Mainstreaming Low Carbon Residential Precincts: the WGV Living Laboratory

Final Report

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- Curtin University
- City of Fremantle
- Josh Byrne & Associates

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Project Partners

Curtin University LANDCORP JOSH BYRNE & ASSOCIATES City of Fremantle

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Programme

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Publications Arising from this Project

Byrne, J. Berry, S. & Eon. C. (2019), Transitioning to Net Zero Energy Homes – Learning from the CRC's High Performance Housing Living Laboratories. Book chapter edited by Peter Newton et al. *Decarbonising the Built Environment*. Palgrave Macmillan.

Byrne, J. Green, M. & Dallas, S. (2018). WSUD Implementation in a Precinct Residential Development: Perth Case Study. Book chapter edited by Sharma, A. Begbie, D. & Gardner, T. *Approaches to Water Sensitive Urban Design*. Elsevier, UK.

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Breadsell, J. Eon, C. & Morrison, G. M (2019). Review of Behaviour and Practice Theories at Scale in Resource Consumption. Submitted to *International Journal of Urban Sustainable Development*

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Introduction

Project Overview

WGV is a 2.2ha medium density, mixed residential infill development located on a former school site in the Fremantle suburb of White Gum Valley. Delivered by the Western Australian State Government land development agency LandCorp, the structure plan area comprises Lot 2089 Stevens Street (2.1 ha subdivided into 28 residential lots and 11.7% public open space) and Lot 2065 Hope Street (0.16ha City of Fremantle stormwater drainage reserve).

As a LandCorp 'Innovation Through Demonstration'[1] project, the WGV development incorporates many leading urban design characteristics such as diverse building typologies, climate sensitive considerations, solar energy generation and storage, alternative water management and creative urban greening strategies. Civil works commenced at WGV in 2014, with construction of the first buildings starting later the same year. As of September 2019, WGV is approximately 70% built out and occupied. A summary of the housing typologies is provided below and an aerial photograph of the site is provided as Figure 1:

- 22 detached and 1 attached (duplex) Net Zero Energy dwellings ranging in size from approximately 250-350 square metres, responding to 'beyond compliance' design controls.
- Gen Y Demonstration House: Three, one bedroom apartments on a 250 square metre block, with shared solar PV, battery and rainwater system.
- Sustainable Housing for Artists and Creatives: A 12 unit affordable housing project providing for professional artists working in the Fremantle area. The building also includes two shared studios, as well as shared solar PV and battery system.
- Evermore apartments: 24 one, two and three-bedroom apartments with shared solar PV and battery system.
- Baugruppe (construction to commence in 2020): Australia's first Baugruppe project will include 17 apartments and one guest unit, and will test the German model of affordable housing and cooperative living.
- Group housing site (still in planning phase) which will include six energy efficiency survey strata detached houses.

WGV has been the subject of several research projects being led by Curtin University in collaboration with government and industry partners. The development is described as a 'Living Lab'[2] where concepts, technologies and practices are created and tested in a real-life setting. This Report documents the research activities undertaken as part of the Cooperative Research Centre for Low Carbon Living (CRCLCL) research project RP3033: Mainstreaming Low Carbon Residential Precincts – the WGV Living Laboratory[3] which ran between July 2014 and June 2019.

Report Structure

The structure of this Report is based on the CRCLCL RP3033 project activities which included:

- Performance modelling to ascertain the operational energy and carbon emission profiles for the different dwelling typologies at WGV.
- Life Cycle Analysis of a selection of dwellings in the precinct representing different typologies, construction methods and building materials.
- The design and implementation of performance monitoring systems to monitor operational energy and water use across the precinct.
- Data collection and analysis to demonstrate the degree of energy and water savings across the various dwelling typologies compared to local averages.
- Resident engagement to understand the impact of home practice on energy and water use.
- Engagement with the City of Fremantle (local government authority) to share the findings of a planning and design process analysis to identify solutions to barriers to the implementation of low carbon developments.

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[1] LandCorp Innovation Through Demonstration: https://www.landcorp.com.au/Our-Work/Innovation-Through-Demonstration
[2] Morrison, G. Eon, C & Pickles, S. 2017, Fifteen Living Labs across Australia. Final synthesis report on CRC LCL project RP3045: Living Lab Director and Coordination, CRC for Low Carbon Living, Sydney, Australia.
[3] Cooperative Research Centre for Low Carbon Living: http://www.lowcarbonlivingcrc.com.au/research

- Documentation and communication of the WGV Living Lab journey via a 10-part web-based video series.

Each of these activities is presented as a dedicated section in this report; including activity overview, outcomes and references. A list of the academic publications arising from this work is provided on page vii. Additional material, including the WGV Estate Plan is provided in the Appendix.

Figure 1 WGV by LandCorp (Photo credit: VAM Media)

Performance Modelling

Activity Overview

This Section presents the results of performance modelling that was undertaken using the PRECINX modelling tool[4] to provide an indication of the operational energy use and subsequent greenhouse gas emissions (CO_2e) of the three main dwelling typologies at WGV including detached dwellings (single residential houses), attached dwellings (sharing a common wall) and apartments. The modelling compared 'Compliance' versus 'As Designed' scenarios. Compliance case assumptions were based on minimum building performance standards as required under the National Construction Code[5], standard industry practice, and relevant energy usage values (Kinesis, 2019). The As Designed assumptions were based on the WGV Design Guidelines requirements and Sustainability Package (LandCorp, 2015) which relate to detached and attached dwellings, and relevant building and service information for the apartment sites (Kinesis, 2019).

Detached Dwellings

Figure 2 presents the results of energy demand modelling and estimated GHG emissions for an As Designed scenario for detached dwellings at WGV, compared with a Compliance case based performance for a new, comparable size dwelling in the same area. The As Designed assumptions includes 7 star NatHERS thermal performance (i.e. <58 MJ/m2 per annum), a mix of hot water systems, including solar thermal (both electric and gas boosted), along with the specified 3 star air conditioner and LED lighting requirements, and an average PV system size of 3.6kW. The Compliance results are based on 6-star NatHERS thermal performance (i.e. <70 MJ/m2 per annum), gas hot water heating, standard air conditioning (2-star, single phase), and standard lighting. No PV is accounted for.

The estimated annual operational energy demand for the Compliance case on a per dwelling basis is 5,362 kWh, made up of 4,645 kWh of grid electricity and 717 kWh of natural gas (or 2,581 MJ). The resultant calculated GHG emissions is 3,753.4 kg CO_2e.

The As Designed case shows a reduction in overall operational energy demand of 16% from the Compliance case resulting from improved performance across hot water heating, space heating and cooling, lighting and appliances. The energy make-up is expected to be 32% self supply from PV, 56% grid and 11% gas. PV export is expected to average 3,402 kWh/year, which equates to 156% of annual import. The calculated GHG emissions is 1,531 kg CO_2e offset by 156% by the surplus PV export.

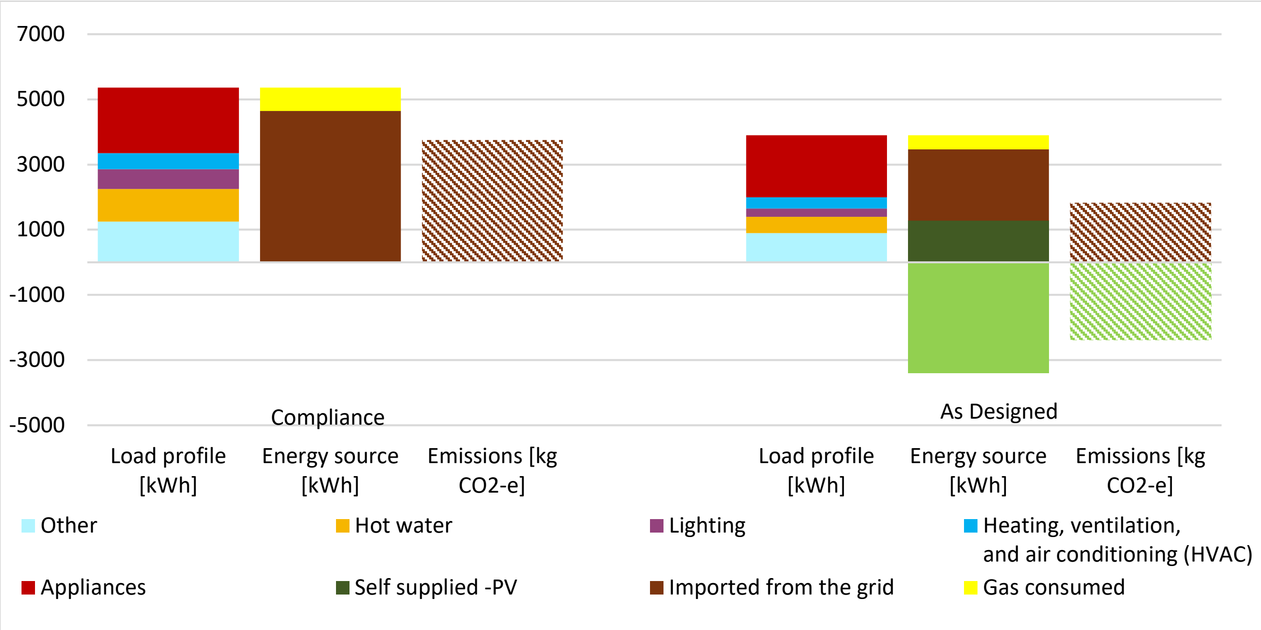

Figure 2. Projected annual dwelling energy demand by load, plus energy sources for the detached lots at WGV, alongside Compliance case. Estimated GHG emissions for each scenario is also provided. (Modelling data source: Kinesis, 2019)

[4] PRECINX modelling tool: https://kinesis.org/ccap-precinct
[5] National Construction Code: https://www.business.gov.au/planning/templates-and-tools/industry-factsheets/national-construction-code

Attached Dwellings

Figure 3 presents the results of energy demand modelling and estimated GHG emissions for an As Designed scenario for attached dwellings at WGV, compared with a Compliance case based performance for a new, comparable size dwellings in the same area.

The As Designed assumptions includes 7 star NatHERS thermal performance (i.e. <58 MJ/m2 per annum), a mix of hot water systems, including solar thermal (both electric and gas boosted), along with the specified 3 star air conditioner and LED lighting requirements, and an average PV system size of 3.6kW. The Compliance results are based on 6-star NatHERS thermal performance (i.e. <70 MJ/m2 per annum), gas hot water heating, standard air conditioning (2-star, single phase), and standard lighting. No PV is accounted for.

The estimated annual operational energy demand for the Compliance case on a per dwelling basis is 11 267 kWh, made up of 10,915 kWh of grid electricity and 352 kWh of natural gas. The resultant calculated GHG emissions is 7,886.8 kg CO_2e.

The 'As Designed' case shows a reduction in overall operational energy demand of 62% from the Compliance case. The energy make-up is expected to be 33% self supply from PV, 60% grid and 7% gas. PV export is expected to average 2,006 kWh/year, which equates to 71% of annual import. The calculated GHG emissions is 2,391 kg CO_2e offset by 71% by the surplus PV export.

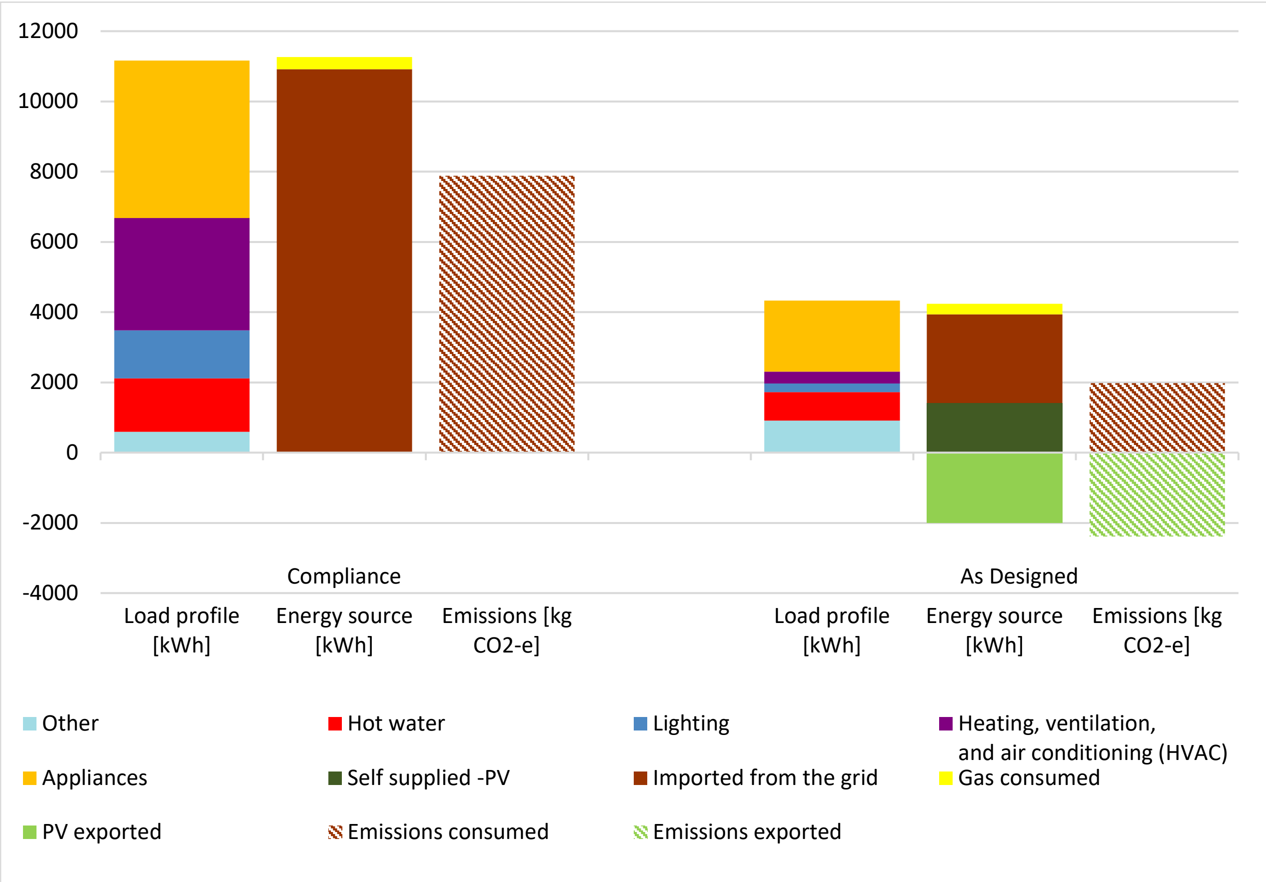

Figure 3. Projected annual dwelling energy demand by load, plus energy sources for the attached lots at WGV, alongside Compliance case. Estimated GHG emissions for each scenario is also provided. (Modelling data source: Kinesis, 2019)

Apartments

Figure 4 presents the results of energy demand modelling and estimated GHG emissions for an 'As Designed' scenario for apartment dwellings at WGV, compared with 'Compliance' based performance for a new, comparable size dwelling in the same area. The As Designed assumptions are based on the average NatHERS ratings, plus specific hot water systems, fixes appliances and PV systems of 39 completed apartments across three buildings. The Compliance results are based 6-star NatHERS thermal performance (i.e. <70 MJ/m2 per annum), gas hot water heating, standard air conditioning (2-star, single phase), and standard lighting. No PV is accounted for.

The estimated annual operational energy demand for the Compliance case on a per dwelling basis is 6,597 kWh, made up of 6,381 kWh of grid electricity and 216 kWh of natural gas. The resultant calculated GHG emissions is 4,335 kg CO_2e.

The 'As Designed' case shows a reduction in overall operational energy demand of 27% from the Compliance case resulting from improved performance across hot water heating, space heating and cooling, lighting and appliances. The energy make-up is expected to be 41% self supply from PV, 53% grid and 6% gas. PV export is expected to average 840 kWh/year, which equates to 33% of annual import. The calculated GHG emissions is 2008 kg CO_2e offset by 98% by the surplus PV export.

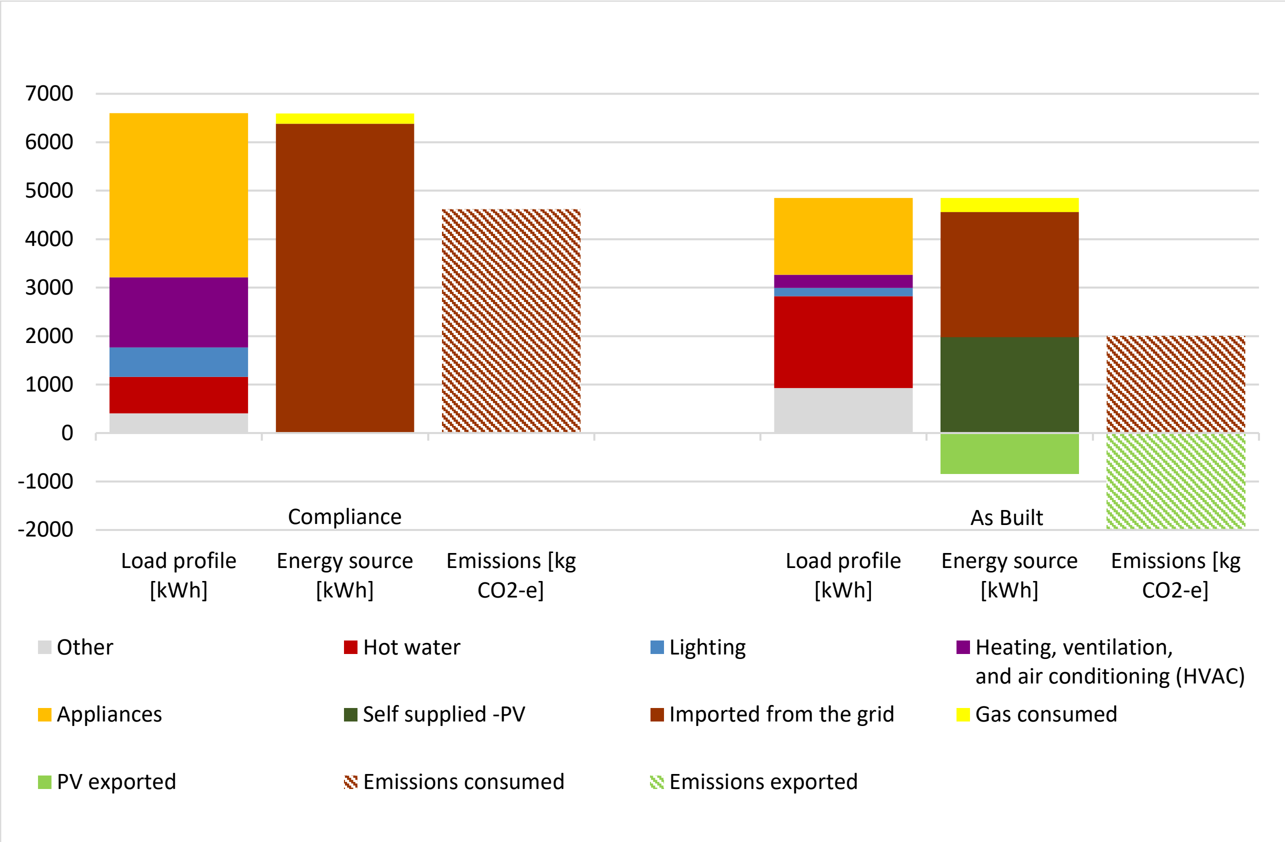

Figure 4. Projected annual dwelling energy demand by load, plus energy sources for the apartments at WGV, alongside Compliance case. Estimated GHG emissions for each scenario is also provided. (Modelling data source: Kinesis, 2019)

Section References

Kinesis. 2019, *WGV PRECINX Analysis Report*, Kinesis, Sydney, Australia.

