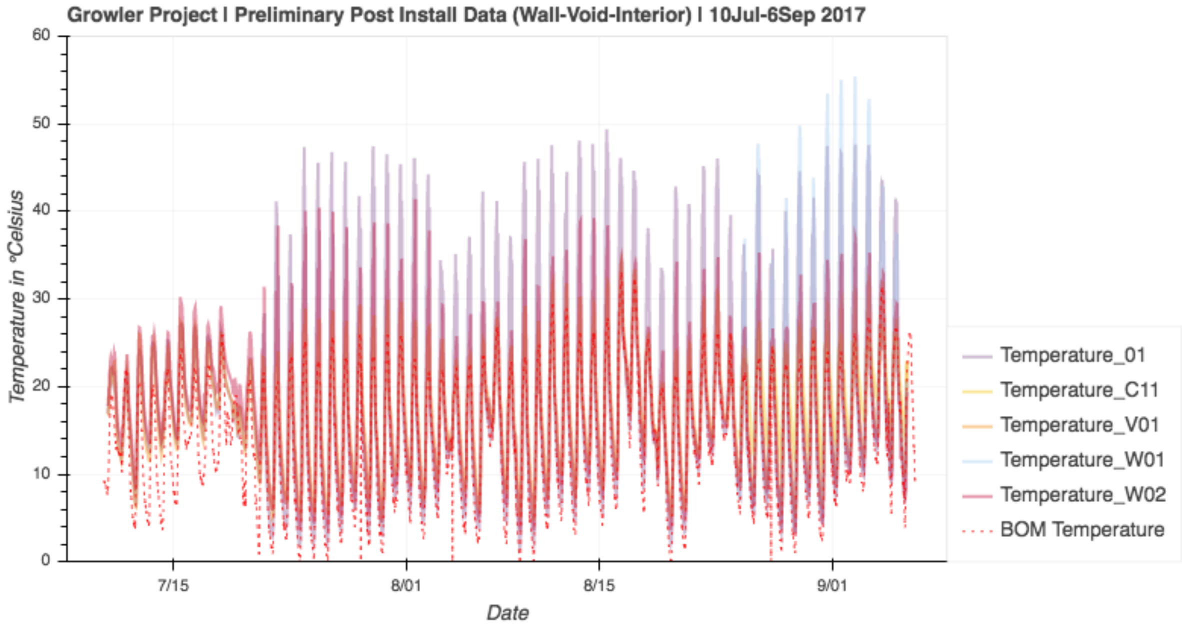
A preliminary analysis of March 2017 temperature data prior to green infrastructure installation was undertaken and reported in HIA Milestone Report 102. This highlighted:

- Indoor temperatures more stable due to air conditioning units being set to 24°C in the two small rooms in demountable building A (Figure 6a)
- Indoor temperatures read from sensors on the West and North walls of demountable building A were much higher than temperatures read from sensors in the two small rooms (Manager's and meeting room) on the South side of the building (Figure 6b)
- Outside temperatures from sensors on brick walls were cooler than temperatures from sensors on corrugated iron (demountable building material). The sensor on corrugated iron facing West recorded higher temperatures than the sensor on corrugated iron on the North side of the building (Figure 6c)



Figures 6a – c Sample preliminary microclimate data analysis over three days in March 2017. **a)** Indoor vs Outdoor, **b)** Results from demountable building A, **c)** Outside results on demountable building A.

30-minute interval weather conditions at Amberley was emailed to QUT researchers once a week from the Bureau of Meteorology. This provided reliable comparison data to QUT data collected on the demountable buildings. A preliminary comparison was included in the QUT presentation at the HIA urban greening research forum (Figure 7a-b).