LandCorp. 2015, *WGV Design Guidelines*, LandCorp, Perth, Western Australia.

Life Cycle Analysis of Selected Buildings

Activity Overview

This Section provides a summary of the Life Cycle Assessment (LCA) undertaken for a selection of residential buildings at WGV, focusing on embodied energy. Five case studies where chosen to demonstrate how different building typologies and construction methods influence carbon emissions over the lifespan of a building. The buildings are of different sizes, forms and occupancy patterns, ranging from a set of three 1-bedroom apartments up to a full sized 5-bedroom family home. Estimated carbon intensity is provided for different construction techniques at different phases of the building lifecycle.

The summary draws on the results of LCA reports prepared by eTool[6] for this project. Details on the scope of their LCA work, including limitations are described below.

Scope

The eTool reports are based on a 'design stage' assessment for the case study buildings and draw on building plans (as prepared for building licence purposes), NatHERS assessment, and other supporting documentation. The values used are eTool template values and have not been specifically monitored or measured during the development of the sites. Details on the specific eTool assumptions, templates and other modelling decisions can be found in the Certifier Review Statement for each site (refer to Section References).

The eTool assessments are conducted in accordance with the following standards:

- IS 14040:2006 (ISO/TC 207/SC 5, 2006a)
- IS 14044:2006 (ISO/TC 207/SC 5, 2006b)
- EN 15978:2011 (CEN/TC 350 2011)

Care should be taken when comparing results across the case study sites, due to the disparate characteristics of the buildings, including occupant density, expected life span, geometry and materials, construction techniques and maintenance requirements.

Site Descriptions

*Site A (*Ngeow, F. 2019a)

Site A is a 2-storey, 3-bedroom detached dwelling (2 main, 1 guest), constructed using concrete slab flooring, a steel frame with combination of SIP panels and brick construction type walls, double glazed windows, and a steel-clad SIP roof. It is a narrow form building, aligned along the north-south axis such that the glazing to the main living areas is to the north and eastern elevations.

Site B (Campbell, R. 2019a).

Site B is a single storey, 1 bedroom dwelling on a split-level block. The garage and storage are on the lower level, with a semi-independent 1 bedroom unit above. It is an insulated timber frame with concrete slab construction, with a combination of steel, fibre cement sheet and timber cladding, double glazed windows and steel roof. It is a narrow form building aligned along the east-west axis, with the glazing to the living areas taking advantage of the northern aspect.

Site C (Campbell, R. 2019b)

Site C is a 2 storey, 4 bedroom detached dwelling with 3 bathrooms and double garage. It is a double brick construction on a concrete slab, with single brick internal walls, low-e single glazed windows and a standard truss-style steel roof. Downstairs consists of the open plan kitchen/living/dining, theatre and guest bedroom, with remaining three bedrooms upstairs. The building is aligned along the east-west axis with the living and kitchen glazing facing north.

Site D (Ngeow, F. 2019b)

Site D is a 2 storey building containing three 1-bedroom apartments. It is a concrete slab on ground with timber frame construction above (including upper cassette floor), with a combination of brick, fibre cement sheeting and metal cladding and low-e single glazed windows. The roof is constructed from steel-clad SIPs. The concrete utilises 30% blast furnace slag to replace cement. The building footprint is U-shaped, such that there is some north-facing glazing to either the living or bedrooms of all three units. In addition to the solar PV array, there is also a 10kWh battery shared between the three units.

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[6] eTool: https://etoolglobal.com/

Site E (Campbell, R. 2019c)

Site E is a 2 storey attached building made up of separate 1-bedroom and 2-bedroom dwellings joined by a common wall. It has a roof garden above the separate, shared double garage. It utilises a concrete slab floor, with recycled rubble rammed-earth walls on the ground floor and SIP walls above. Windows are double glazed in a thermally broken aluminium frame. The roof is constructed from metal decked SIPs. The building is predominantly a single-room deep, aligned across the east-west axis with the main glazing on the north face.

Main Features

Table 1 Summary of LCA case study features.

Feature	Site A	Site B	Site C	Site D	Site E
External Walls	145mm SIPs, 90mm steel studs, brick cavity, reverse brick veneer and single brick	Timber framed with R4.0 insulation	Double brick with reflective foil cavity insulation, rendered on both sides. No bulk insulation	Metal clad/fibre cement clad timber framing and brick veneer with R2.5 insulation and Air-cell Insulbreak 65	Ground floor - rammed earth using recycled rubble, upper Floor - OSB faced SIPs
Internal Walls	145mm SIPs, single brick, 90mm steel studs	Timber stud frame with R2.5 acoustic insulation	Single brick, rendered on both sides	Timber framing with R2.5 insulation	Ground floor - rammed earth using recycled rubble, upper floor - OSB faced SIPs
Floors	100mm concrete slab on ground, 172mm suspended concrete slab, suspended steel frame and suspended timber frame	100mm concrete slab on ground, 100mm suspended concrete slab above garage with R2.5 acoustic insulation	100mm concrete slab on ground, 100mm suspended concrete slab	100mm concrete slab on ground with 30% blast furnace slag replacing cement, and elevated timber frame and cassette flooring with R3 insulation	100mm concrete slab on ground, 100mm suspended concrete slab
Ceiling	N/A – Skillion, no roof space	Plasterboard with R5.0 bulk insulation	Plasterboard with R5.0 bulk insulation	Mostly skillion no roof space, assumed plasterboard where roof space exists with Solarspan above	N/A – skillion, no roof space
Roof	175mm SIP panels and steel framed roofing	Timber frame with Colorbond sheeting, Surfmist finish	Colorbond with ‘medium’ colour finish, ventilated roof space	150mm Bondor Solarspan with R4.1 insulation	150mm SIP panels with Colorbond Surfmist finish
Windows	Double glazing in uPVC framed windows	Double glazed, low e uPVC framed windows	Single glazed, low E, aluminium framed windows	Single glazed low-e aluminium framed windows Single glazed low-e timber framed clerestory window	Double glazed aluminium framed windows with thermal break
HVAC	Ceiling fans, in-floor hydronic heating from heat pump	Reverse cycle AC	Reverse cycle AC	Ceiling fans, reverse cycle AC	Ceiling fans and hydronic heating from heat pump

Feature	Site A	Site B	Site C	Site D	Site E
Hot Water	Heat pump	Heat pump	Heat pump	Gas instantaneous	Heat pump
Cooking	Electric cooktop with electric oven	Gas cooktop with electric oven	Gas cooktop with electric oven	Gas cooktop with electric oven	Induction cooktop with electric oven
Lighting	LED throughout	LED throughout	LED throughout	LED throughout	LED throughout
Energy Generation	6.5kW solar PV system	5.6kW solar PV system	Shared 3.85kW solar PV system	Shared 9kW solar PV system with 8 kWh shared battery storage	Shared 6.21kW solar PV system
Water	3kL rainwater tank, bore water for all garden irrigation	5kL rainwater tank, bore water for all garden irrigation	3kL rainwater tank, bore water for all garden irrigation	10kL rainwater tank, bore water for all garden irrigation	5kL rainwater tank, bore water for all garden irrigation

Life Cycle Analysis

The eTool LCA software package provides assessment across seven indicators, including Global Warming Potential, Ozone Depleting Potential, Acidification Potential, Eutrophication Potential, Photochemical Ozone Creation Potential, and Abiotic Depletion Potential. This summary focuses on the GWP.

Global Warming Potential

The GWP of these sites is a statement of the calculated greenhouse gases emitted, reported in terms of the equivalent mass of carbon dioxide that would be emitted to have the same greenhouse impact in the atmosphere. These results provide an indication of what impact the sites have on anthropogenic global warming.

Table 2 eTool LCA results for total GWP of each site and key assumptions.

Item	Benchmark (10 dwellings)	Site A	Site B	Site C	Site D	Site E
Assumed Lifespan (years)	54	30	30	25	90	55
Dwellings	10	1	1	1	3	2
Occupants	24	2	2	4	4	3
Gross Floor Area, GFA (m2)	3,010	294	241	260	488	209
Global Warming Potential, GWP (kg CO_2e / Occupant/Yr)	4,100	1,900	591	2,020	478	670
Global Warming Potential, GWP (kg CO_2e /m2 GFA)	1743	455	164	788	624	523
Global Warming Potential, GWP (kg CO_2e /m2 GFA/Yr)	32	15	5	32	7	10

System Boundary

Figure 5 shows the lifecycle phases that make up the eTool LCA.

Note: B6 'Integrated Operational Energy' includes heating, cooling, ventilating, lighting and water-heating. B6+ 'Non-Integrated Energy' represents all other 'plug loads'.

Note that household vehicle use, domestic waste disposal and food consumption are not included as these are not directly influenced by the building, according to the eTool's assumptions.

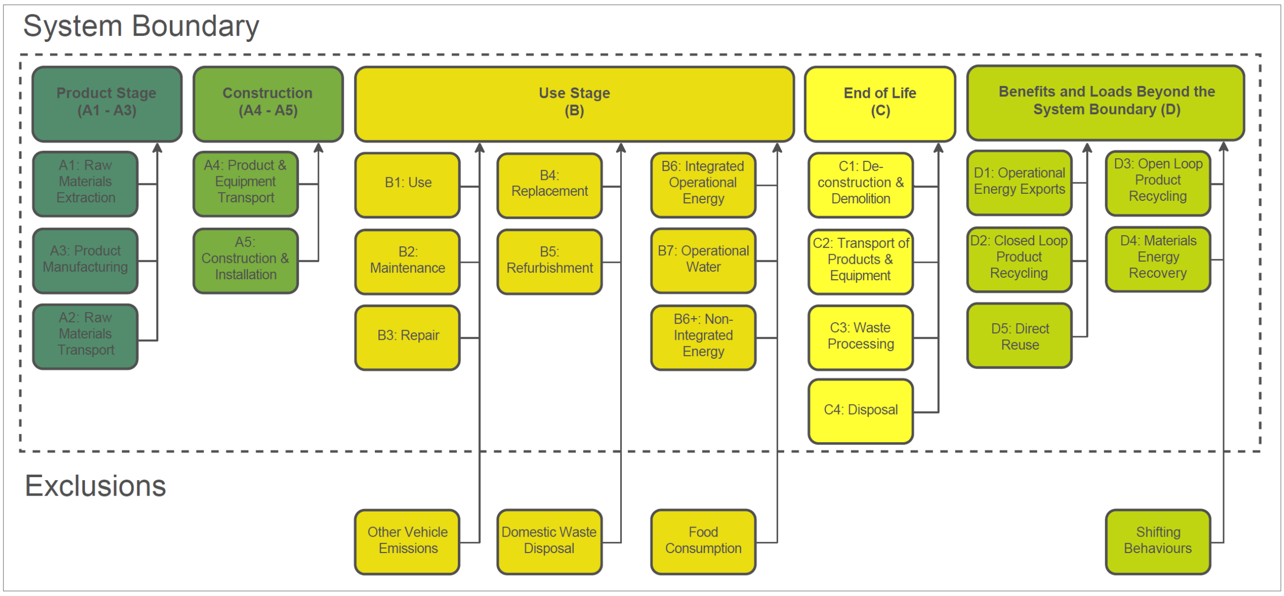

Figure 5 eTool LCA system boundary.

Construction Type and Materials

Flooring

All sites used a concrete slab on ground, and then either a suspended concrete slab, timber or steel frame, or some combination thereof, for the second floor. This is common across the case study sites, however Site D utilises recycled furnace slag to reduce the amount of cement required.

Walls

There are a range of walls used across the case study sites. Table 3 and Table 4 show which construction types are present across each site. Some sites feature more than one wall type.

Table 3 External wall constructions in use across case study sites.

Item	Site A	Site B	Site C	Site D	Site E
Single Skin Brick	✓	×	×	×	×
Double Brick	✓	×	✓	×	×
Brick Veneer	×	×	×	×	×
Reverse Brick Veneer	✓	×	×	×	×
SIP	✓	×	×	×	✓
Steel Clad	×	✓	×	✓	✓
Fibre Cement Clad	×	×	×	✓	×
Timber Clad	×	✓	×	×	×

Item	Site A	Site B	Site C	Site D	Site E
Rammed Earth	×	×	×	×	✓
Reflective Insulation	✓	×	✓	✓	×
Added Bulk Insulation	✓	✓	×	✓	×

Table 4 Internal wall constructions in use across the case study sites.

Item	Site A	Site B	Site C	Site D	Site E
Brick (Single)	✓	×	✓	×	×
SIP	✓	×	×	×	✓
Plaster on Stud	×	✓	×	✓	×
Rammed Earth	×	×	×	×	✓
Added Bulk Insulation	×	✓	×	✓	×

Roof and Ceiling

Table 5 shows the range of roof and ceiling configurations and constructions used across the case study sites.

Table 5 Main roof and ceiling constructions in use across the case study sites.

Item	Site A	Site B	Site C	Site D	Site E
Roof Space Between Ceiling and Roof	×	✓	✓	✓	×
Raked Ceiling/Flat Roof	✓	✓	×	✓	✓
Steel Clad	✓	✓	✓	✓	✓
SIP	✓	×	×	✓	✓
Plasterboard + Bulk Insulation	×	✓	✓	×	×

Carbon Analysis

As the case study sites consist of different building types, sizes, number of dwellings and number of occupants, care must be taken in comparing the GWP of each case site. This report is intended to focus on the GWP related to the built form, thus modules reliant on occupant behaviour have been removed from the analysis. The included modules are shown in Table 6.

Table 6 Modules included in the LCA

Stage	Module	Assessed by eTool	Included in Embodied Analysis
Product	A1-A3	✓	✓
Construction	A4	✓	✓
	A5	✓	✓

Stage	Module	Assessed by eTool	Included in Embodied Analysis
Use	B1	✓	✓
	B2	✓	✓
	B3	×	×
	B4	×	×
	B5	✓	×
	B6	✓	×
	B6+	✓	×
	B7	✓	×
End of Life	C1	✓	✓
	C2	✓	✓
	C3	✓	✓
	C4	✓	✓
Benefits and Loads Beyond the System Boundary	D1	✓	×
	D2	✓	✓
	D3	✓	✓
	D4	✓	✓
	D5	✓	✓

Figure 6 to Figure 8 shows which stages in the lifecycle of the site are the most or least carbon intensive against three different metrics: occupant per year, m^2 Gross Floor Area (GFA) per year and m^2 GFA.

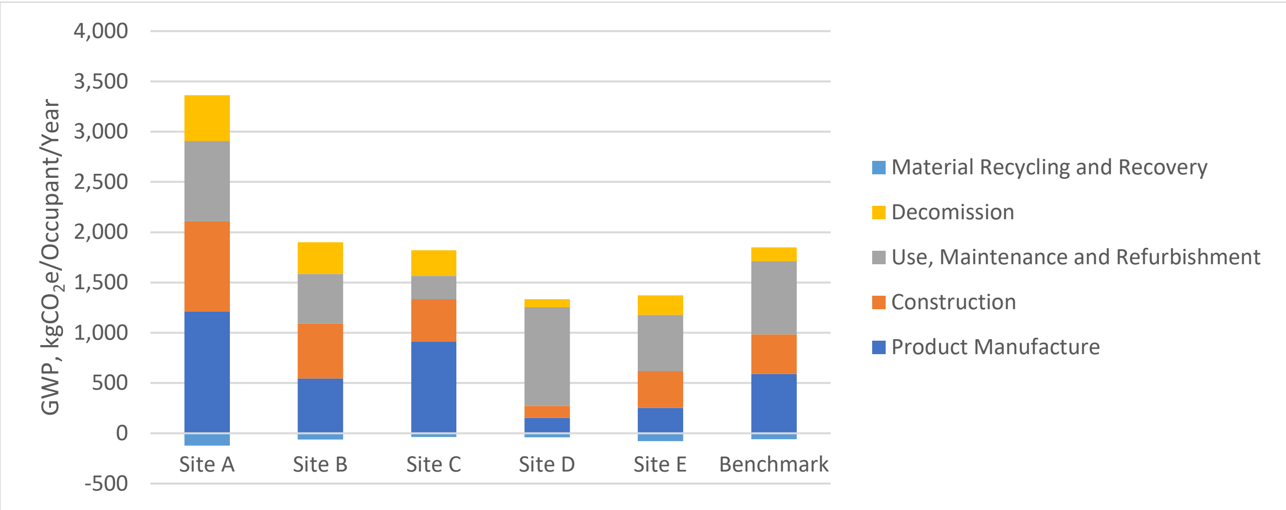

Figure 6 Carbon emissions across case study site lifecycle per occupant per year

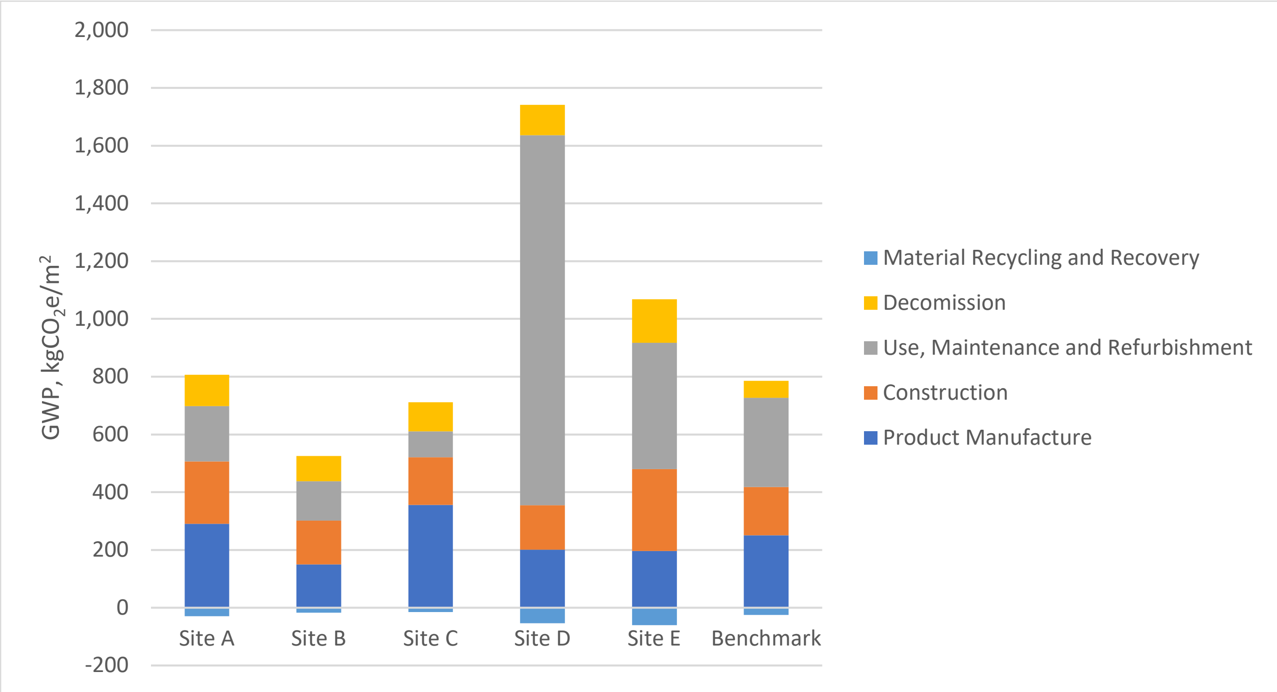

Figure 7 Carbon emissions across case study site lifecycle per m2 GFA per year.

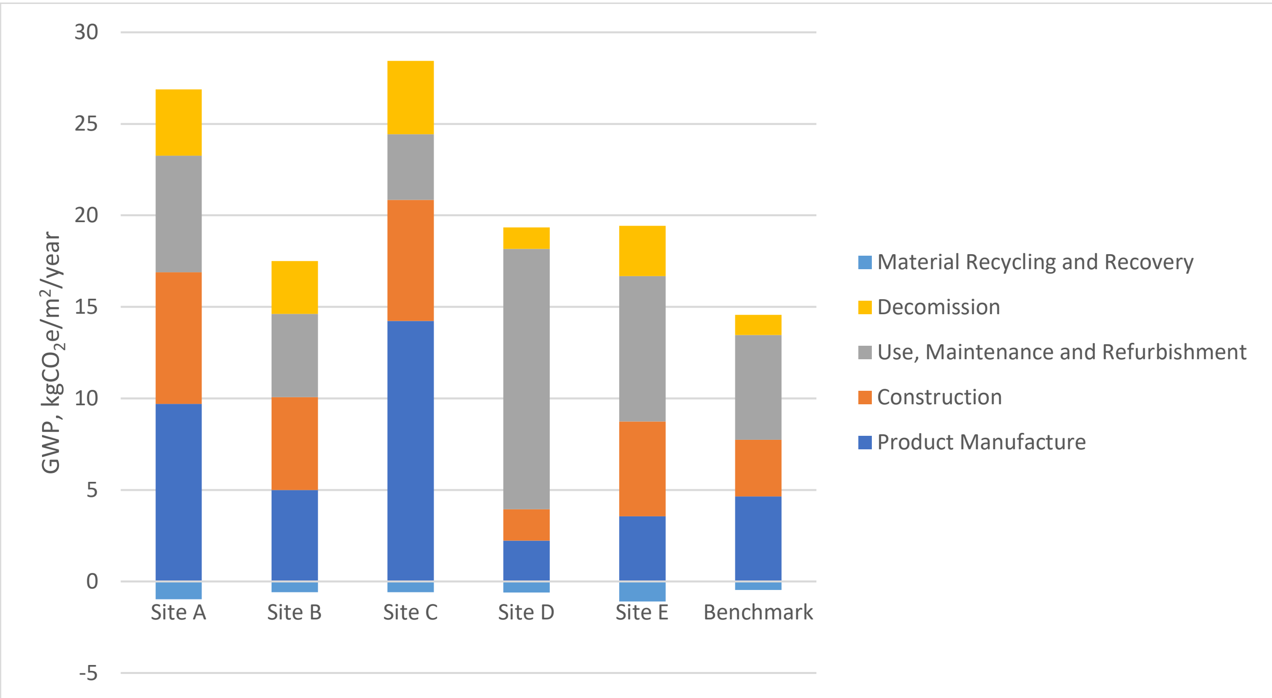

Figure 8 Carbon emissions across case study site lifecycle per m2 GFA across lifetime.

Case study sites A-C are the sites with the shortest lifespans, between 25 and 30 years. Product manufacture, construction and decommission emissions total approximately three times maintenance and replacement emissions for sites A and B, and seven times for site C. While increasing the lifespan of these buildings will ultimately increase the maintenance and replacement energy, it amortises the much larger manufacture and construction emissions over a longer period. This may be a critical element in reducing the overall global warming potential of residential construction projects.

It should be noted at this point, that part of the lifespan calculations for these buildings included 'redevelopment potential' of the site. It is noted that the two multi-dwelling sites, D and E, have longer lifespans than the three single-dwelling sites, A, B and C. There is some concern that the redevelopment potential of the single-dwelling sites may be overstated, artificially reducing the lifespan of sites A, B and C. Given the recent development of the WGV precinct and the relative size of the blocks, it may be argued that the lifespans are overly pessimistic for these buildings. This does not however take away from the point illustrated: increasing the lifespan of buildings may reduce the carbon intensity of residential construction in the longer term, based on a typical level of emissions due to maintenance and replacement.

The decommission stage of the building lifecycle accounts for similar proportions of carbon emissions across each site. This indicates that decommissioning may simply be a standard factor when observing overall impacts.

Material Use

Table 7 and Table 8 show the top five materials used by each site, either by volume or mass. This shows the differences between the sites in terms of construction materials and may indicate whether the building is likely to have a high construction stage impact, and potentially if the impact will be offset during the Use stage, or in offsite benefits.

Table 7 Top five case study site building materials by volume.

Site A		Site B		Site C		Site D		Site E	
Insulation	39%	Insulation	49%	Concrete	23%	Insulation	34%	Bulk aggregates sands and soils	44%
Concrete	25%	Concrete	18%	Bricks, blocks and pavers	21%	Timber	18%	Concrete	23%
Bulk Aggregates Sands and Soils	15%	Bulk aggregates aands and soils	15%	Insulation	20%	Concrete	17%	Timber	15%
Timber	9%	Timber	13%	Bulk aggregates sands and soils	15%	Bulk aggregates sands and soils	15%	Insulation	10%
Bricks, Blocks and Pavers	7%	Plaster and gypsum derived products	3%	Cements and limes	10%	Plastics	8%	Bricks, blocks and pavers	3%

Table 8 Top five case study site building materials by mass

Site A		Site B		Site C		Site D		Site E	
Concrete	46%	Concrete	51%	Concrete	34%	Concrete	39%	Bulk aggregates sands and soils	54%
Bulk Aggregates Sands and Soils	27%	Bulk aggregates sands and soils	41%	Bricks, blocks and pavers	27%	Bulk aggregates sands and soils	32%	Concrete	31%
Bricks, Blocks and Pavers	12%	Plaster and gypsum derived products	3%	Bulk aggregates sands and soils	21%	Timber	11%	Timber	6%
Timber	5%	Fibre board	2%	Cements and limes	10%	Bricks, blocks and pavers	4%	Bricks, blocks and pavers	4%
Steel	4%	Ceramics	1%	Timber	3%	Rock and stone	3%	Steel	3%

Concrete is a major portion of the materials used across all sites, by both mass and volume. As concrete is not a material that is easily recycled, extending the lifespan of the building may be an effective strategy to reduce the life-cycle impacts of the carbon investment made during the construction stage.

Key Findings

- Extending the lifespan of buildings tends to reduce annual average emissions, although maintenance and replacement regimes need to be well understood prior to drawing any firm conclusions in specific cases.
- In these LCA case studies, decommissioning appears a consistent fraction of GWP regardless of construction type.
- Using recyclable materials may decrease the construction phase greenhouse gas emissions of a building.
- Embodied emissions result mainly from construction choices. The ability to offset those emissions during operation may depend on factors such as occupant numbers, behaviour, building lifespan, and other elements in addition to performance improvements resulting from the design.
- Occupancy is a significant factor.

Extending building lifespan is not simply about construction of durable buildings, it is also about planning: understanding how building use may change in the future and designing adaptable buildings. Where building lifespan is necessarily short, high levels of recyclability in the construction and materials choices may present an alternative approach to reducing life cycle GWP. This is highlighted by the fact that redevelopment potential is included in determining the building lifespan for the eTool LCA reports. Getting the most out of buildings that have been constructed is the most efficient way to use reduce the overall impact, regardless of construction materials or dwelling type.

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Performance Monitoring Methodology

Activity Overview

Central to the WGV Living Lab research has been the establishment of monitoring capabilities to enable the collection of data on energy, water and other parameters in an organised and reliable way. This Section provides an overview of these data collection activities, including system design, equipment, data flow and access.

There is a range of performance monitoring activities at WGV fulfilling different purposes. Some activities are long term, for example where monitoring is required for service provision and end-user billing. Others are likely to be shorter term such as data collection for research purposes. In many cases, the equipment deployed to meet the needs of one activity is utilised to fulfil another for efficiency. A summary of the main monitoring activities is provided below:

- Equipment performance assessment by system managers and/or service providers such as strata scale solar energy systems, or the management of the community bore non-drinking water scheme (long term).
- Internal billing of residents for energy and water use by apartment building strata managers, or billing agents (long term).
- Resident feedback on energy and water use via data dashboards (short to medium term).
- Accessing performance data by researchers and industry (short to medium term).

WGV Metering Architecture, Systems and Equipment

The scale of WGV, combined with the staged building construction and different property title types (green title, survey-strata title and built-strata title), meant that an adaptive metering architecture was required. Funding for the metering equipment and servicing has come from various sources, such as the head developer (LandCorp) where the meters were considered essential infrastructure items, from strata lot development proponents where equipment was required for billing purpose, and grant funds where equipment was linked to specific research activities.

From the early planning stages of WGV, consideration was given to how the various metering systems would form an integrated schema to enable the systematic collection of certain performance data from all dwellings, along with other required information from services such as the precinct community bore (JBA, 2017), and environmental data such as groundwater levels and stormwater flows into an infiltration basin located adjacent to the site (Byrne et al, 2018). Figure 9 illustrates the metering and data collection architecture for the site.

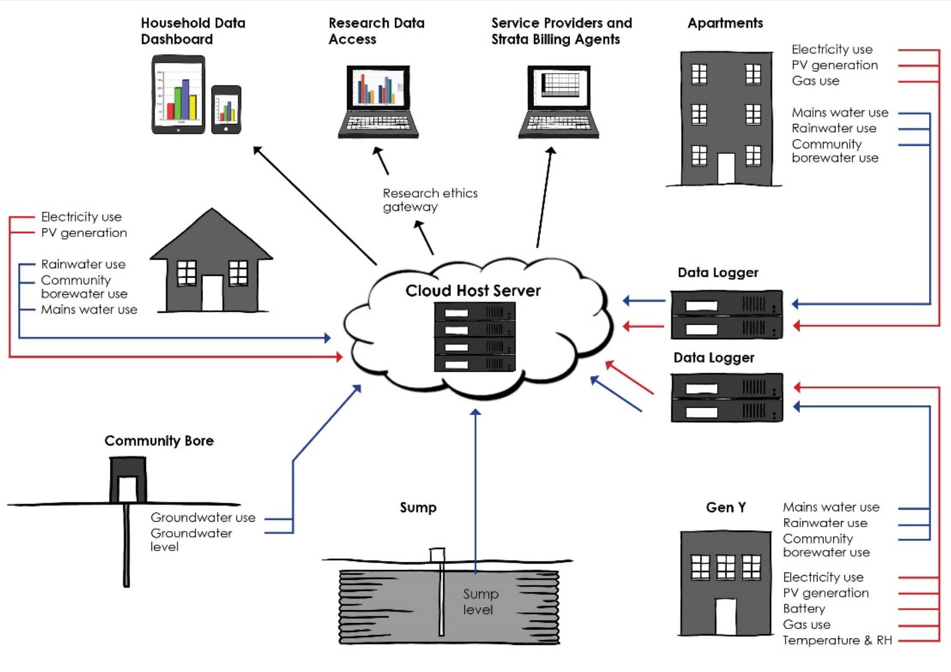

Figure 9 Diagrammatic overview of the WGV data collection architecture.

The following sections describe the specific metering equipment and systems that service the different development sites (detached and attached dwellings, and apartment), as well precinct services such as the community bore, groundwater levels and stormwater basin levels. A schedule of data sources is provided in the Appendix 2.

Detached and Attached Dwellings

Energy and water data is collected from the detached residential sites using individual smart meters and data loggers. Energy use, solar generation and import/export data is collected via the property solar inverter and smart meter systems (typically Fronius[7]) that were installed during house construction and supported by the LandCorp Sustainability Package (LandCorp 2015). The devices are connected to the Fronius server as part of the standard installation procedure. Data can then be accessed via the Fronius API. The Fronius inverters can also be programmed to poll data and push to additional server destinations. Both data transfer methods are currently being used for trial purposes, with the data push being sent to a third party server managed by Balance Utility Solutions[8]. Data telemetry for both methods is via the household's internet service and data intervals are set at 5 minutes.

Water use (mains water, rain water and community bore) is metred via Itron TD8 water meters with cyble sensors connected to battery operated data loggers (WASPs) and transmitted daily via 3G network to a third party server managed by Outpost Central[9]. Data is accessed via Outpost Central's API and data intervals are set at 15 minutes.

Apartments

The metering architecture and convention is similar for the three apartment buildings currently built at WGV (Gen Y, SHAC and Evermore), with the main difference being the number of apartments and types of common services, and therefore the number meters and interface modules (Schneider SIM 10M) required. Each building has a central data logger (Schneider ComX 510) which records energy and water use data (plus gas, indoor temperature and humidity for Gen Y) from each individual apartment, building common services (e.g. lighting), as well as solar energy generation and storage (via the battery management systems). SHAC and Evermore also have additional meters for monitoring electric vehicle (EV) charging points.

Three types of energy meters are in use. Apartment energy consumption is metered using KMP1-50 energy meters cabled to the data logger or SIM devices using digital connection. Grid import/export is measured using an IEM3255 bidirectional 3 phase meter connected to the logger via Modbus RS485 RTU protocol. Schneider IEM3350 and IEM3255 energy meters are used for monitoring the EV charging points at SHAC and Evermore respectively. All energy meters are NMI compliant so are suitable for billing purposes.

Apartment water use is measured via either Itron TD8 or Elster V100 water meters fitted with cyble sensors and pulse kits respectively, and either cabled to the data logger, or SIM devices using digital connection.

The Gen Y building is serviced by gas (for cook tops and hot water systems), with each apartment having its own gas meter (Ampy 750) which is fitted with a pulse kit and connected to either the data logger or SIM device by digital connection. Each Gen Y apartment also is also fitted with a temperature and humidity sensors (Kimo TH110) in the main living area which use ZigBee wireless communication protocol to communicate with receivers connected to the data logger or SIM devices digitally.

Data is transmitted daily to a cloud hosted server managed by Balance Utility Solutions[10] via each building's internet connection. Current data resolution is set at 15-minute intervals.

A summary of the meters and sensors in use at the WGV apartments is presented in Table 9.

Table 9 Meter types for the WGV apartment buildings.

Unit	Electricity Meters	Water Meters (submeters)	Gas Meter	Temperature & Relative Humidity Sensors
Gen Y	KMP1-50 (Apartments) IEM3255 (Grid/Overall Load)	Itron TD8 with cyble sensor	Ampy 750 with pulse kit	Kimo TH110
SHAC	KMP1-50 (Apartments) IEM3255 (Grid/Common area) IEM3350 (EV Charger)	Itron TD8 with cyble sensor	NA	NA
Evermore	PMC-220 (Apartments) IEM3255 (Grid/Overall Load) IEM3255 (EV Charger)	Elster V100 with pulse kit	NA	NA

[7] Fronius: https://www.fronius.com/en-au/australia
[8] Balance Utility Solutions: https://www.balanceservicesgroup.com.au
[9] Outpost Central: http://outpostcentral.com
[10] Balance Utility Solutions: https://www.balanceservicesgroup.com.au

Note: PV, battery output and battery state of charge data is sourced via the building battery management systems associated with each building.

Figure 10 illustrates the general monitoring arrangement for the WGV apartments.

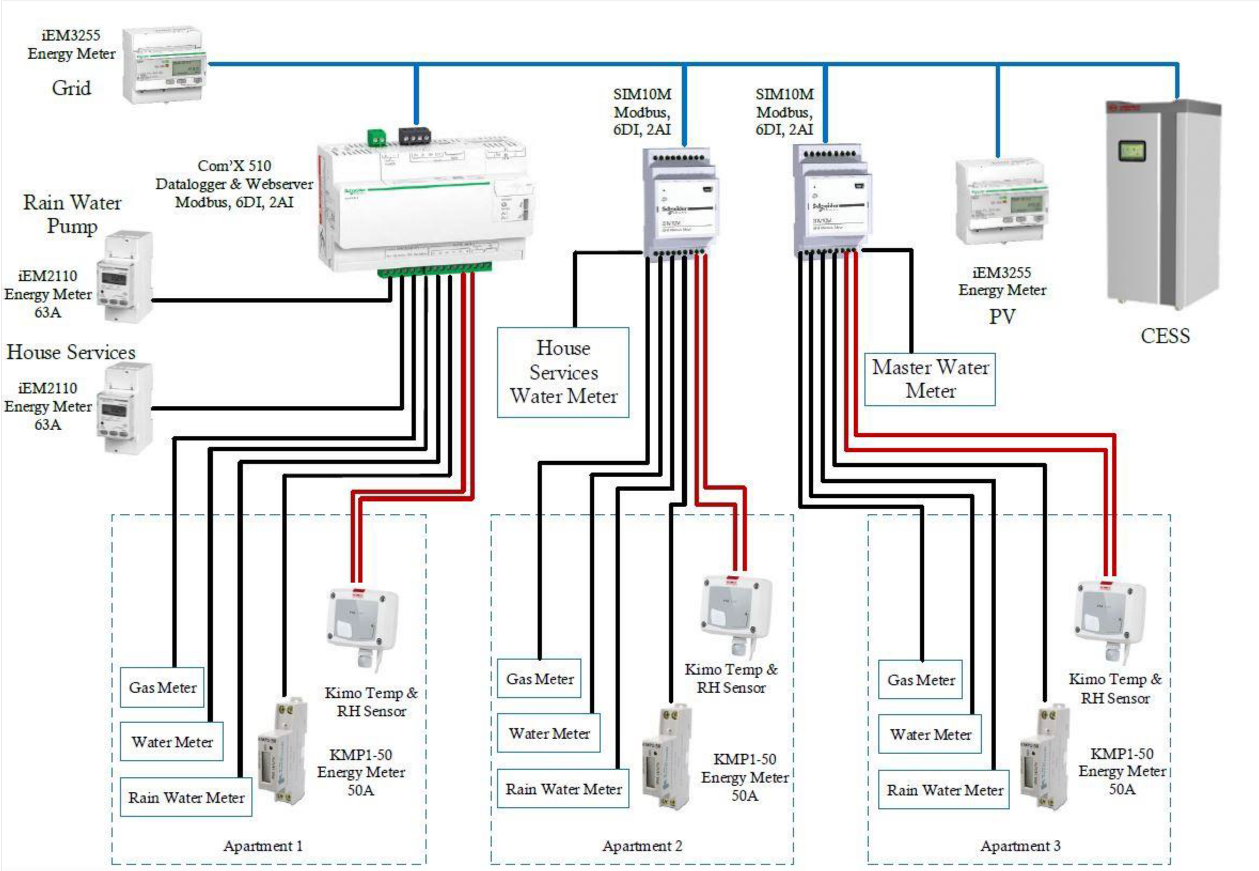

Figure 10 Schematic sensor arrangement for the WGV apartment sites (Lot 7 – Gen Y example).