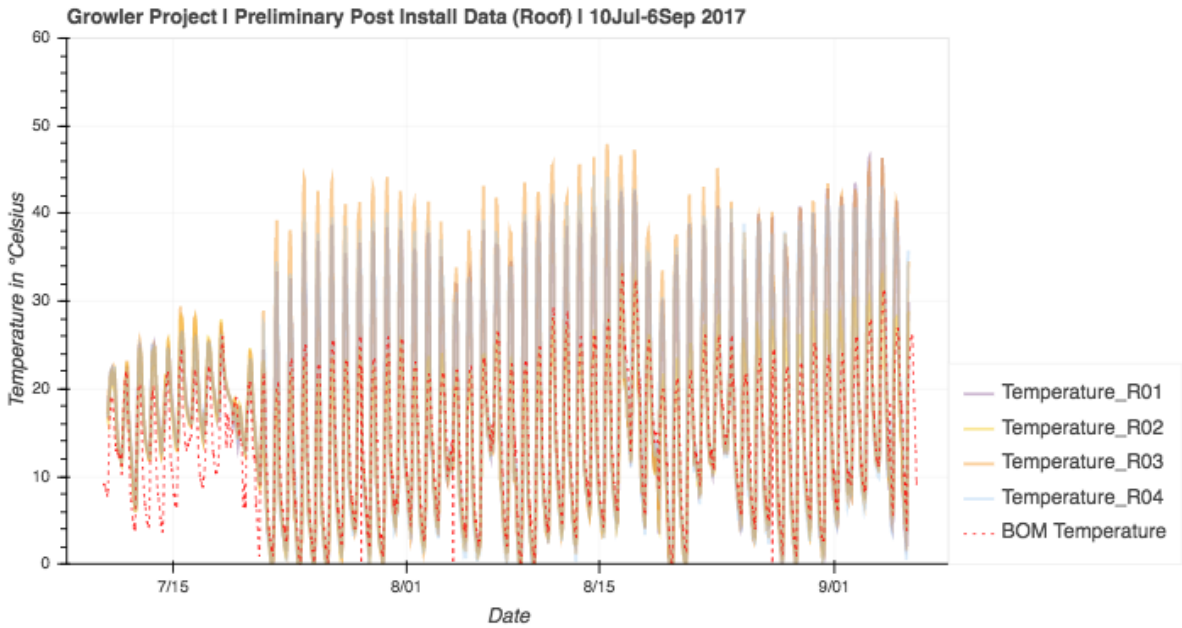
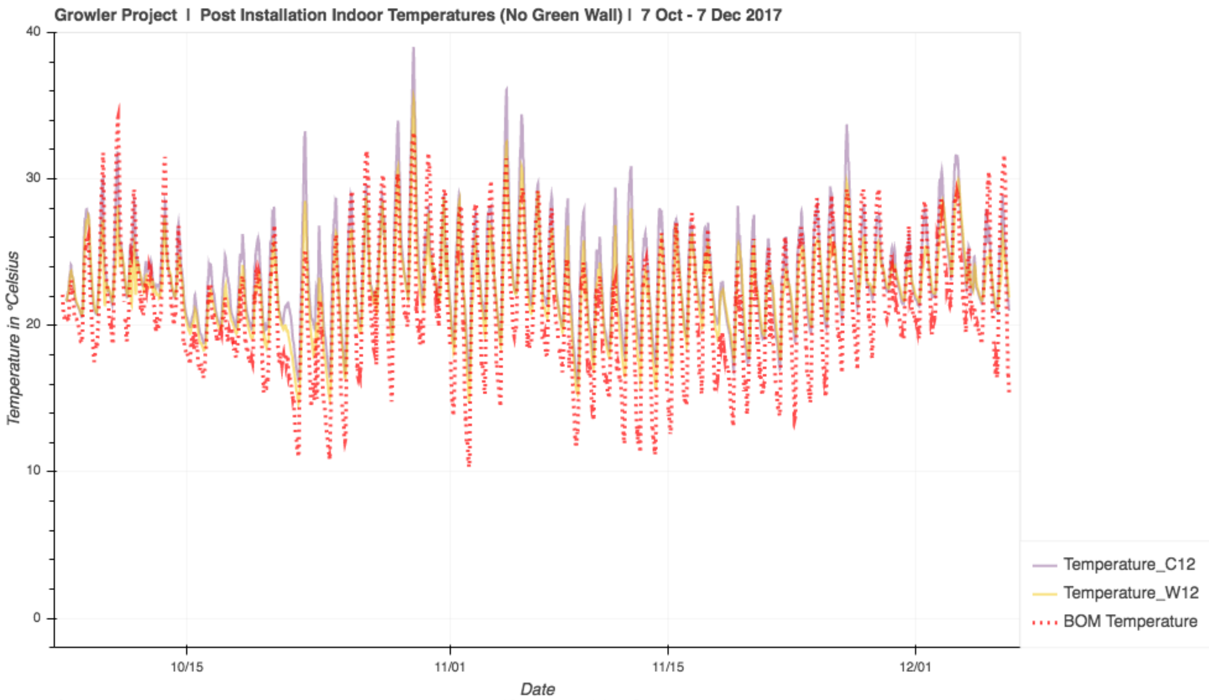