All sites at WGV are serviced by a non-drinking water community bore irrigation scheme which was installed by LandCorp and is now managed by the City of Fremantle. Each lot connection is metred using an Itron TD8 water meter with cyble sensor which is monitored via a standalone battery powered data logger (WASP) with data transmitted daily by 3G to a cloud hosted server managed by Outpost Central. Each apartment's mains water property meter is also individually logged via this approach.

Community Bore and Stormwater Basin

The community bore has a main meter installed to monitor overall volumes. There are also water level sensors (Mercoid Series SBLT2) installed in the bore hole to monitor groundwater levels and in the stormwater sump to record inflow levels inside the underground drainage cells. Data is collected via a series of separate battery powered data loggers (WASPs) and transmitted daily via 3G network to a cloud hosted server managed by Outpost Central. Data intervals are set at 15 minutes.

Additional submetering is in place to record the balance of groundwater usage between public open space areas and private (on lot) usage, as well as pump energy use, however these are directly connected to the WGV community bore scheme irrigation controller which is managed directly by the City of Fremantle. Data can be accessed remotely as required.

Data Management and Visualisation

Data Flow Path

Figure 11 shows the data flow path from source to remote server where it is stored, processed and used for various applications such as dashboards and research (see following sections), or made available to third party service providers such as billing agents. As described in previous sections, data is collected from various meters and sensors, logged at the building level, or via individual device loggers, and transmitted either directly, or via a third party platform to a remote server hosted by Balance Utility Solutions running a proprietary database and dashboard application (Schneider Power Monitoring Expert, or PME). PME software provides a number of different applications for data processing, dashboard display and user management services. It also works as a bridging platform between a Structured Query Language (SQL) database and offsite devices.

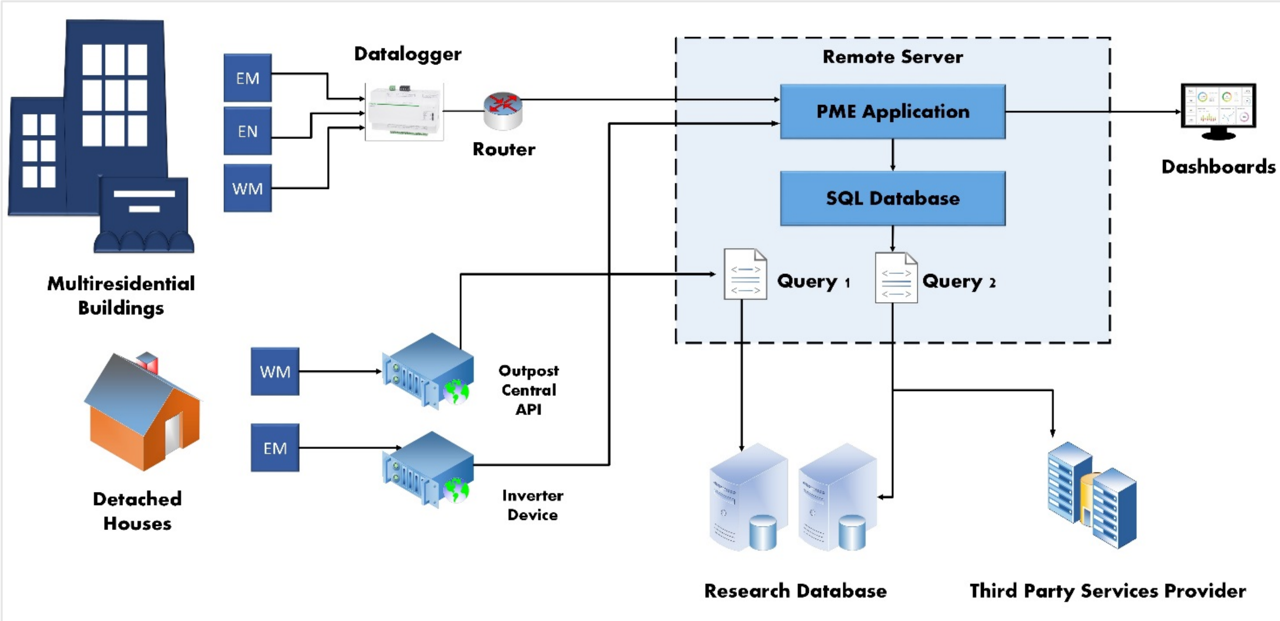

Figure 11 WGV data flow schematic from field sources to end use.

Data Dashboards

At WGV the PME platform has been used to create 'dashboards' to display real-time data collected from the various sources in a way that makes it easy to visually interpret. The intention is that these dashboards can be used by building strata managers to monitor common services usage, as well detect leaks and other issues which may otherwise go unnoticed. Likewise, the dashboards enable services providers to check that systems are working as intended. Finally, the dashboards can be utilised by residents to monitor their household energy and water use to identify problems with equipment, avoid wastage and potentially reduce the size of their bills.

Each WGV resident is being set up with their own private dashboard. Residents of the apartment buildings also have access to a 'building' level dashboard which provides information about the overall building such as the performance of the shared energy system and energy and water use averages across the apartments. Examples of the dashboards are shown in Figure 12 and Figure 13.

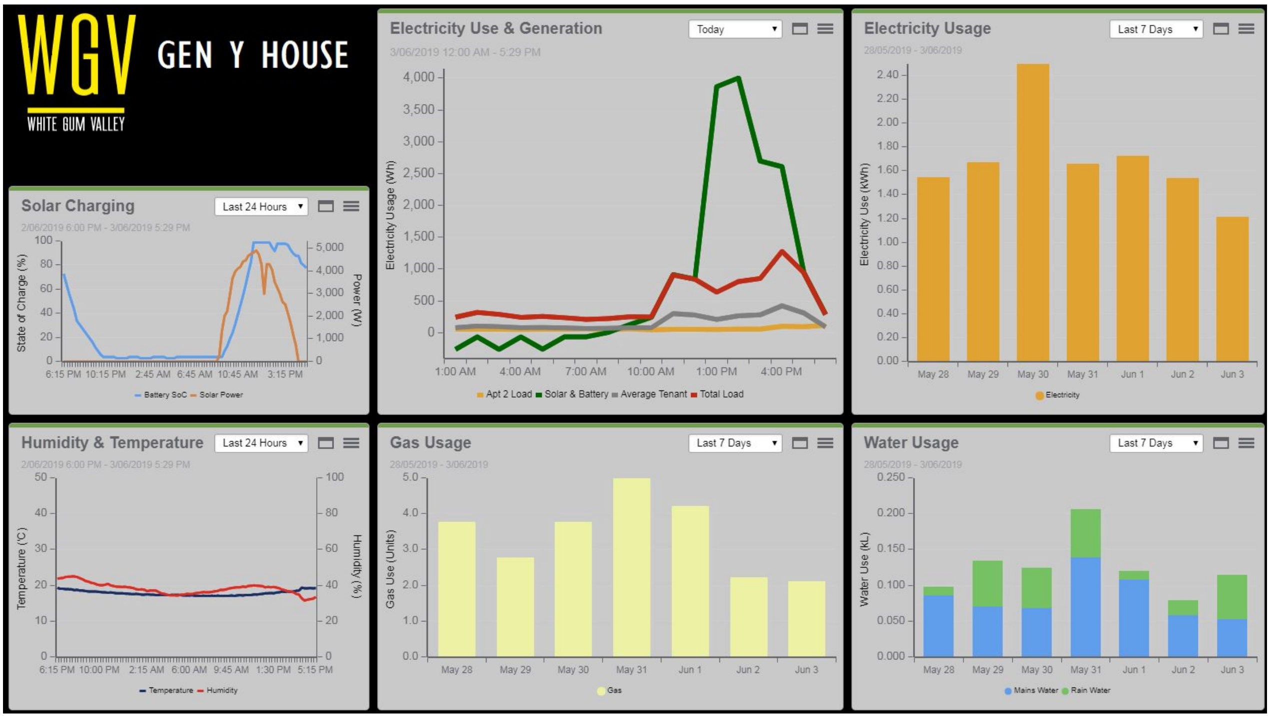

Figure 12 WGV resident dashboard showing apartment-level data.

Figure 13 Resident dashboard showing building-level data.

WGV Research Database

The monitoring system and the personal dashboards discussed thus far are primarily designed and built to meet the needs of service providers (for management of services and billing) and residents (access to dashboards). In this section the data infrastructure that was designed and developed to suit the requirements of academic research is presented. The research requirements are in many ways similar to the needs of the residents. For example, regular and high precision meter readings benefits both residents and researchers alike, allowing intra-day trends to be observed, which are particularly relevant for detecting and understanding short lived consumption patterns such as cooking. However, the velocity of those individual measurements reaching researcher workflows is less critical. For example residents are likely to be interested in knowing the impact certain actions in real-time (or near real-time). This is reflected in the database requirements below.

Database Requirements

As previously described, data is acquired on multiple channels, across multiple devices, all physically distributed across many sites. For researchers to be productive, complete datasets need to be available spanning the various original data sources through to a single database. This database needs to be easily accessed, and access carefully managed in accordance with the Curtin University research ethics requirements and research participant consent. The specific requirements are listed below:

- There should be a single location that researchers can find all data relating to this wider project.
- Ability for data to be retrieved and utilised in CSV format.
- Data should be grouped and sensibly labelled to enable logical navigation and selective downloading of data.
- Parameters can be set to eliminate spurious data that may result from equipment faults.
- Alerts for major faults should be automated – i.e. transmission breakdowns.
- Able to be queried to extract specific data requirements.
- Deidentified in line with Curtin University Human Research Ethics approvals.
- Controlled access via password protection in line with Curtin University Human Research Ethics approvals.

Data Flow and Integration

Figure 14 provides an overview of the research data workflow. The workflow is best understood as three distinct phases, each addressing a specific set of requirements. The first phase is ingestion, the second is validation and indexing, and the third is exploration and visualization.

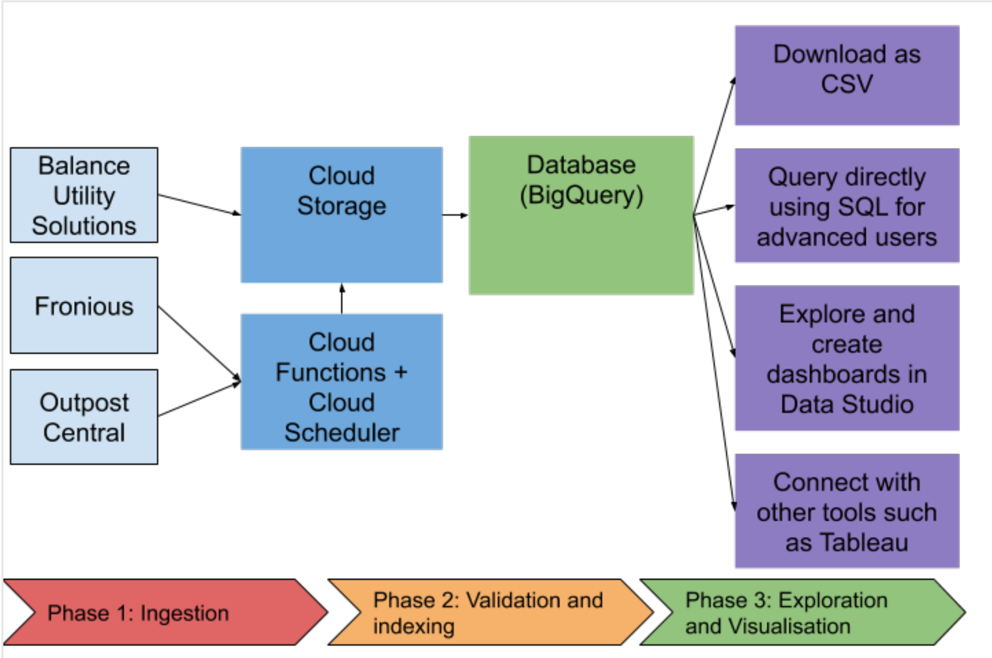

Figure 14 WGV research data workflow.

Ingestion

The primary goal of this phase is to provide a highly available, secure and low maintenance mechanism for receiving the data from third party sources (Balance Utility Solutions, Fronius and Outpost Central). As outlined in earlier sections, Balance Utility Solutions provides the data for the multi-residential lots, while both energy and water data for the detached lots (and some precinct scale items) is obtained directly from Fronius and Outpost Central respectively. Functionality built in partnership enables data to be 'pushed' from Balance Utility Solutions and 'pulled' from Outpost Central and Fronius (via API). Both of these mechanisms are described below, but first the commonalities across all data feeds are presented.

Whether the data is pushed or pulled, it is always saved to Google Cloud Storage. This service, which is very similar to AWS S3, provides a highly available (the underlying servers will always be available), automatically backed up (no additional overhead to manage), secure (all data is encrypted and has access controls put in place) and elastic (there is no storage limit, nor must disk space be provisioned in advance) location to save all incoming data. The next step for all data is to then be ingested into a Google BigQuery SQL database. The details of this step are described in the following section, and it is here where additional data quality and assurance steps are implemented. The reason to not load the data directly into BigQuery, and to use Cloud Storage as an intermediate step, offers both a second location for the raw data (should any unforeseen issue effect the database, the raw data can be reloaded) and also a staging location that allows additional validation checks (or potentially corrections) to be made to the data before ingestion into the database. The three integrations with the project's data partners are now presented:

- Balance Utility Solutions (data is pushed from their servers).
- On Balance Utility Solutions server, a lightweight command line utility was installed that manages the data transfer from their server to a receiving Cloud storage bucket. This utility is able to retry and restart transfers that fail, and importantly encrypts all data in transit.
- With regards to securing access to the receiving storage bucket, Balance Utility Solutions was provided a secure cryptographic key that allows them to upload data. By keeping this key private this ensures that only Balance Utility Solutions is able to upload data. Additionally, this key only allows write access, and does not permit balance to download any data or modify it. This provides an extra level of assurance should the key be lost or stolen.
- Lastly, and as shown in Figure 14, a clean folder structure was initiated for saving data. Data from each location is stored in separate folders, and then further broken down by date. Currently, data is sent every 30min as a CSV file that containing records sampled at 15 minute intervals. This design is flexible though, should there be any issues with the Balance Utility Solutions server, files can be sent that contain records from a much longer period of time.
- Fronius and Outpost Central (data is pulled from their servers).
- In contrast to Balance Utility Solutions, code was written for fetching data from both Fronius and Outpost Central. For both, user accounts and private passwords are used for authentication.
- The environment used to run the code are built on two services called Google Cloud Functions and Cloud Scheduler. The later, schedules the data ingestion once a day at a scheduled time. The former spins up a small server (2GB RAM, 1 CPU) for a

period of a few minutes. This is the time taken to make a connection to partners servers, and make a request for the water and electricity data from the previous day.

- The data that is returned from Fronius and Outpost Central is then saved into Cloud storage, which at this point the process from this point onwards matches the apartment data that is pushed from Balance Utility Solutions.

Validation & Indexing

This phase is all about maximising the usefulness of the data. This is achieved via three mechanisms: Firstly, validating the schema of the incoming data is correct and the fields all contain sensible values, secondly checking and the number of records expected for the day is within accepted levels and then thirdly, by loading the records into a managed database (with clearly defined schemas and datatypes), the power of SQL can be utilised by researchers to further interrogate date quality and to address any unforeseen issues. Together, these allow downstream analytics to have a certain trust in the data quality.

The key features of this design include:

- At the end of each day, the data from each site is analysed. Firstly, the schema of the CSV files is compared against a template to ensure the correct fields and number of fields are present. Secondly, the number of total rows is counted. The granularity of data being sent by Balance is at 15min intervals. So, at the end of the day, there should be 96 records for each device or sensor being recorded. (15 minutes x 96 measurements = 24hours worth of measurements).
- Thresholds can then be set, sending an email should the number of records drop below a certain amount, or if the CSV files sent do not match the desired schema.
- Lastly, the entire days data is then ingested into a database called BigQuery. This is a SQL database, where data is stored in rows (individual records with timestamps) and columns (the actual values, with a specific data type, such as energy measured in kWh). The two main advantages of having data in a database like this are that it enforces the validity of values, that is if the unit being saved is in kWh, any value that is not a floating-point number cannot be saved in that field, and will raise an error that will be investigated; and secondly the data is automatically indexed, that is, is becomes very quick to ask for filtered sets of data, such as between certain dates, fields with values greater than a set amount, or to only return subsets of the data. These affordances enable exploration and visualization which is discussed next.

Exploration & Visualisation

Exploration and visualisation of the data enables researchers to quickly spot trends and issues, as well as present data for reporting and publishing. The four key means for exporting and working with this data are described below:

- At the most basic, data is able to be downloading as a CSV. Allowing researchers to continue using their existing tools. Importantly, access control is enforced on downloading this data, so first a user must be given permission to export the data. More fined grained control of this access (perhaps only certain fields, aggregations, or slices in time) are able to be setup and enforced too. This will be discussed in the following section.
- Dashboards and charts are able to be created using Google Data Studio. Data Studio is designed to work with BigQuery and is fully hosted (no software needs to be downloaded). Reports created in Data Studio work in much the same way as other Google Docs, Sheets and Slides, and allow multiple people to share and work on these dashboards and charts. Importantly, there is a large, global community of users using this tool. Researchers can benefit from the insights and existing documentation.
- The structured data saved in BigQuery can be utilities from a range of other tools. Tableau for example is commonly used, and can easily be connected with BigQuery.
- Lastly the data is able to be queried using SQL which is the defacto standard for relational databases used around the world from large enterprises to research. Complex, or simple, queries can be written to aggregate, filter and sort and classify data. Additionally, a concept called views can be utilised when allowing someone access to the whole dataset is not permitted. A view is able to aggregate data into less granular units (such as daily, rather than 15 minute) or it could hide, or anonymise certain sensitive or personally identifying fields. Like Data Studio, researchers can benefit from a large existing collection of documentation and tutorials.

Examples of Outputs Using Google Data Studio

Figure 15 is a simple stacked bar chart showing the monthly summed energy usage for apartments, plus common services at one of the multi residential sites at WGV, along with the monthly solar energy generation as a running line. Charts like this can be quickly generated to observe trends.