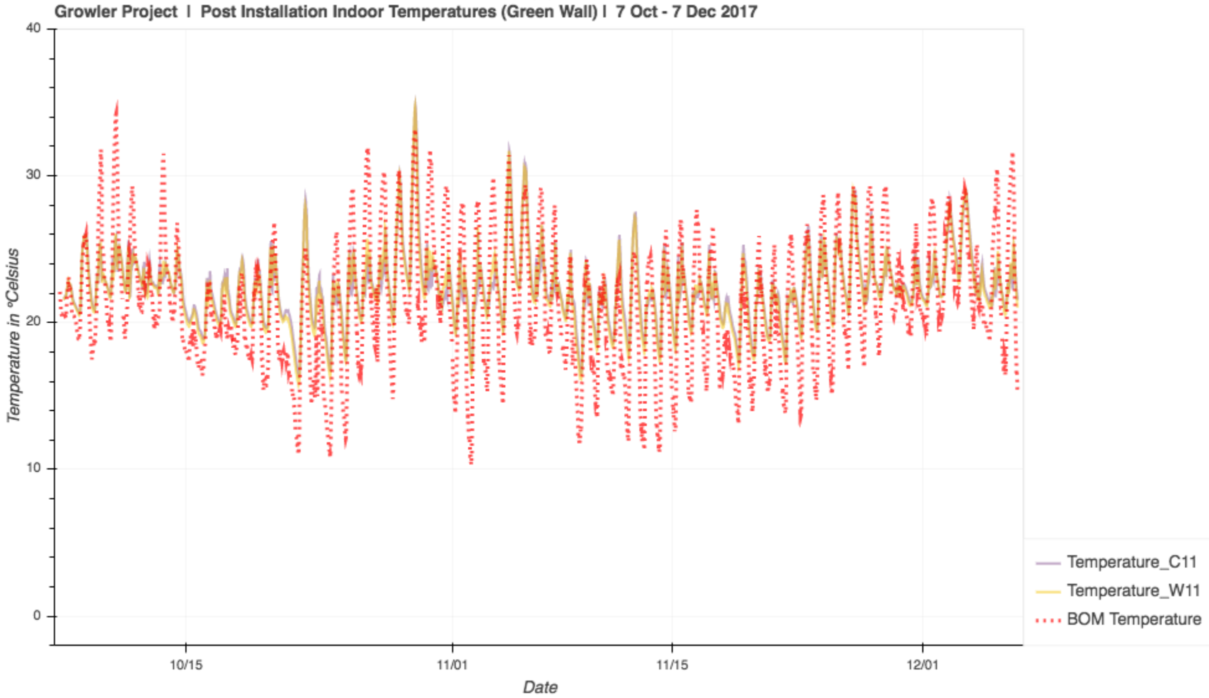
Figure 7a (top) and **b** (bottom) Sample comparison of BoM data and preliminary QUT collected data on site at Amberley from 10th July 2017 – 6th September 2017. Lack of QUT data for Growler_TC11 and Growler_TW01 sensors is because the two sensors were not deployed until late August. (QUT did not have all *TinyTag* sensors readily available for replacement in July). Labels correspond to sensor positions in Figures 2a and 2b.

A final analysis of the most recent temperature data from the Amberley site was undertaken and is displayed in Table 2 and Figures 8a, b, 9a, b and 10a, b.

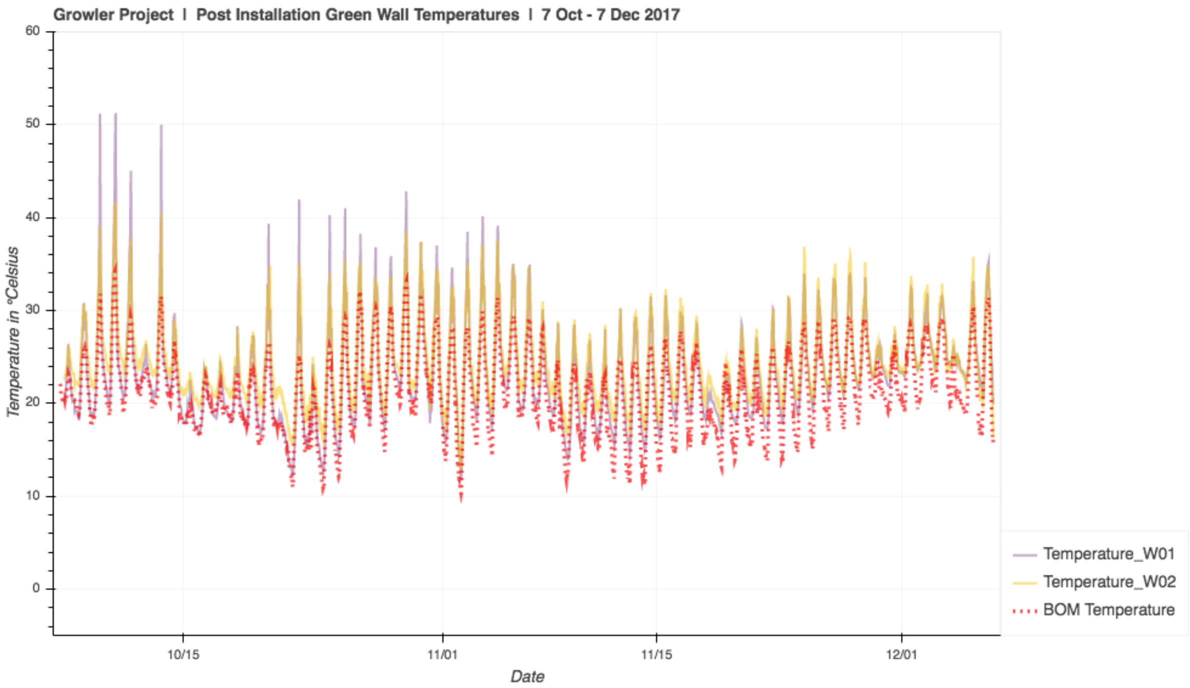
Table 2 Sensor descriptions corresponding with Figures 2a and 2b with results of mean temperature and standard deviation between 7th October and 7th December 2017.

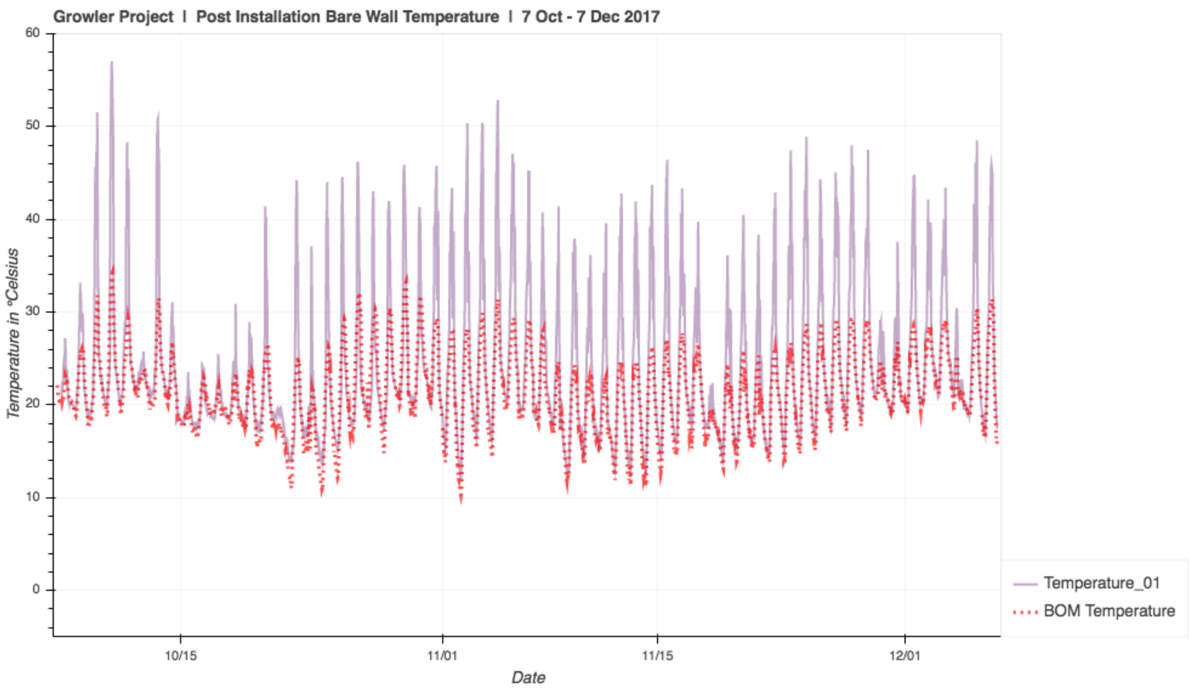
Sensor (updated, TinyTags)	Mean Temperature	Standard Deviation
TW01 (Green wall)	22.98	5.08
TW02 (Green wall)	24.31	4.25
T01 (Outside bare wall)	23.98	7.75
TW11 (Indoor wall behind green wall)	22.25	2.43
TW12 (Indoor bare wall)	22.50	2.89
TC11 (Ceiling under green roof)	22.36	2.36
TC12 (Ceiling under bare roof)	23.47	3.30
TV01 (Green roof / roof void)	22.19	4.43
TV02 (Green wall / wall void)	21.62	3.84
TR01 (Green roof)	22.78	7.68
TR02 (Green roof)	22.35	6.82
TR03 (Green roof)	*Battery failure therefore unable to collect data on last visit.*	
TR04 (Roof)	25.33	11.22