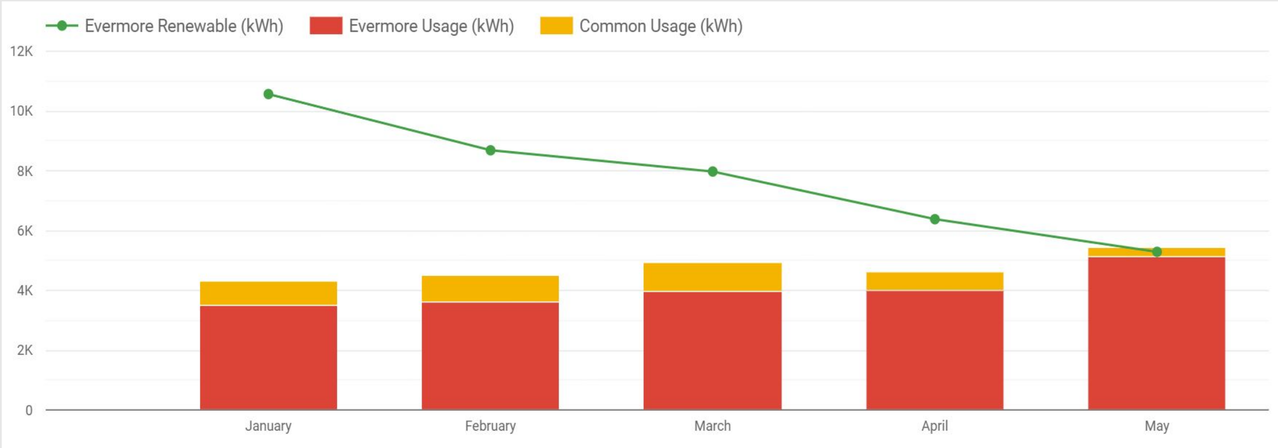

Figure 15 Monthly energy use by sum of apartments and common services, compared with monthly solar generation at Evermore.

Figure 16 shows a heat map table generated to identify outlying values in a particular data set. This is a quick way to identify items of interest, or potential system issues such as the low number of data points received on the 31 May, which can then be investigated.

	timestamp ▾	Record C...	FromGenToGrid	FromGenToConsumer	FromGridToConsumer
1.	May 31, 2019	157	-8,387.9	4,697.21	4,880.7
2.	May 30, 2019	288	-11,301.2	5,482.83	7,067.88
3.	May 29, 2019	288	-16,338.6	6,239.68	7,241.74
4.	May 28, 2019	288	-16,919.4	5,769.14	7,795.47
5.	May 27, 2019	288	-17,210.2	5,654.67	9,919.92
6.	May 26, 2019	288	-17,737.6	5,053.78	9,560.18
7.	May 25, 2019	288	-17,423.25	5,891.63	8,149.35
8.	May 24, 2019	288	-16,040.7	5,448.33	7,491.1
9.	May 23, 2019	288	-8,655.6	4,946.31	10,554.75
10.	May 22, 2019	288	-16,502.2	5,273.69	7,170.3
11.	May 21, 2019	288	-9,849.7	6,307.84	10,674.67
12.	May 20, 2019	288	-13,871.55	5,384.83	10,733.03
13.	May 19, 2019	288	-15,319.25	7,612.04	9,786.07
14.	May 18, 2019	288	-15,615	9,356.11	9,301.4
15.	May 17, 2019	288	-16,283.25	6,708.09	9,496.45
16.	May 16, 2019	288	-4,269	3,804.1	12,218.21
17.	May 15, 2019	288	-12,775	6,106.62	7,627.77
18.	May 14, 2019	288	-18,059.2	5,422.88	6,476.2

Figure 16 Data heat map identifying value outliers.

Security and Data Access

The two key areas of security and access are ensuring only the right people have access to the data, and secondly additional restrictions and deidentification can be applied on data used by authorised users.

The process of ensuring only authorised users can access the data using the following three concepts:

- Permissions: These are based on research ethics approval and research participant consent processes. These permissions define which database tables, or database views are able to been seen or if there is permission to download the data.
- Groups: Groups define certain types of people, and what those types of people should have access to. Such examples would be project researchers such as PhD students who may have research ethics approval for accessing identifiable data, and industry partner who only have permission to access de-identified data. There may also be a group that defines which users have the permission to add users to each group.
- User identities: These can be thought of as login credentials. Once a user has an account, they can be added to one, or more, groups.

The process of deidentifying data is also supported, both with respect to removing fields that identify the property in question, but also for aggregating data across multiple detached lots, or across every unit in an apartment block. Both of these techniques are powered by the concept of database views, which was introduced in the previous section. Views are essentially queries in their own right, as explained with SQL where defined queries can perform aggregation across multiple lots and remove columns that contain identifiable information. From here, permissions to access this view is assigned to a group, which in turn contains certain specified people. This allows some groups of have full access to the data (should that be justified) and other groups to only have access to aggregated data, supported by views. There is no practical limit to the number of views, groups, and users added to these groups.

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Performance Monitoring Results

Activity Overview

This Section provides energy and water use data for the dwellings at WGV obtained from the performance monitoring as outlined previously. Results are provided by dwelling type and include comparisons with local bench marks where relevant.

The period of data collection varies between buildings based on time of completion, occupancy and monitoring equipment installation. Where necessary, data has been annualised. The assumptions and qualifiers used for processing data, as well for establishing local bench marks, are provided at the end of this Section.

Energy

Figure 17 presents the daily energy profiles of each typology for WGV, including imports (electricity and gas), self-supplied and export (by solar PV), and the resultant GHG emissions and offsets.

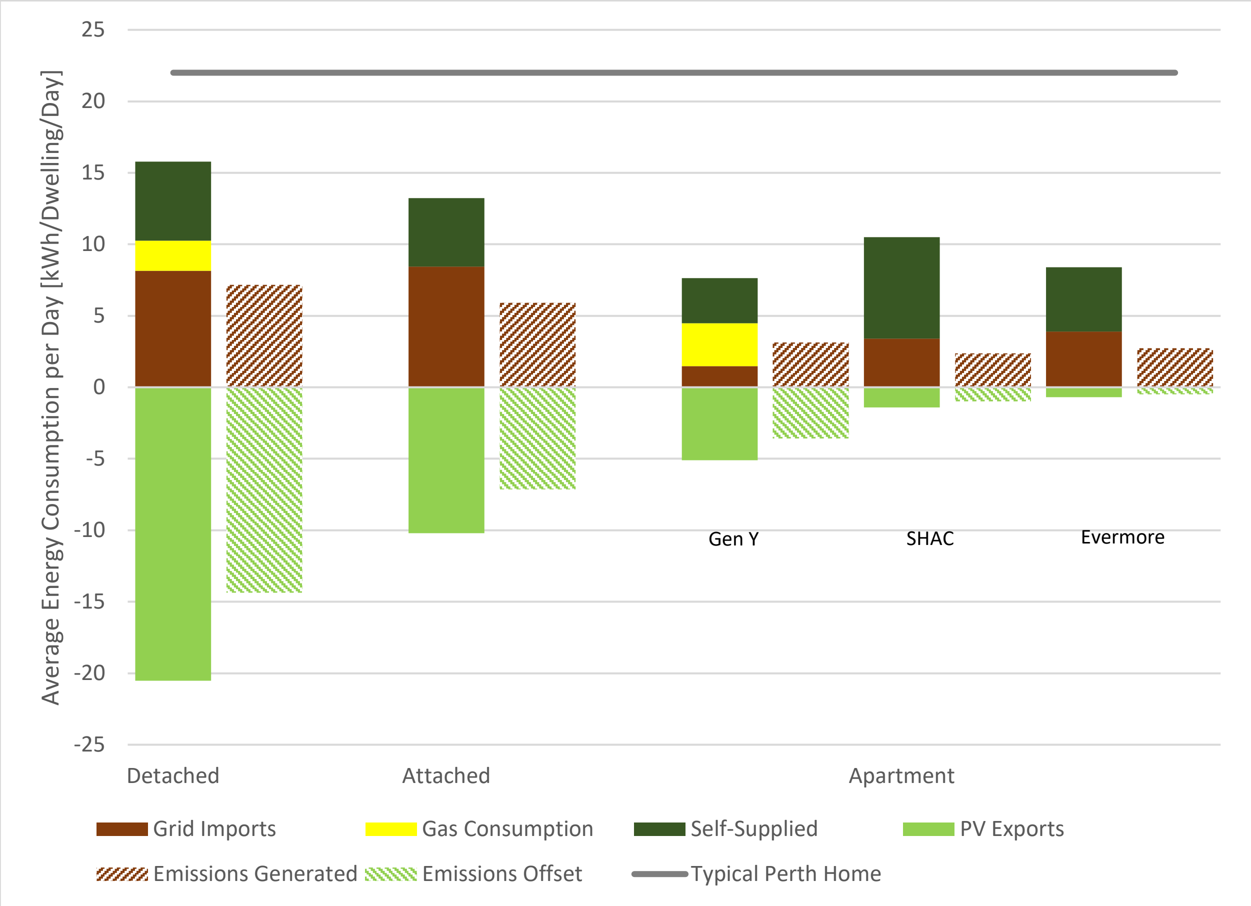

Figure 17. WGV residential energy daily profile by typology and apartment building.

The average detached dwelling has a 3.75 kWp PV system, with an energy demand of 15.7 kWh/day which consists of 5.5 kWh/day of self-supplied energy and 8.1 kWh/day of grid imported electricity and 2.1 kWh/day of gas, whilst exporting 20.5 kWh/day to the grid.

The average attached dwelling has a 2.5 kWp PV system, with an energy demand of approximately 13.2 kWh/day consisting of 8.4 kWh/day of self-supplied and 4.8 kWh/day of grid imported energy, whilst exporting 10.2 kWh/day to the grid.

Gen Y consists of three dwellings with a 9 kWp PV system and a 10 kWh (8 kWh effective) battery system. Gen Y's energy demand is made up of 3.2 kWh/dwelling/day of self-supplied energy, 1.5 kWh/dwelling/day of imported grid electricity and 3.0 kWh/dwelling/day of gas, whilst they export 5.1 kWh/dwelling/day.

SHAC consists of 12 dwellings with a 20 kWp PV system and a 40 kWh battery system. The average SHAC dwelling consumes 10.5 kWh/dwelling/day, made up of 7.1 kWh/dwelling/day of self-supplied energy and 3.4 kWh/dwelling/day of grid energy. SHAC exports 1.4 kWh/dwelling/day back to the grid.

Evermore comprises of 24 dwellings with a 53.6 kWp PV system and a 150 kWh battery system. Evermore apartments consume 8.4 kWh/dwelling/day on average consisting of 4.5 kWh/dwelling/day of self-supplied energy and 3.9 kWh/dwelling/day of grid imported energy, whilst exporting 0.7 kWh/dwelling/day back to the grid.

Both the detached and attached dwellings are net energy exporters, exporting 12 kWh/day and 10 kWh/day to the grid respectively. Gen Y is also a net energy exporter, exporting 0.6 kWh/day to the grid.

SHAC and Evermore apartments consume more energy than the amount of renewable energy generated on site, with the SHAC apartments importing an average of 3.8 kWh/day, and the Evermore apartments importing an average of 5.7 kWh/day.

When averaged out across the precinct, WGV dwellings are indicating a net export of 3.5 kWh/dwelling/day.

The energy profile values for each typology is further detailed below in Table 10.

Table 10 Energy profile for the different typologies and apartment buildings at WGV.

Typology	Energy Imported (Electricity + Gas) [kWh/Dwelling/Day]	Self-Supplied [kWh/Dwelling/Day]	PV Exports [kWh/Dwelling/Day]	Emissions Generated [kg CO_2e /Dwelling/Day]	Emissions Offset [kg CO_2e /Dwelling/Day]
Detached	10.2	5.5	20.5	7.1	14.4
Attached	8.4	4.8	10.2	5.9	7.1
Gen Y	4.5	3.2	5.1	3.1	3.6
SHAC	3.4	7.1	1.4	2.4	1.0
Evermore	3.9	4.5	0.7	2.7	0.5
Average	6.8	4.3	9.1	4.8	6.4

Figure 18 presents the average energy profile (kWh/day) by month for the detached lots at WGV to show the seasonal variation in proportion of self-supply.

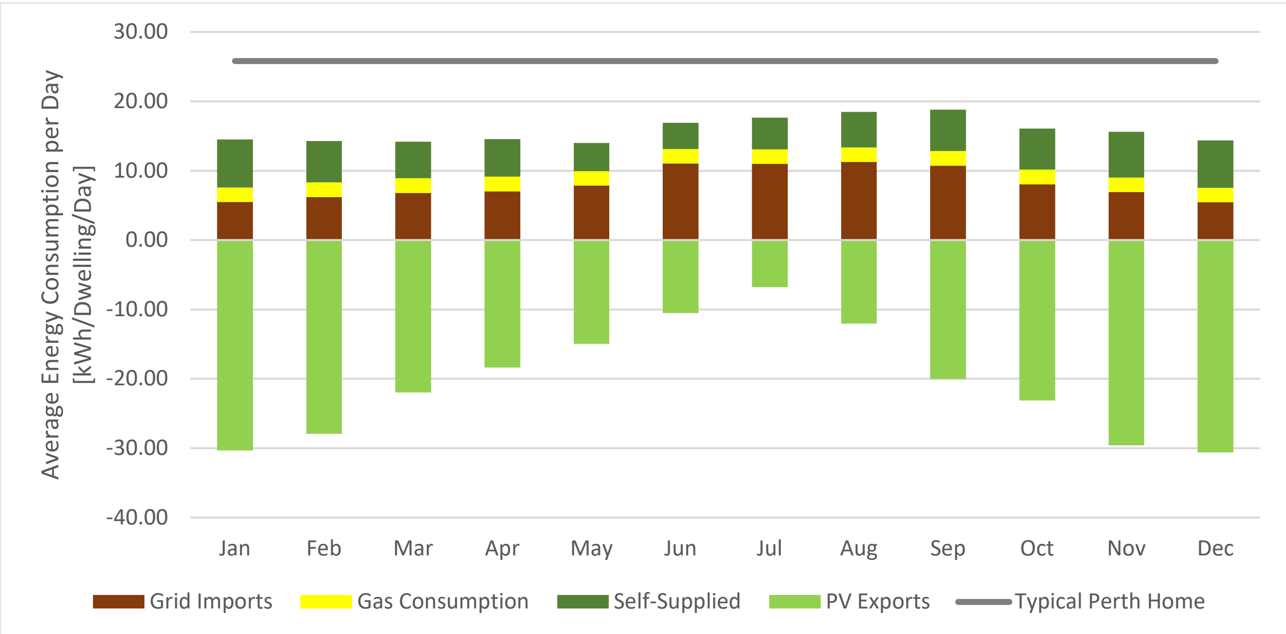

Figure 18 WGV detached lots residential energy profile.

The average detached dwelling daily energy demand at WGV is 15.7 kWh/dwelling/day which is a 39% reduction to typical Perth home energy demand of 25.8 kWh/dwelling/day. Grid Imports (electricity) and Gas Imports are the largest contributor making up

64% of the total energy demand whilst self-supplied energy makes up the remaining 36%. The daily energy exported to the grid averages 20.5 kWh/dwelling/day.

Figure 19 presents the average energy profile (kWh/day) by month for the attached dwellings at WGV to show the seasonal variation in proportion of self-supply.

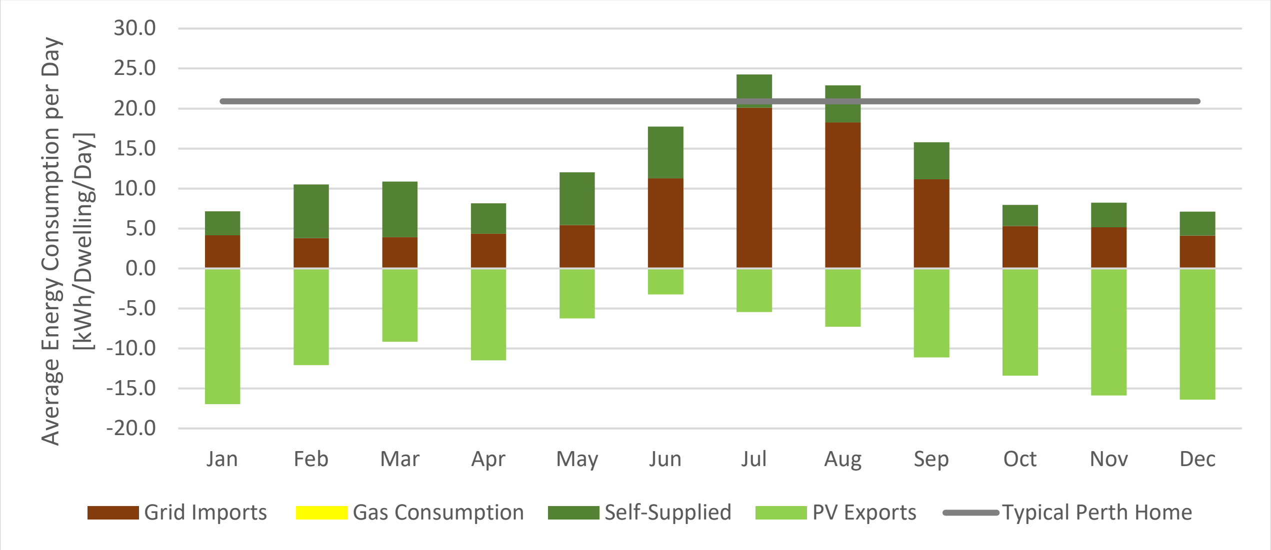

Figure 19. WGV attached lots residential energy profile

The average attached dwelling daily energy demand at WGV is 13.2 kWh/dwelling/day which is a 37% reduction to the typical Perth attached dwelling energy demand of 20.9 kWh/dwelling/day. Energy imported from the grid is the largest contributor making up 59% of the total energy demand whilst self-supply contributes 41%. The average daily energy exported to the grid is 10.2 kWh/dwelling/day.

Figure 20 presents the average energy profile (kWh/day) by month for the apartments (grouped) at WGV to show the seasonal variation in proportion of self-supply.

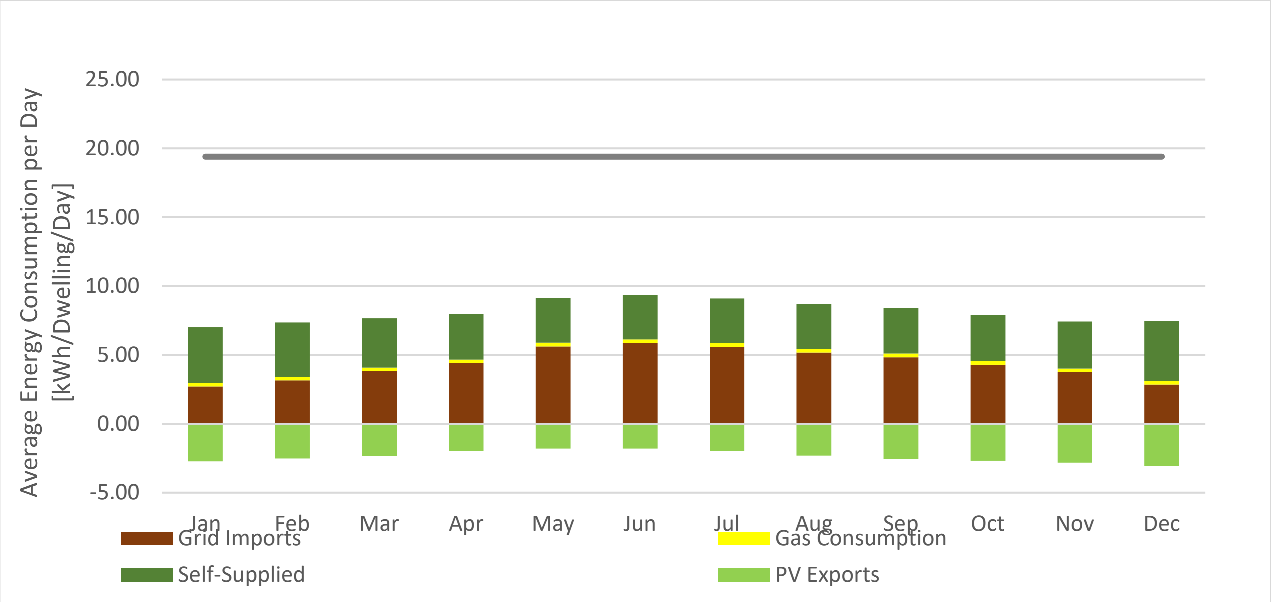

Figure 20. WGV apartment lots residential energy profile.