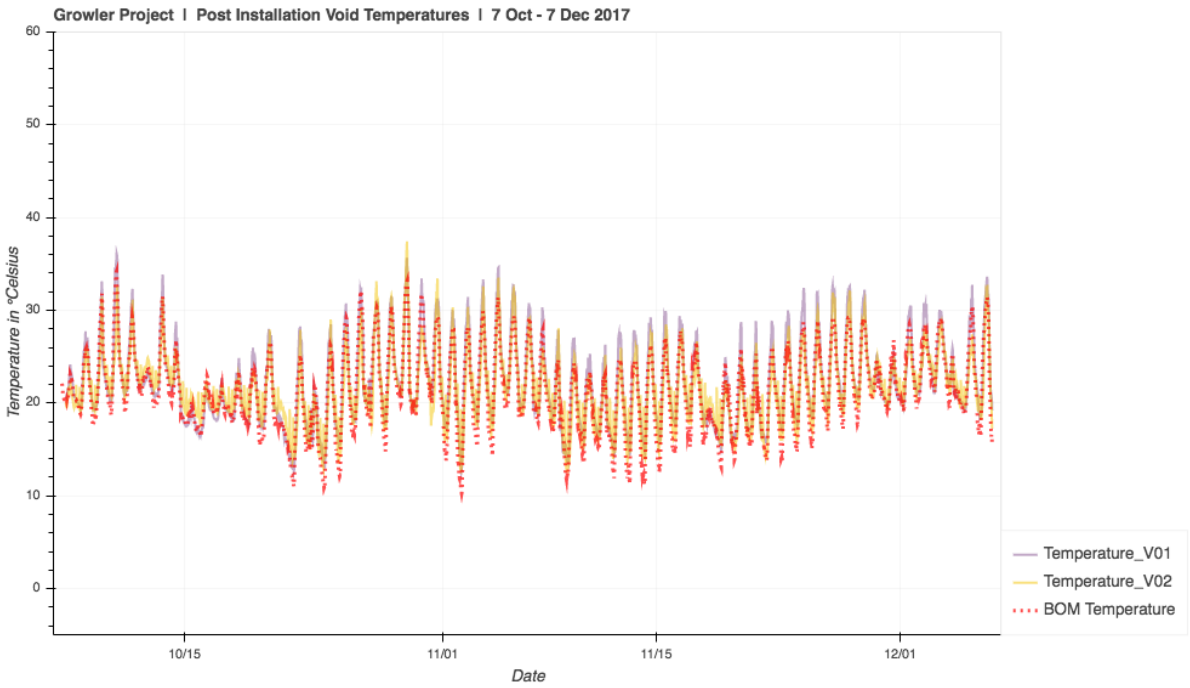


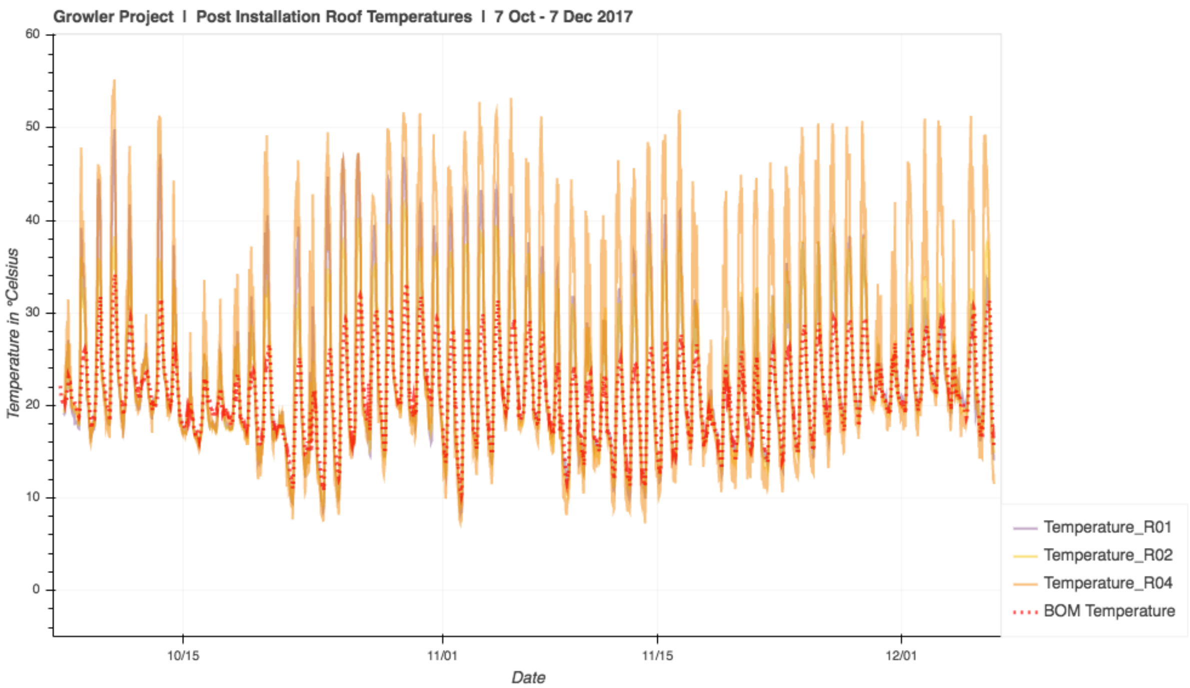
Figures 8a (top) and **8b** (bottom) Comparison of the latest QUT collected temperature data and BoM Amberley data from 7th October – 7th December 2017. **8a** Sensor comparison is TC12 and TW12 (ceiling and indoor wall not covered by green wall/roof) with **8b** depicting the readings from sensors TC11 and T11 (ceiling under green roof and indoor wall behind green wall, respectively).





Figures 9a (top) and **9b** (bottom) Comparison of latest QUT collected temperature data and BoM Amberley data from 7th October – 7th December 2017. **9a** sensor comparison is TW01 and TW02, two different places on the green wall. A decrease in maximum temperatures is shown for TW01 as plant growth shades the sensor (TW02 is already shaded by vegetation cover). **9b** shows that temperature recorded on the demountable building bare wall is much higher than what is being recorded by the BoM sensor.



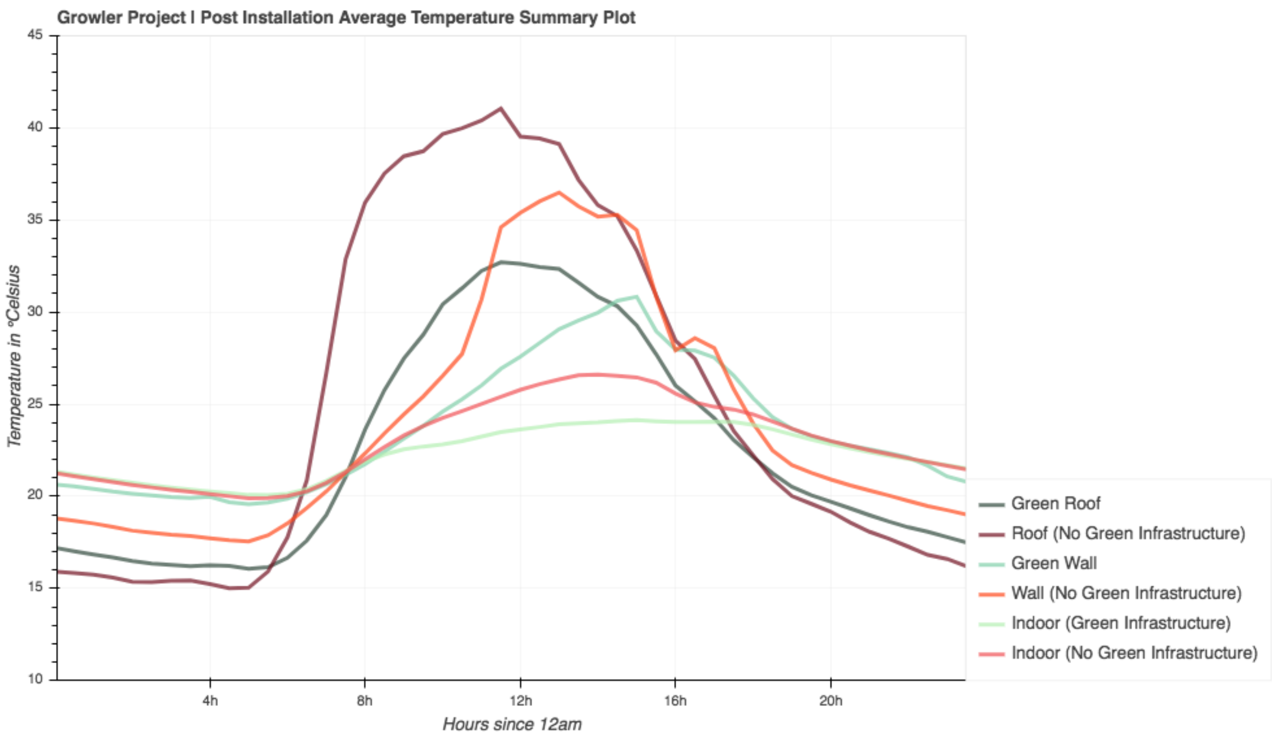


Figures 10a (top) and **10b** (bottom) Comparison of latest QUT collected temperature data and BoM Amberley data from 7th October – 7th December 2017. **10a** sensor comparison is TV01 (green roof / roof void) and TV02 (green wall / wall void). On average, TV01 reported higher temperatures than TV02, with both sensors reporting higher temperatures than the BoM. **10b** sensor comparison is TR01, TR02 (both in different places on green roof) and TR04 (on the bare roof beside the green roof). The colours on the graph make it difficult to ascertain, but TR04 reported the highest temperatures and largest fluctuations.