The average apartment dwelling daily energy demand is 8.2 kWh/dwelling/day which is a 57% reduction to typical Perth apartment energy demand of 19.4 kWh/dwelling/day. Grid imports are the largest energy contributor to the average apartment dwelling in WGV, providing 58% of the annual daily energy demand, whilst self-supplied energy meets 42% of the energy demand. The average daily energy exported to the grid is 2.3 kWh/dwelling/day.

Water

Figure 21 shows the water use at WGV by typology, including mains water, rain water and bore water compared to the Perth average.

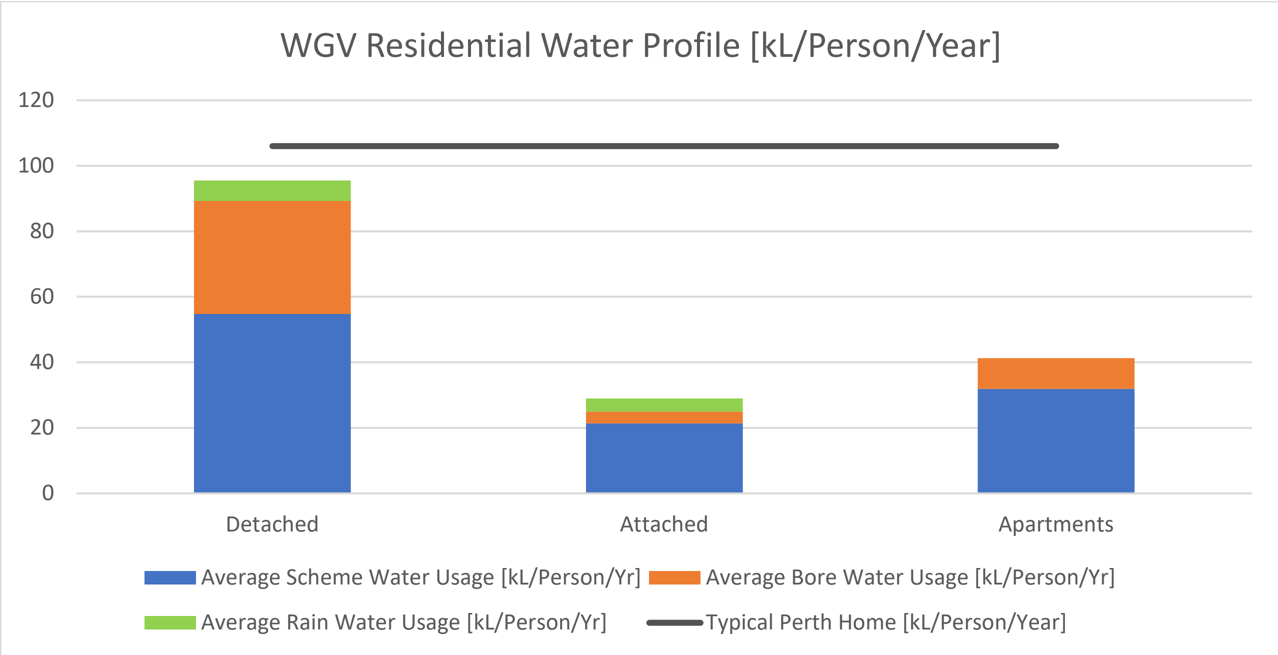

Figure 21. WGV residential water consumption

Mains water consumption for the detached dwellings averages 55 kL/person/year, which is a 48% reduction compared to the Perth average. Bore use for garden irrigation averages 34 kL/person/year and rainwater use (toilets and washing machines) averages 6 kL/person/year.

For the attached dwellings, the average mains water use is 21 kL/person/year, which is a 80% reduction to the Perth average. Bore use for garden irrigation is 4 kL/person/year, and rainwater is also 4 kL/person per year.

For the apartments, the average is 32 kL/person/year, which is a 70% reduction to the Perth average, and bore use average 9kL/person/year.

Overall the average resident at WGV consumes 37 kL/year of mains water, representing a 63% to the Perth average.

Figure 22 shows the average mains water use on a per person per year basis for each apartment building at WGV.

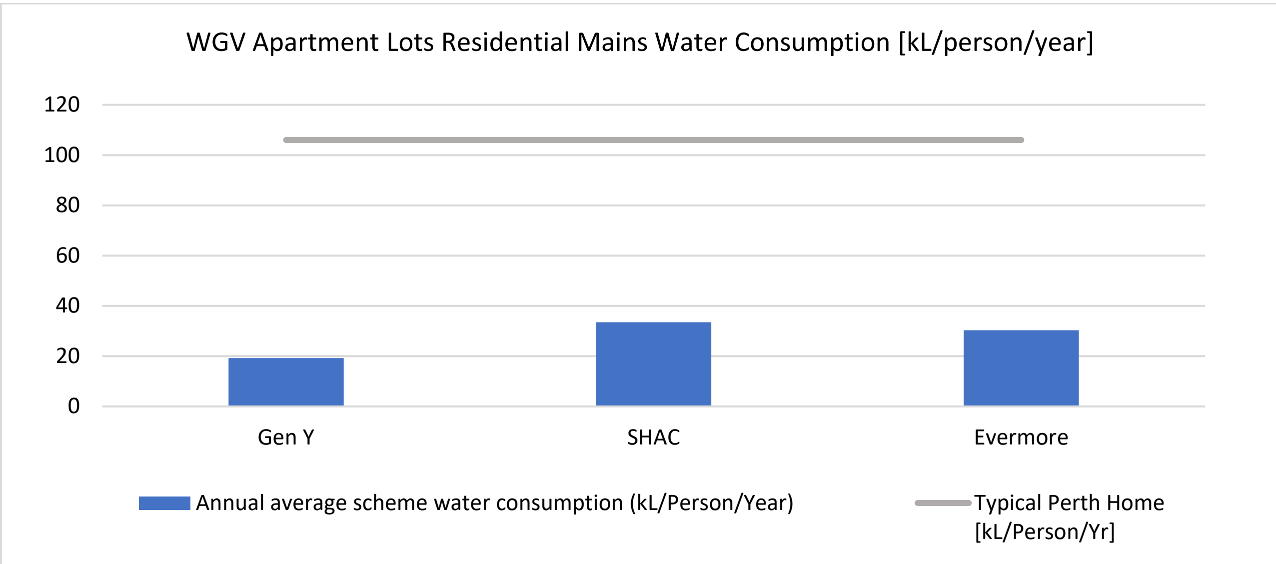

Figure 22. WGV apartment lots residential mains water consumption.

The average Gen Y water mains water use is 19 kL/person/year, compared to 34 kL/person/year for SHAC and 30 kL/person/per year for Evermore. The average across all apartments is 32 kL/person/year, which is a 70% reduction on the Perth average.

Assumptions and Qualifiers

- Data collected over 2018 and 2019.
- Available data varies across typology depending on completion, occupancy and monitoring equipment commissioning.
- Detached lot energy values based on eight homes.
- Detached dwelling water use based on 15 homes.
- Attached dwelling values based on 2 of 2 dwellings occupied.
- Gen Y values based on 3 of 3 units occupied.
- SHAC values based on 12 of 12 units occupied.
- Evermore based on 19 of 24 units occupied.
- Any lot that does not record data over at least 50% of the month, the data has been extrapolated using previous trends.
- Any irregulates or spikes in the data have been replaced with the average of the previous and following values.
- Typical home energy usage adapted from Energy Made Easy, 2017.
- Detached dwelling gas values based on Kinesis's As-Built Modelled values as gas was not metered.
- Perth average water use reference figure of 106 kL/person/year, Water Corporation, 2010.
- Occupancy: Detached dwellings 2.8 person/dwelling; Attached dwellings 2.8 person/dwelling; Apartments1.9 person/dwelling, ABS, 2016.

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Resident Engagement – Understanding Impact of Home Practice

Activity Overview

This Section describes the research activities undertaken to understand the role of occupant practice in low carbon residential developments, including impact of behaviour on building performance, as well as resident expectations and motivations.

Introduction

There are a number of housing projects around the country that showcase how (beyond compliance) energy efficiency and other sustainability initiatives can be incorporated into highly liveable developments in Australia. Low-Carbon Developments (LCD) such as Christie Walk, The Commons, Bowden, Central Park and WGV provide working examples at different scales (Byrne & Hutchens, 2017). These developments have focused primarily on the physical design of the developments, while questions remain around what resident perceptions are of the LCD, if the design of the home is a major concern for residents, what drives their perceptions, motivations and expectations of LCDs and post-occupancy satisfaction. A holistic understanding of the resident systems of practice and associated resource flows and their influence by the move is also needed. This research provided these answers through a longitudinal study of the residents of the WGV development, pre and post-occupancy.

The occupants of low-carbon and similar homes (passive houses, low-energy houses, zero-energy houses) have been described as a special segment of the population with specific lifestyles, user behaviour and practices and views. With an increase in low-carbon homes around Australia, the study of these residents is vital in understanding how these buildings are integrated into society in the future. Individual user experiences of LCDs are highly personal and the many reasons that motivate people to move into a LCD, which include health and wellbeing, lifestyle, environmental beliefs or simply price and location, should be acknowledged by builders, real-estate agents and policy makers (Berry et al., 2019; Hauge et al., 2011; Meir et al., 2009; Mlecnik et al., 2012). The absence of empirical evidence documenting the resident's perceptions of these low-energy and low-carbon homes, particularly in a variety of climates, limits the ability of policy makers and designers to understand residents life at home (Berry et al., 2014; Sherriff et al., 2019). The work conducted by Hagbert & Femenías (2016) highlighted this and has shown that a sustainable home is more than just an energy-efficient building, it must encompass a holistic view of economic, environmental and social aspects of resident's lives.

Previous studies examining housing preference in Perth, elsewhere in Australia and globally (Dunse et al., 2013; Jansen, 2013; Kelly et al., 2011; Kleit & Galvez, 2011) use a stated preference market choices methodology (Department of Housing and Planning, 2013; Kelly et al., 2011), as distinct from what people have actually chosen when purchasing a home. There is often a large variation in what people would state they would buy versus what they actually do buy (Department of Housing and Planning, 2013). Therefore, less emphasis can be placed on findings from stated market preference studies (Department of Housing and Planning, 2013; Jones et al., 2004) compared to studies with actual market preferences methods. This research is therefore based on the post-occupancy evaluation (POE) methodology of studying occupants of buildings for feedback and/or through measurements of the building's performance (Grijp et al., 2019; Meir et al., 2009; Mlecnik et al., 2012).

Improved building envelope design and technology are known to significantly reduce energy and other resource demands in households, however they are not the only influencing factor (Berry & Davidson, 2015; Hansen et al., 2018). Individuals are a key actor making everyday decisions and influencing usage through their behaviours and practices, which in turn are influenced by place, technologies, interpersonal relationships, society and information (Shove et al., 2012). Social Practice Theory (SPT) has developed into a widely recognised and utilised theory for understanding individual's actions and subsequent resource flows. It has since been offered as an alternative approach to the traditional socio-psychological theories to change people's behaviours and associated resource flows. SPT is centred on the idea that the world is populated by practices (Schatzki et al., 2001). Practices are the mundane, normalised actions that we undertake that consume resources and involves individuals as practitioners performing and transferring practices, instead of being the centre of analysis (Røpke, 2009; Schatzki, 2002; Shove et al., 2012; Shove et al., 2007). Practices are made up of a variety of elements: the meaning associated with a practice, the technology used to perform the practice and the skills required to perform the practice. The sequential repetition of practices in a habitual routine are interlocked (i.e. interconnected) in a system of practice (SOP) (Watson, 2012). Practices are also context dependent and evolve over time as new technologies emerge (Shove et al., 2015). It follows that affecting one or more elements of the practice should result in a modification of resource use and enable (as opposed to persuade) occupants to save energy or water while continuing to meet their intrinsic needs (the meaning element of the practice) (Brynjarsdottir et al., 2012; Spurling & McMeekin, 2015).

Drawing on SPT and POE, this research applied a SPT framework to the WGV living laboratory case study (Wiktorowicz et al., 2018). It also examines socio-psychological theories in their relationship to SPT and discusses the application of the two schools of thought to resource consumption at different scales, in the home, community and society level and how policy can influence this. To address the user experiences and resident's resource flows and SOP pre and post-occupancy in WGV, six sub-questions were posed:

1. What are the theories and methods typically used to understand and influence home occupants and over what scales do these occur?
2. Is there a home system of practice and if so, can it be influenced to enable the reduction of resource consumption?

3. What are the features of the WGV development and how does it relate to the Sustainable Development Goals and precinct urban planning?
4. What is the home system of practice of residents who will be moving into WGV and how does the degree of interlocking affect the resource flows of households?
5. What are the resident's motivations, perceptions, expectations and experiences of establishing a home in WGV?
6. What changes occur to individual practices and the Home System of Practice (HSOP) when people moved into WGV?

Methodology

This research used a mixed-method design approach, with both qualitative and quantitative data methods and desktop research, derived on a living laboratory methodology (Liedtke et al., 2015). As well as employing living laboratory methods, the methodology is based on Praxiography: the practice of doing practice theory driven research as outlined in (Bueger, 2014). This type of research focuses on the implicit or tact knowledge, knowledge that is rarely verbalized and not easily distinguishable. Practices are the mediator and carrier of such knowledge and as such they must be studied to unveil the resources utilised in their performance. This can be done through observation of the practice and discussion with the practitioners themselves to understand and interpret the implicit background knowledge and meanings. A time of change is ideal for studying practices because participants are more actively aware of how the new situation can be accommodated into existing practices (Higginson et al., 2013). Studying situations of change allow learnings about old practices and newly emerging practices to occur (Bueger, 2014).

The longitudinal case study was the WGV development and a cohort of resident's moving into it. The analysis of the housing design and water flows throughout the development is covered by other researchers on the project (and documented elsewhere in this report) and as such is outside of this aspect of the study. The additional and complimentary element of this research was examining how the residents are experiencing the development and in what way they are interacting with the technology features included. This provides the opportunity to study the residents and households in a longitudinal study across the dwelling typologies. This research also made a conscious decision to control for space in analysing practices. The household was chosen as the boundary to discuss practices in, although travel practices and shopping practices that revolve around the household are also examined. This has resulted in time being prioritised over space when examining practices, as undertaken in (Torriti, 2017). This is to support the investigation of holistic, longitudinal studies of resource use in LCDs, which is lacking in the literature.

Research Participants

The WGV development studied consists of multiple dwelling types with approximately 80 dwellings when completed, including multistorey dwellings. The first residents began moving in to WGV in mid-2017. The homes are designed for a Mediterranean climate with sustainability features including passive solar design allowing for airflow and sunlight levels (solar gain) to assist the regulation of international temperature. The average outdoor temperature is between 10°C and 27.3°C annually (Bureau of Meteorology, 2019).

A cohort study of 14 residents of 13 homes has been undertaken with data collected both pre- and post-occupancy in the LCD. The residents studied have moved into a variety of dwelling typologies Table 11. One cohort (five residents studied) is Sustainable Housing for Artists and Creatives (SHAC), who are leasing apartments and two studio spaces from a local social housing provider, with rental payment concessions received from the Australian Government. Another cohort (six residents studied) are owner occupiers of apartments sold at market rates in a commercial development called Evermore. The third cohort (three residents studied) are owner occupiers of two semi-detached units, while the final resident studied is an owner occupier of a standalone (detached) house. Three households across two cohorts have previously had sustainability features in their homes.

Table 11 Resident's dwelling, house and occupancy lifestyle at WGV

Dwelling	House	Occupancy lifestyle
Evermore Apartments	A	Works full-time off-site
	B	Works 4 days a week off-site; daughter is a student home most days
	C	Works 4 days a week off-site
	I	Retiree
	O	Works full-time off-site; son is a student home most days
SHAC Apartments	D	Works part-time off-site, part-time on site; son works part-time off site
	H	Works part-time off-site, part-time on-site

	J	Works part-time off-site
	L	Works part-time off-site, part-time on-site; 5 year old part-time school student
	N	Works part-time on-site
Semi-Detached House	F	Both residents work full-time off-site
Semi-Detached House	M	Both residents work full-time off-site
Detached House	G	Shift work full-time off-site; daughter is a student home most days

Residents self-selected through an open invitation sent to those who had already purchased property in the LCD or were intending to become a tenant through SHAC (n=27). An original sample size of 16 individuals in 15 dwellings were part of the pre-occupancy data collection, however one household decided to rent out their apartment in WGV and another removed themselves from the study. Their results are not included in the results published after their removal. Pre-occupancy data collection was conducted between April and June 2017 for SHAC residents and between December 2017 and March 2018 for Evermore and single house residents. Post-occupancy data collection was conducted between December 2018 and March 2019 for all residents. The long period of time for data collection pre-occupancy was intended to allow for a greater sample size of residents to self-select. However, there is a bias towards those whose post-occupancy is in SHAC or Evermore due to the requirement of the resident residing in WGV during 2018 and to allow for post-occupancy data collection within the research time constraints.

Mixed methods were employed pre and post-occupancy for data collection (Browne et al ., 2015; Liedtke et al., 2015). The data collection methods focused on the themes of energy, water, waste, food, transport, social network practices and the residents' expectations and motivations for moving into WGV. A structured interview explored the occupant's motivations and experiences of the move to WGV, while text probes, hygiene and transport diaries provided contextual experience data. The interviews[11] were for approximately one hour and were undertaken in the resident's pre- and post-occupancy accommodation except for one which was conducted at an independent venue. In households with multiple adults, only those moving into WGV were interviewed. Children, including those over 18 and still living at home, were not interviewed due to uncertain circumstances surrounding their residency arrangements once their parents moved into WGV. A workbook was completed over two weeks, allowing residents to respond to short-answer questions about their resource use and habits[12] along with 5[13] and 7[14]- point Likert scale survey questions. Text probes were sent periodically through these two weeks to gain in-situ qualitative contextual data on current practices, minimising the impact of recall difficulties during interviews (Thoring et al., 2013). The text probe method is a combination of cultural probe methods developed in the past two decades that require participants to take photos of objects during their daily life with a disposable camera (Crabtree et al., 2003; Gaver et al., 1999; Thoring et al., 2013). The advent of mobile phones has allowed a significant advancement in this method. Text messages are a low effort, quick and familiar method for the participant, increasing response rate. Examples of the questions used are "tell me how you have kept warm today?" or "in a picture or a few words, tell me what home means to you?"