Key findings from the temperature data during the period of 7th October 2017 – 7th December 2017:

- Sensors W11 and TC11 (indoor wall behind green wall and ceiling under green roof respectively) were on average higher than the BoM temperatures by 0.92 and 1.03 degrees Celsius respectively.
- Sensors TW12 and TC12 (indoor bare wall and ceiling under bare roof respectively) temperatures were on average higher than the BoM by 1.17 and 2.14 degrees respectively.
- Green roof and green wall reported lower mean temperatures and a narrower temperature range (refer to 'Standard Deviation' column in Table 2). In the absence of detailed energy modelling, this data appears to establish that the green wall has a demonstrable effect upon the building's temperature stability
- The bare wall and roof experienced larger temperature fluctuations between maximum day temperature and minimum night temperature. This can be observed from both the mean and standard deviation and with reference to the graphs

Data from latest collection from 7th October 2017 – 7th December is summarised in Figure 11 and Table 3.



Figures 11 Summary plots of the mean hourly temperature over the last data collection period normalised over different surfaces

Table 3 Summary statistics of the last data collection period normalised over different surfaces

Surface	Mean Temperature	Standard Deviation
Green Roof	22.57	7.21
Roof (No Green Infrastructure)	25.33	11.22
Green Wall	23.64	4.63
Wall (No Green Infrastructure)	23.98	7.76
Indoor (Green Infrastructure)	22.31	2.38
Indoor (No Green Infrastructure)	22.99	3.05

Acoustic monitoring

Sensors were deployed at the next available site visit on the 7th December 2017 and the only set of data collected was at QUT's last site visit on the 15th December 2017. Though this only provides one week of data, preliminary analysis has shown:

- Noticeably lower average sound level detected in the Manager's room during periods of increased noise (i.e. during working hours) and;
- Though highly variable depending on the source of noise and its location in relation to the sensors, there appears to be a dampening effect when peak sound level measurements are in medium range. This effect appears to become increasingly mild as the sound becomes more intense.

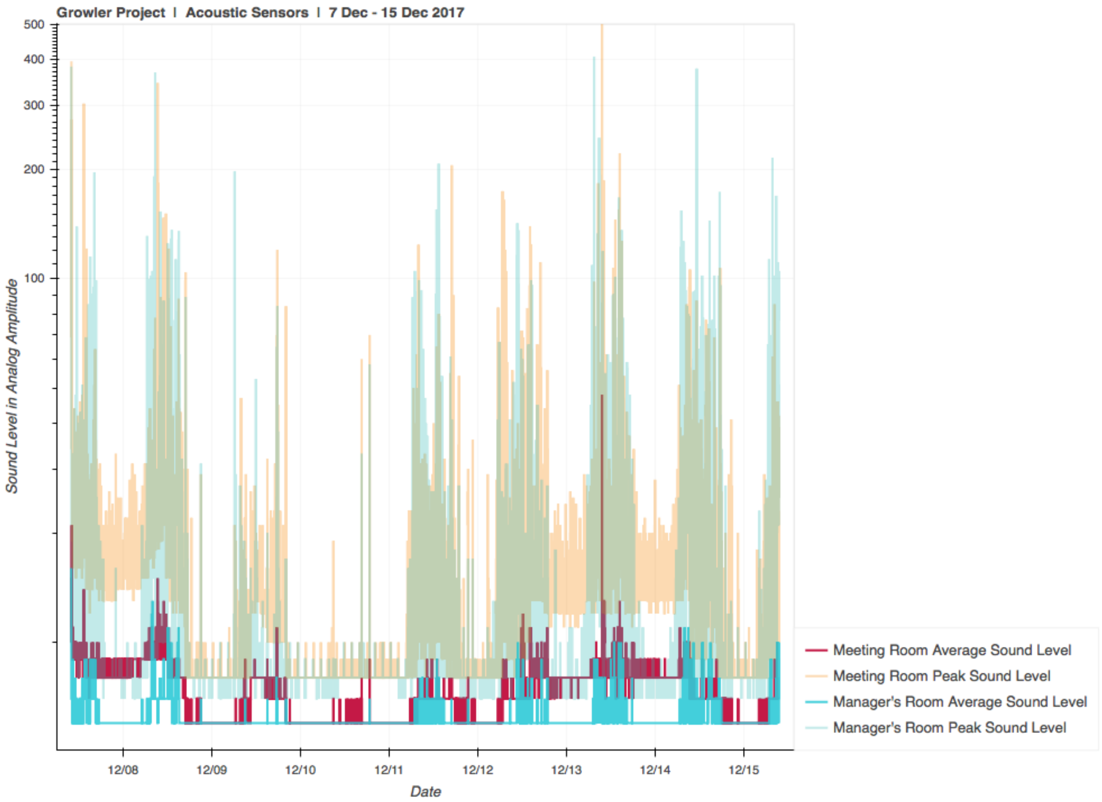


Figure 12 Acoustic data comparison of Manager's room (green infrastructure) and meeting room from 7th Dec – 15th Dec 2017.