Data Analysis

The water and energy use pre-occupancy data was collected through bills provided by the residents for up to a year before the interview. A daily household average was calculated for comparison to the post-occupancy data. Post-occupancy, a daily household average was also calculated through monitoring of the energy and water flows to each dwelling. These were at 5 minute intervals for all participating households post-occupancy except for Evermore residents which were at 15 minute intervals due to a programming error. The water consumption data was also divided into source (rainwater or mains water) for the semi-detached and house dwellings studied. As all the dwellings post-occupancy use bore water for irrigation, a daily landscaping contribution was added to the household total. For the semi-detached and detached households, this figure was provided by monitoring data. For the apartment households, a daily landscaping contribution was arrived at by dividing the total outdoor water use by the number of apartments in the dwelling. Over a 3 month period post-occupancy, all the households also contained a temperature and relative humidity sensor logging at 5 minute intervals.

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[11] Questions in the semi-structured interview ask residents how they keep warm and cool, the routines they go through each day and how their lives have changed since moving to WGV.

[12] An example of a short answer question is: Do you have difficulties in getting to places?

[13] 5-scale Likert question example: How comfortable are you finding the house in relation to temperature: very comfortable, mostly comfortable, neutral, mostly uncomfortable, very uncomfortable.

[14] 7-scale Likert question example: How often do you use the public outdoor areas in WGV?: every day, a few times a week, about once a week, a few times a month, once a month, less than once a month, never.

Qualitative data analysis occurred after the first round of data collection and again after the second round. The Likert scale data was analysed through tabular and graphical visualization of the results to identify trends, which were then compared with the qualitative data collected. A thematic analysis was performed using NVivo software to analyse the various data sources across 43 themes[15]. It was during this analysis that the themes of home, sense of place and the concerns around moving to WGV were identified as noteworthy. This research is based on the further thematic analysis of the data with these themes in mind, following the method set out in (Robison & Jansson-Boyd, 2013) as well as the post-occupancy evaluation of how residents are experiencing life in the LCD.

Key Findings

This section will explore the results of each of the research questions, as are answered through 8 publications (Breadsell, Eon, & Morrison, n.d.; Breadsell, Eon, Morrison, & Kashima, 2019; Breadsell & Morrison, n.d.; Breadsell, Morrison, & Byrne, n.d., 2019; Eon, Breadsell, Morrison, & Byrne, 2018, 2019; Wiktorowicz et al., 2018).

3.1 What are the theories and methods typically used to understand and influence home occupants and over what scales do these occur?

The results of this research question are outlined in a publication currently under review (Breadsell et al., n.d.). The practices and behaviours of individuals inside the home influence resource consumption and are shaped by a multitude of psychological, social and technical factors. Each theory has their own qualitative and quantitative methods which allude to different conclusions and recommendations for resource consumption initiatives. A review of the debate surrounding the application of both the theories, referred to as the Chalk and Cheese debate in the literature was discussed, as is the potential for both theories to be used at different scales, from the individual in the home for practice interventions to behavioural insights being applied at a community and society level. Social psychology theories view resource consumption as something that an individual will use depending on their values and social norms. Adopting a SPT approach focuses on the practices and bundles of practices that resources are involved in when these practices are performed (Shove & Walker, 2014). Human choices are dependent upon the conditions under which the choice is made: these choices have temporal and spatial dimensions (Borch et al., 2015). This was identified early on in the SPT literature by Schatzki, stating that practices are both anchored in and dispersed across space and time (Schatzki, 1996). We posit that insights from behaviour and practice and subsequent interventions have different roles based on the temporal and spatial dimensions they are being employed in Figure 23. Practice interventions can result in almost immediate changes in the way that a practice is performed, while behaviour interventions often entail a longer term cultural and societal shift in the habits and values of an action.

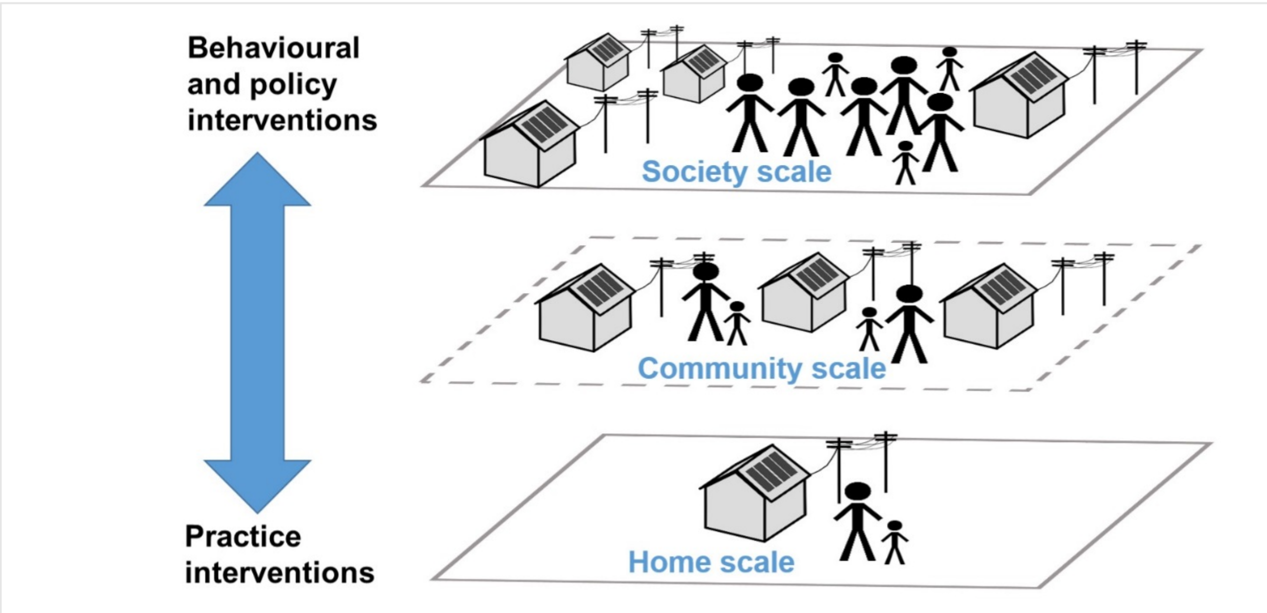

Figure 23 The different scales that behavioural and SPT interventions can be best targeted to (Breadsell et al., n.d.)

3.2 Is there a home system of practice and if so, can it be influenced to enable the reduction of resource consumption?

[15] A short list of initial themes was drawn up before the thematic analysis based on the researchers notes from the interviews, this was then added to through the analysis. Themes include affordability, comfort, control, convenience, energy, health, ownership, privacy, stability, thermal comfort, time, employment, cooking, fresh air, routine, washing, animals, children and sense of community.

The results from this research question are published in a journal article and book chapter (Eon et al., 2018, 2019). While individual practices are influenced by meaning, skill and technology, they are also constrained by other home occupants and interlocked practices inside and outside the home. Practices are performed in a sequential temporal spectrum as part of a routine and are influenced by interlocked practices as well as interlocking routines from other home occupants. Practices also follow established daily patterns reflected by a frequency distribution curve where the standard deviation reflects the degree of habituality of the practice. For instance, peak water use occurs earlier in houses occupied by early risers who are economically active and therefore bound by the practices of breakfast, transport and work. Late risers, on the other hand, do not have a specific water use pattern and are not interlocked in binding activities constraining the hour of water use. Highly interlocked practices with a high degree of habituality are challenging to affect. However, automation could enable resource intensive activities to be dis-interlocked from an established routine and make change within the home system of practice easier and more flexible.

3.3 What are the features of the WGV development and how does it relate to the Sustainable Development Goals and precinct urban planning?

The results of this research question are published in Wiktorowicz et al. (2018). The WGV project is an infill residential development in a middle suburb of Perth, Western Australia. Its urban planning innovation is in its attempt to demonstrate net zero carbon as well as other sustainability goals set by urban planning processes such as community engagement and the One Planet Living accreditation process. It is a contribution to the IPCC 1.5 °C agenda which seeks to achieve deep decarbonisation while also delivering the UN Sustainable Development Goals (SDGs). Solar photovoltaics and battery storage are incorporated into the development and create net zero carbon power through an innovative ‘citizen utility’ with peer-to-peer trading. The multiple sustainable development features such as water sensitive design, energy efficiency, social housing, heritage retention, landscape, sense of place and community involvement, are aiming to provide inclusive, safe, resilient and sustainable living.

3.4 What is the home system of practice of residents who will be moving into WGV and how does the degree of interlocking affect the resource flows of households?

The results from this research question are published in Breadsell et al. (2019). When people move into sustainable houses, they bring practices with them that have temporally evolved along with their daily lives. A common misconception is that change to individuals’ resource use can be persuaded without consideration of previous practices. The personal hygiene, thermal comfort, clothes drying, garden watering and waste practices of 14 households pre-occupancy in WGV was examined. Results identified HSOPs with different degrees of interlocking and highlighted how various combinations of meaning, skill and technology elements of a practice as well as contextual influences can affect resource use.

Households with working residents or children have a regular routine they must adhere to that interlocks with their showering, travel, shopping and socialising practices, forming bundles of practices. Households that comprise of the self-employed or retired have less structure driving their daily practices, resulting in them being performed at various times of the day. However the duration of the practice concurrent with the meaning remains within a similar range. The implication of a highly interlocked HSOP is that practices are less likely to be influenced as they are constrained by a very rigid routine with a high degree of habituality. By focusing on the meaning of a practice, or the technology used in its performance, alteration to the resources consumed by the practice’s performance can be achieved.

3.5 What are the resident’s motivations, perceptions, expectations and experiences of establishing a home in WGV?

The results from this research question are published in (Breadsell et al., (2019). There is some understanding of how an individual’s daily practices consume resources in the home, but the home as a space itself and people’s relationship to it remains an interesting research area. The results show that home is associated with being a place for community, sustainability, safety and comfort, as well as incorporating aesthetically pleasing features. The important features of a home post-occupancy are shown in Figure 24, compared with pre-occupancy. The motivation for moving into an LCD for residents is to have housing stability, live the life they want (including performing sustainable practices) and the attractive design of the LCD. Residents of the LCD primarily found out about the opportunity to move into the LCD through their social networks of friends and workmates. The user experiences of living in the LCD include unexpected design influences on daily practices and an appreciation of the community atmosphere created. The strong sense of community and the self-reported thermally comfortable homes meet resident’s expectations post-occupancy. Some design and community aspects were met with surprise post-occupancy. The lighting and security aspects of the Evermore development have mostly negative views from the residents, as influencing the ease at which they can move about the LCD precinct and interact with other residents. The communal barbecues also had mixed reactions and engage some, but not all residents. Other options for community interaction and meeting places should be explored to accommodate other preferences.

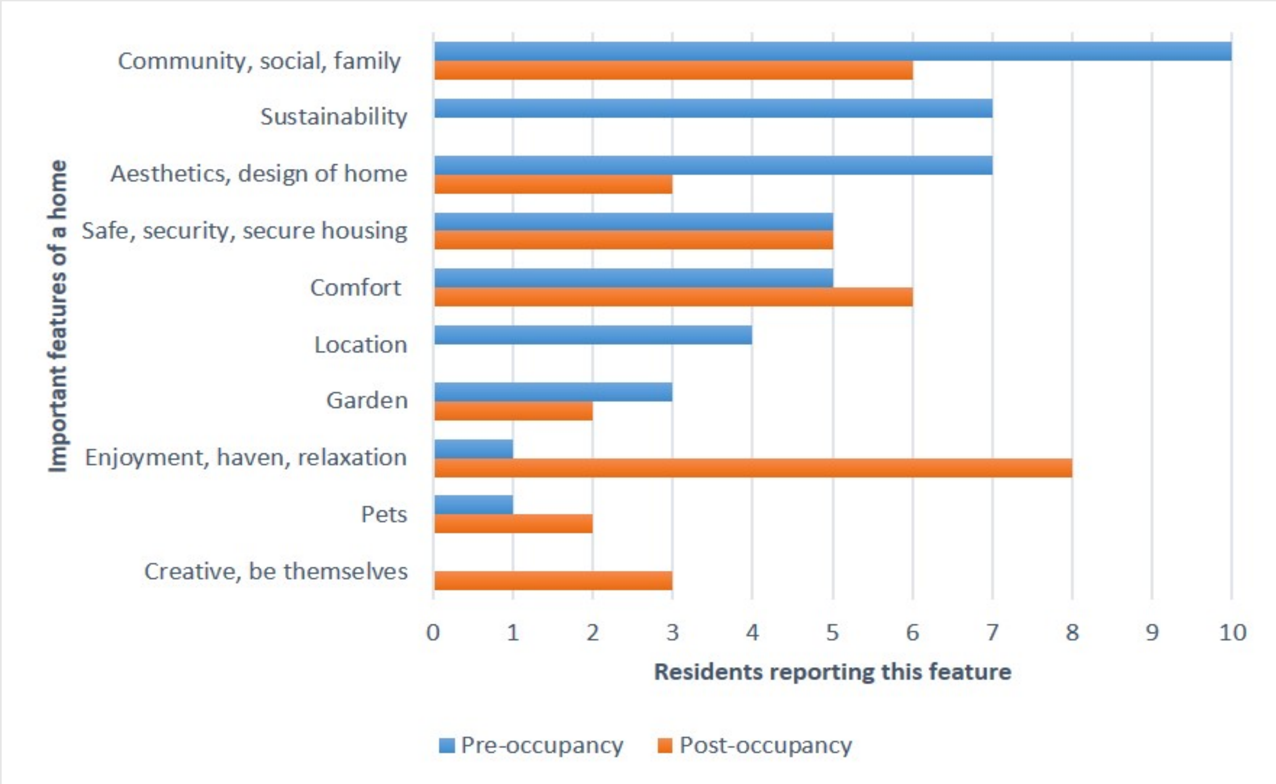

Figure 24 Important features of and associations with a home as reported by 14 resident's pre and post-occupancy in the LCD (Breadsell et al., (2019)

3.6 What changes occur to individual practices and the HSOP when people move into WGV?

The results from this research question are in writing for two publications (Breadsell & Morrison, n.d.; Breadsell et al., n.d.). Cooling, heating and personal showering are the most resource intensive practices in many counties around the world, including in Australian homes (DEWHA, 2008; Water Corporation, 2010). Household water and energy use decreases post-occupancy in WGV due to technology and design influences, however personal practice history influence the resident's use of water and energy. Changes to the meaning element of personal hygiene practices both pre and post-occupancy show how practices are interlocked with others, and unlikely to change in their duration when there are other demanding practices to be undertaken.

When residents were asked how often they felt thermally uncomfortable in their WGV dwellings, 75% or above answered that for less than once a month they feel too hot or too cold. This indicates that their adaptive thermal comfort practices, mechanical technological use as needed and the design of the dwellings are mostly adequate. Most residents have maintained similar practices that were employed pre-occupancy in remaining thermally comfortable when necessary. These include the use of blankets, hot water bottles, opening and closing windows and blinds and finally, the use of fans, heaters or air-conditioners.

There were some comments from residents on certain design aspects that have hindered their thermal comfort, particularly in Evermore. Due to the location of two apartment buildings with a common area in between, a wind tunnel is created between the apartments. Paired with the strong westerly breezes that are common in the afternoon in this location, some residents choose not to open their windows facing into the common area due to the loud noise of the wind. This prevents cooling cross ventilation practices being fully employed and may be influencing the use of mechanical cooling instead.

The relationship between time of day, the HSOP and energy use is highlighted in the post-occupancy data. In households where residents are out of the house on weekdays, have low energy use during the day and only have higher levels of consumption during the early morning and evening when the residents are home. This contrasts to the household with a resident home during the day due to differing work conditions, who is utilising energy throughout the day in their practice of staying thermally comfortable. On a weekday where all the residents of the households are home and practices such as cleaning and washing are being undertaken, the energy use profiles of the households feature more peaks throughout the day.

Consideration of practices that involve resources outside of thermal comfort and personal hygiene should be undertaken to have a holistic understanding of resource use. The opportunity to study resident's pre-and post-occupancy consumption is a unique situation to examine how design, technology and community influence household practices. Therefore, residents travel practices, recycling practices and use of appliances were also studied.

Pre-occupancy, residents expected their travel practices to change quite significantly, especially an increase in the use of bikes, the electric vehicle and walking. However, the use of transport post-occupancy did not change for the majority of residents with the exception of one resident who walks to work now instead of driving. Some residents have replaced some local trips to a café or bottle shop with walking or biking instead but otherwise shopping and work practices have remained the same. There was been an increase in the use of personal bikes however the hills around the LCD are a deterrent to the older residents who are more car dependent, especially for shopping trips. Those who report using public transport (bus or train) in the LCD are only those who were already using these forms of transport before they moved in.

In regards to recycling practices post-occupancy, SHAC and Evermore residents independently implemented a soft plastics recycling system for each development that is then taken to a local drop off point by a volunteer. This resulted in all apartment residents now recycling soft plastics, along with the continuation of the council run standard recycling scheme. One resident had separate bins installed in her house to separate the recycling at the source and cites this as assisting her to recycle. All apartment and semi-detached house residents also compost through a shared compost system, while the remaining standalone house resident had not implemented a compost system at the time of interviewing but was planning to in the future.

Post-occupancy, the presence of solar panels influenced when residents put the dishwasher, washing machine and drier on. Many residents are conscious of putting these on during the day or use timers where they had not previously. The use of automatic systems is minimal though, a few houses reported using the timer settings on the washing machine, dishwasher or AC unit but most will only report using these when they are home. This resulted in these practices now utilising renewable energy but hasn't restricted the use of air-conditioner to only during the day. This indicates that residents are not willing to alter their thermal comfort practices based on energy source. Residents who had automatic reticulation pre-occupancy have now all moved into apartments in WGV and only hand water pot plants. Those in single houses all have reticulation on their gardens, which is set to automatic and is different to their pre-occupancy dwelling.

Post-occupancy, only 2 residents changed their interlocking status from lightly too highly. This was due to one resident's son starting school with consistent hours that allowed for her work to become more consistent and washing and cooking routines to become interlocked. The other resident who changed was a resident who was moving between multiple houses before settling in WGV. Having a stable residence has allowed him to standardise his travel times between work, shopping and leisure times and has then flowed on to interlocking his cooking, washing and showering practices also. Overall, interlocking of resident's SOP has not changed due to resident's lifestyles not altering drastically post-occupancy and household composition remaining the same for most residents. Resident's still work the same hours each week and undertake household chores and socialising at similar times and places than pre-occupancy in the LCD. Ultimately, these are the factors that influence one's practices and the timing of them.

Conclusion

It was clear from this research that the home is a complex system of physical and emotional elements (Fabi, Spigliantini, & Corgnati, 2017) and the various ways of categorising it provide opportunities to change resource consumption in the related practices. It is with this open policy direction in mind that this research explored how residents perceive their homes and what they expect out of the LCD's that are being built to withstand future environmental climate change. For housing policy to develop attractive homes in the future, it is important to understand which elements of the design of a home are desired by residents post-occupancy and how these influence their daily practices. Understanding the timing of resource intensive practices in the home such as heating and cooling, showering and garden watering, allows for smart city technology to be designed with the end-user in mind and fitting into their lifestyle and routines. Co-creation with the user during the planning phase of smart cities will allow this to occur as outlined in (Scott, Bakker, & Quist, 2012). Examining the practice of recycling highlights the influence of community and social networks on changing resident's practices. This research is of interest to academics in the low carbon and social science sectors, real estate agents and property developers as it provides insight into motivations and expectations of low carbon dwelling residents.

This research features results from a small cohort of WGV residents, however it is unique in tracking them both pre and post-occupancy. This was mostly due to the low uptake in residents who fit the time limit criteria for moving into WGV in 2018. Some residents were also reluctant to participate due to not having stable housing pre-occupancy, as this influenced the energy and water aspects of the research not discussed in this paper. However, with a small cohort study, particular themes could be examined in greater detail with the residents, such as how the different methods of hearing about WGV influenced their decision to move in. Future research should examine a larger sample size of residents and from different locations to assess whether other themes and concerns arise. A second post-occupancy study could also be completed once residents have resided in WGV for a longer period of time. For most of the residents in the standalone and semi-detached houses and Evermore, they had been living at WGV for less than 6 months when this data was collected. The SHAC residents had been residing at WGV for more than a year. This may have influenced their perceptions of their experience. Further research areas should continue to investigate LCD housing in a variety of climatic and design landscapes, outside of the Australian and European regions to broaden the lessons learnt, the residents engaged with and the policy settings LCD are situated in. Mixed methods research focusing on a longitudinal view of LCD residents is vital for understanding how residents access a LCD, move in and settle over the years with new technology and communities. POE studies will contribute to this understanding and should continue to be conducted to further the understanding of resident practices in a LCD.

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Local Government Engagement – Process Analysis and Learnings

Activity Overview

This project activity required the delivery of a workshop with industry partners, LandCorp and the City of Fremantle, to share research findings from the mapping and analysis of the planning and development process of WGV. It was also intended to identify barriers/solutions for low carbon outcomes in housing developments.

Workshop Aim and Objectives

The aim of the workshop was to identify ways to improve the precinct planning and development process for the achievement of innovation, sustainability and low carbon outcomes. The specific objectives included:

1. To present research findings from the mapping and analysis of the planning and development process of the WGV residential precinct.
2. To facilitate an interactive and participatory workshop among key development stakeholders for co-creation of ideas for future planning and development processes.
3. To identify the barriers and potential solutions for an improved planning and development process for low carbon outcomes.
4. To strengthen social capital between key stakeholders through opportunity for dialogue, interaction and social learning.

Research Method

The mapping of the WGV planning process applied a comparative-historical analysis approach combining historical, actor-network and path dependence analyses, with a casual narrative to identify contingent events and the critical juncture for change in the planning and development path. Data was collected via semi-structured interviews with key planning and development stakeholders together with an analysis of archival records and planning related documentation. The outcomes of the mapping process were communicated to industry partners in an interactive, participatory workshop that applied a participatory action research approach.

The participatory workshop was held at Sullivan Hall, the community hall at the residential precinct site of WGV. The workshop was held on Tuesday 27 March 2018, from 12noon – 2.30pm. An informal setting was chosen to support relaxed interaction and dialogue between the participants and an onsite venue was chosen to reflect the place-based approach of the planning process. Participant's name tags displayed participants' first names only to mask, to some degree, the hierarchical or organisational power differentials between participants. The intention was to create a sense of equality that would support open dialogue and interaction.

Workshop participants included: local residents, a housing cooperative member, the Mayor, landscape architect, community housing provider, City of Fremantle officers, LandCorp officers, and Curtin University researchers. The estate architects and urban planners were invited, but provided apologies.

The delivery of the workshop was aligned with the One Planet Living (OPL) principles. OPL was the sustainability framework used by the developer as the WGV precinct's assessment, certification and goal setting tool.

Workshop Programme:

Presentation of Research Findings

The PhD researcher gave a 24 minute presentation (using power point slides) on the analysis of the planning process of WGV and preliminary findings.

Figure 25. PhD candidate Tanya Babaeff presenting to workshop participants.

Question Time

Approximately 10minutes question time was allowed.

Communal lunch

Participants were invited to lunch in the picnic area on site. A community-style lunch was served whereby food dishes (locally sourced) were placed on the centre of each meal table for participants to pass around and share. This was designed to encourage informal interaction during meal time, to establish/re-establish connections and a sense of trust between the planning and development stakeholders prior to them undertaking the group activities related to the planning process.

Small Group Activity

Participants were hand selected into three groups of six people. Selection was aimed at ensuring diversity of knowledge type, gender, and professional background. The small group size enabled sufficient time for each group member to interact, while allowing sufficient diversity of ideas.

The Mayor opened the activity, indicating the intention of the activity was to identify what had been done well in the planning and development process and what could have been done better. Each group was provided with an A1 sized poster of the research analysis where they recorded ideas, made notations and wrote suggestions in relation to the actions and sequencing during the planning and development activities.

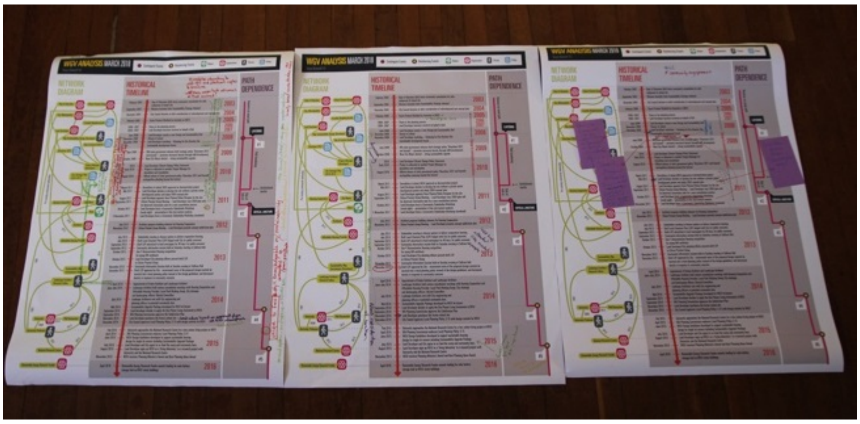

Figure 26. Research analysis poster.

Large Group Activity

The small groups were brought together in a plenary session to share their feedback and discuss their learnings for implementation in future planning/development processes. The discussion was primarily recorded via notations on a large 1.8m poster of the research analysis, with some brief segments of video/audio recording.

Figure 27. Large group activity.

Key Findings

Key Findings

- In the first instance, the developer needs to hold a business objective to innovate. This needs to be reflected through inclusion of sustainable development objectives (via visioning and context analysis) during the high-level business case development stage.
- The developer and key stakeholders need to engage early in the process – key stakeholders include the local community, landscape architects, and researchers.
- The developer and local community need to engage early in co-creating the shared vision and values for the place, including jointly defining the problems, opportunities and constraints (including through site/context analysis).
- Partnerships for innovation need to be identified early in the process.
- The planning and development process needs to uphold an open, transparent and flexible approach in order to support collaboration and innovation among stakeholders.
- The use of a 'demonstration project' approach offers the space and mandate for stakeholders to engage in trial and error necessary for innovation.

Participant Feedback

The development industry partner has provided feedback to indicate that the workshop has "crystallised key learning/success factors" including the understanding that innovation and sustainability are about the process, such as visioning at the high level business case stage and developing an understanding of place.

The research has confirmed intuitive actions taken by the developer during the WGV project and has focused these actions into a more deliberate approach. Application of these findings include the deliberate actions taken by the developer on new projects such as the adoption of an open and collaborative engagement process; early community engagement, which has influenced ideas for water/energy efficiencies, recycling and reuse, and retention of landform and trees at a new development in Hamilton Hill - all of which contribute to reduced carbon emissions compared to a business-as-usual development approach. The research has also encouraged the developer to deliberately seek industry and research partnerships for two new developments (Hamilton Hill and East Village); and to utilise these two new developments as demonstration projects to trial new ideas.

A workshop participant from the local community provided post-workshop feedback stating that the workshop made an impression with its "open and transparent" process; and that the sharing of a meal removed the "sense of hierarchy and softened the tone of conversation". The event was described as being "radically different to any workshop" the community member had attended. This feedback suggests that the research methods successfully achieved an inclusive and participatory context.

Conclusion

The mapping process and participatory workshop enabled the key planning and development stakeholders to critically reflect on the impact of their individual, and joint, decisions and actions in the planning and development process of WGV. This process has identified a range of actions for an ideal planning and development process aimed at sustainable, low carbon development.

The participant dialogue about the research analysis has supported the developer to become cognisant of its pre-reflective actions and has validated intuitive actions. This has empowered the developer and other key stakeholders to take focused and directed actions in at least two subsequent planning and development projects in this local government area. The research has assisted to expand the knowledge and application of principles for innovate and sustainable, low carbon development by this developer.

Density by Design Video Series

Activity Overview

Density by Design is a 10-episode factual web series showcasing a selection of medium to high density residential development projects from around Australia. Hosted by Dr Josh Byrne in his role as a Research Fellow with Curtin University and the CRC for Low Carbon Living, and produced by VAM Media[16], the series was developed to document and communicate the research activities of RP3033 to a wide audience.

The first four episodes covers projects in Adelaide, Melbourne and Sydney and includes interviews with leading practitioners in sustainable urban design. The series then moves on to document WGV in detail, following the progression of the development from design, through construction and eventually occupancy.

The series aims to address the following questions:

- How can the design, construction and delivery of low carbon, high performance developments at the precinct level be optimised and streamlined in order to be mainstreamed and delivered at scale?
- What set of conditions (e.g. policies, planning processes, funding models and market uptake) are needed to successfully deliver precinct-scale low carbon, high performance developments?
- How do you best measure the impact (i.e. carbon reduction and lower cost of living) of the low carbon, high performance design features of precinct-scale development?
- What on-going engagement and governance processes are needed to ensure the development operates, post construction, at the intended level of performance (i.e. occupant behaviour and ongoing maintenance of the precinct)?

Video Summaries

Christie Walk

Figure 28 Christie Walk - Adelaide, South Australia

Adelaide, South Australia

Video released April 2017

Access: www.densitybydesign.com.au/christie-walk

Christie Walk, named after the late environmental activist Scott Christie, is a multi-residential infill development on the edge of the Adelaide CBD, accommodating 27 dwellings and approximately 40 residents on a 2,000m^2 lot. Dwelling types include apartments, town house and detached cottages.

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[16] VAM Media: https://vammedia.com

Kicking off in 1999, Christie Walk is a pioneering project that reflects the 'eco village' aspirations of the environmental movement of the day, and this is expressed in the vernacular, materials and community driven process underpinning the development.

The project began as a development cooperative, led by Urban Ecology Australia. Completed In 2006, the development is nationally recognised and widely visited. It is home to a mix of original and newer residents with a strong focus on the importance of community.

The Commons

Figure 29 The Commons - Melbourne Victoria

Location: Brunswick, Melbourne, Victoria

Video released April 2017

Access: www.densitybydesign.com.au/the-commons

Located on the rail line in Brunswick, Melbourne, The Commons is a project that is sending ripples through the urban development industry. The five story, 24-unit apartment building demonstrates design excellence and exceptional sustainability credentials, it's challenging the very core of how conventional multi-residential housing is being delivered.

Led by Melbourne-based Breathe Architecture, and completed in 2013, The Commons is the prototype of the Nightingale model, which promotes designer-led, rather than profit-led housing. The Commons' raw, stripped-back style speaks to its authenticity.

The reductionist approach saves materials, maintenance and money. Absent ceilings create greater internal volume, and shared facilities mean more generous living areas. The designer-led process translates to quality, simplicity and detail.

Bowden

Figure 30 Bowden - Adelaide South Australia

Location: Adelaide, South Australia

Video released April 2017

Access: www.densitybydesign.com.au/bowden

Located 2.5km from the Adelaide CBD on former industrial land, Bowden is arguably the South Australian Government Development Agency, Renewal SA's, most ambitious development project. The 16ha mixed-use project commenced in 2008 and is forecast to be completed by 2026, targeting 2,500 residential dwellings, 10-12,000 square metres of retail space, and approximately 15-20,000 square metres of commercial office space.

Bowden demonstrates significant leadership in urban planning, with carefully considered design guidance and review processes. All buildings are required to achieve a 5 Star GBCA Green Star rating and be assessed by an architectural review panel.

Now mid-way through development, Bowden provides a good opportunity to see how considered planning and good design transfer into reality along a continuum that spans from planners, to developers, to architects and consultants, to builders and early residents.

Central Park

Figure 31 Central Park - Chippendale, Sydney, New South Wales

Location: Chippendale, Sydney, New South Wales

Video released April 2017

Access: www.densitybydesign.com.au/central-park

Central Park in Sydney's CBD is a 5.8ha mixed-use precinct that gives us a glimpse of the 'city of the future'. One where exciting architecture and biophilic design justifiably earn their place in the heart of our cities. Once complete, the former industrial site will yield around 2,400 apartments, 400 hotel rooms, 1,000 student accommodation beds, 6,000 square metres of commercial space and 20,000 square metres of retail. One third of the 5.8-hectare site has been devoted to public open space.

The project incorporates the flagship One Central Park Tower, designed by French Architectural Firm Ateliers Jean Nouvel (with PTW Architects), featuring an iconic heliostat and extensive green walls. There is also cutting-edge precinct-scale utility infrastructure including a tri-generation plant which provides power, heating and cooling energy, and a wastewater treatment plant that processes sewerage into high quality recycled water for local reuse.

Central Park blends modern high-density development with adaptive use of historic buildings and provision of quality public amenity. It has opened an otherwise inaccessible part of the city and triggered the activation of the surrounding area.

WGV – An Introduction

Figure 32 WGV - White Gum Valley, Western Australia

Location: White Gum Valley, Fremantle, Western Australia

Video released July 2017

Access: www.densitybydesign.com.au/wgv - tab 1

What is WGV, how did it come about, and what are the team hoping to achieve? In the first of six episodes on WGV, Dr Josh Byrne takes a closer look at the urban design principles underpinning the project and examines the planning mechanisms and design controls put in place to deliver the vision of a diverse, medium-density, highly liveable residential precinct. Informed by early research by Curtin University and the CRC for Low Carbon Living, this episode explores what sets WGV apart from others around Australia.

WGV – Multi-Residential Housing
Location: White Gum Valley, Fremantle, Western Australia

Video released October 2017

Access: www.densitybydesign.com.au/wgv - tab 2

The innovative approach to multi-residential housing at WGV includes the Gen Y Demonstration House by LandCorp, SHAC by Access Housing and Australia's first Baugruppen project. In the *WGV – Multi-Residential Housing* episode We learn how the various projects are attempting to address housing affordability, sustainability and community participation.

WGV – Net-Zero Energy and Beyond
Location: White Gum Valley, Fremantle, Western Australia

Video released February 2018

Access: www.densitybydesign.com.au/wgv - tab 3

WGV is targeting 'net zero energy' status, meaning it will generate as much energy as it uses, balanced over the year. This will be achieved through a combination of energy efficient building design, coupled with rooftop solar energy generation. The apartment sites are incorporating solar energy storage which will see grid energy reliance reduced by up to 80%. The *WGV - Net -Zero Energy and Beyond* episode looks at the design strategies, technologies and governance models employed to achieve this goal.

WGV – Waster Sensitive Urban Design
Location: White Gum Valley, Fremantle, Western Australia

Video released August 2018

Access: www.densitybydesign.com.au/wgv - tab 4

WGV is demonstrating leading water sensitive urban design through an integrated approach to water conservation, stormwater management and urban greening. Household mains water use is expected to be 70% less than the local average as the result of a suite of water efficiency and alternate water supply initiatives, including plumbed rainwater tanks and a community bore. Smart metering will capture water use data in real time to inform responsible water-use, supported by resident engagement programs.

WGV – Engaging People and Fostering Community
Location: White Gum Valley, Fremantle, Western Australia

Video released June 2019

Access: www.densitybydesign.com.au/wgv - tab 5

Urban infill projects like WGV have the challenge of meeting the expectations of an existing community whilst designing for the needs of future residents. This episode investigates the role that the local community played in shaping WGV from the early planning stages, and the way that new residents are bringing the precinct to life.

WGV – Series Wrap Up
Location: White Gum Valley, Fremantle, Western Australia

Video released July 2019

Access: www.densitybydesign.com.au/wgv - tab 6

As the WGV precinct nears completion Dr Josh Byrne reflects on what has been achieved and he assesses the on-ground outcomes against the original vision of the project. Josh reviews early performance data and other research outcomes plus he calls on expert opinions to assess the importance of WGV as an 'innovation through demonstration project'.

Appendix

Appendix 1: WGV Estate Plan

Appendix 2: WGV Data Source Schedule

Appendix 1

ESTATE PLAN

INNOVATION THROUGH DEMONSTRATION

WGV

WHITE GUM VALLEY

SINGLE RESIDENTIAL
APARTMENT SITE
MAISONETTE SITE
SEWER LINE AND CONNECTION
ELECTRICAL SUBSTATION
ELECTRICAL SUPPLY PILLAR
WATER CONNECTION
DESIGNATED CARPORT/GARAGE LOCATION
CARPORT ONLY PERMITTED (LOT 6)
RETAINING WALL
PUBLIC OPEN SPACE

N

GET IN TOUCH

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LANDCORP.COM.AU/WGV

LANDCORP

Appendix 2
WGV Data Source Schedule by Lot
Version at: 8/07/2019

Logger (& Telemetry)		Smart Meters & Inverters (Household Internet Sevice)	WASP Loggers (3G)			WASP Loggers (3G) &/or Manual Reads	Building Data Logger (Building Internet)
Lot	**Typology**	**Property Electricty/PV**	**Property Mains Water Meter**	**Property Community Bore Water Meter**	**Rainwater Meter (On Lot)**	**Property Gas Meter**	**Electricity/PV/Battery & Water Sub Metering**
Lot 1	Apartments (24 dwellings)	NA	Elster V300 50mm w/ pulse kit	Elster 25mm V100 pulse capable	NA	NA	Electricity sub metering & source; MW sub metering
Lot 2	Apartments (No. TBA)	TBA	TBA	TBA	TBA	TBA	TBA
Lot 3	SHAC Apartments (12 dwellings)	NA	Elster V100 25mm w/ pulse kit	Elster 25mm V100 pulse capable	NA	NA	Electricity sub metering & source; water sub metering
Lot 4	Attached Dwelling	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	NA	Electricity sub metering
Lot 5	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 6	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 7	Gen Y House (3 dwellings)	NA	Elster V100 25mm w/ pulse kit	Itron TD8 20mm with cyble	Electricity sub metering & source; MW & RW sub metering; Gas; Temp & RH		
Lot 8	Single Residential	Solar Edge	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 9	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 10	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	NA	NA
Lot 11	Group Housing - TBA	TBA	TBA	Elster 25mm V100 pulse capable	TBA	TBA	TBA
Lot 12	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 13	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 14	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 15	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 16	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 17	Single Residential	Solar Edge	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 18	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 19	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 20	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 21	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 22	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 23	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 24	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 25	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	NA	NA
Lot 26	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 27	Single Residential	TBA	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA
Lot 28	Single Residential	Fronius	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	Itron TD8 20mm with cyble	TBA	NA