Evaluation and discussion

This report has outlined and detailed the findings and outcomes of this project including survey, temperature and acoustic data. The project was subject to many personnel changes, initial ethics delays prior to survey dissemination, installation of green infrastructure delays, delay in obtaining long term access onto the RAAF airbase and equipment failure resulting in replacing all temperature sensors and rebuilding acoustic sensors. Despite these delays however, the team managed to collect approximately six months of useful temperature data from the *TinyTag* temperature sensors and one week's worth of preliminary acoustic data.

The survey participant sample size was too small to collect significant data and there seemed a general disinterest in completing the survey. Initially, many participants seemed skeptical of the green infrastructure prior to installation; however, post-installation many employees were interested in the project. During site visits, both QUT and Grow Collective employees were asked how the green infrastructure is going, commenting on how good it looks and mentioning that they have seen birds and insects (primarily bees) visiting the green roof and wall. The spike in interest prompted Grow Collective to design and install an information board beside the green wall detailing the potential benefits of being in contact with nature, how the green infrastructure was designed and made, and why temperature is being monitored.

The temperature data from the *TinyTags* is showing positive results that the green infrastructure is working to reduce the amount of heat from outside going inside the building. A quick scan of the data shows that there is a significant temperature difference between the readings on the bare wall as opposed to temperature recorded on the green wall. Comparing temperature filtered through the green roof and wall to the void and the temperature on the inside is also showing significant results that the green infrastructure is indeed cooling the inside room. Moreover, the temperature variability of the surfaces seems to be better for green infrastructure as indicated by lower deviation of the collected data. A thorough analysis has not as yet been completed but when it is, the research team will aim to publish these results in a journal article.

The sample of acoustic data was only small as the sensors were only rebuilt and deployed towards the end of the project. It is still very early to analyse the results, and more data and information is required (e.g. what times do the planes fly over to compare specifically at those times, how many people are in the room at the time). If Grow Collective takes over the monitoring, QUT will aim to deploy another acoustic sensor on the outside of the building as a control.

As previously noted, all temperature and acoustic sensors have been left on site with the intention to hand over data collection to Grow Collective. They intend to continue monitoring for at least another six months, totaling one year of data collection. This will continue to be discussed and QUT intends to still be involved and continue communication with Grow Collective as the results will aim to be published.

QUT have identified potential for future research:

- Impact of green infrastructure on energy performance
- Life cycle cost analysis of green infrastructure
- Performance assessment for different plant species

Future research identified for the green infrastructure from Grow Collective:

- Maintenance of green infrastructure: man hours, resources (water), harvested waste (biomass)
- Plant tissue samples: determine absorption / uptake of carbon and airborne pollutants and air quality
- Storm water mitigation: investigate impact green roof has on storm water runoff
- Plant trials: investigate replanting with alternate species to build a library of native and exotic 'low' maintenance plants
- Leaf area index: investigate which plants and density offer the best relief from heat radiation

Scientific refereed publications

None to report.

Intellectual property/commercialisation

No commercial IP generated.

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Appendices

Appendix 1 Survey statements for post-installation survey.

Statement	Description	Relevant Literature
Health and Well-being		
1	When stressed, viewing or being in nature helps me to relax.	Ulrich, 1979
2	When stressed, viewing or being in nature helps alleviate mental fatigue.	Kaplan, 1995
3	When stressed, viewing or being in nature helps promote work productivity.	Larsen et al., 1998
4	When stressed, viewing or being in nature makes me feel motivated.	
5	Viewing or being in nature helps me more when I am stressed as opposed to just tired.	Ulrich, 1981
6	Being in nature when I'm not stressed can sometimes make me too relaxed, unproductive or unmotivated.	
7	Spending my break inside or in an urban setting can make me more stressed.	Ulrich, 1981
Environmental Perception		
8	I care about having a view of nature from my desk or on my break.	
9	Having a view of nature from my desk or on my break is important to me.	
10	I actively seek to spend my break in nature or viewing nature.	
Environmental Aesthetics		
11	I prefer to have a window rather than no window near my work desk.	Tennessen et al, 1995
12	I prefer viewing nature from a window than an urban scene e.g. city traffic or brick wall.	Tennessen et al, 1995
13	Viewing a lively urban setting can be more stimulating than an unspectacular natural setting.	Ulrich, 1981
Opinion of green roof and wall		
14	I like the installed green roof and wall	
15	Installing the green roof and wall was a good idea.	
16	I think it's worth investing money in installing green roofs and walls on dongas.	
17	The green roof and wall makes the donga more visually appealing.	
18	The green roof and wall helps with glare off the building.	