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Life Cycle Assessment of Hot Water Delivery

WEB VERSION

Prepared for

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I declare that this report complies with ISO14040:2006 and ISO14044:2006 standards.

27/05/2013

Dr. Wahidul Biswas

Melbourne, 28th May 2013
VERSION N° 4.0 (Draft for Peer Review)

QA Review

Reviewed by	Date
Dr. Enda Crossin	18th April 2013
Dr. Wahidul Biswas	10th May 2013

Release and Revision Record

Revision Date	Release/Revision Description	Change Reference
18/04/13	First release – V1.0 (For internal peer review)	1.0
19/04/13	Final release – V2.0 (For external peer review)	2.0
17/05/13	Final peer reviewed release for comment	3.0
28/05/13	Final peer reviewed release	4.0

File name: S:\SECURE\CFD\COMMON\01 Research Areas\04 Products\01 Current Projects\Microheat\Full Report\Life cycle assessment HWS peer review response final.docx

Last Save Date: 28 May 2013

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Executive Summary

This report presents a peer-reviewed Life Cycle Assessment (LCA), examining potential hot water systems (HWSs) in the built environment, for medium and high density apartment buildings. It compares the potential environmental impacts of either centralised or point of use hot water delivery within two buildings. LCA is the process of evaluating the potential effects that a product, process or service has on the environment over the entire period of its life cycle. The process for undertaking LCA is outlined in the ISO 14040 series of standards. This study conforms to both the requirements of the ISO14040:2006 and ISO14044:2006 LCA standards.

In order to understand the environmental impacts of hot water systems and to substantiate environmental marketing claims, MicroHeat Technologies (MicroHeat) commissioned the Centre for Design at RMIT University to compare the full product life cycle of potential HWSs in two existing buildings as specified by engineers Wood and Grieve. MicroHeat was interested in comparing global warming potential, water use, cumulative energy demand and solid waste for these systems. The two buildings used as case studies were;

1. An existing high-density apartment complex, La Banque building, located in the Melbourne CBD at 380 Little Lonsdale Street, consisting of 257 apartments on 35 levels.
2. A proposed medium-density apartment complex, the Brahe Place building, located in East Melbourne at 18 Brahe Place, consisting of eight apartments on three levels.

Table 1 presents key modelling assumptions of the assessed hot water systems. Building life was assumed to be 50 years.

Table 1: Hot water systems under study (base case scenario)

<table>
<tr><th>Building</th><th colspan="2">Type of hot water system</th><th>Household size profiles (people)**</th><th>Annual hot water per resident (kL)***</th><th>Temp. rise for 50°C water (°C)</th><th>Number of residences</th></tr>
<tr><td rowspan="2">La Banque</td><td>HWS 1</td><td>Gas plant ring main</td><td rowspan="2">257 (low)
382 (avg.)
643 (high)</td><td rowspan="2">20.1 (low)
26.8 (avg.)
40.2 (high)</td><td>59* winter
52* summer</td><td>257</td></tr>
<tr><td>HWS 2</td><td>Continuous flow electric water heater (CFEWH)</td><td>39 winter
32 summer</td><td>257</td></tr>
<tr><td rowspan="3">Brahe Place</td><td>HWS 3</td><td>Gas plant ring main</td><td rowspan="3">8 (avg.)
16 (high)</td><td rowspan="3">20.1 (avg.)
33.6 (high)</td><td>59* winter
52* summer</td><td>8</td></tr>
<tr><td>HWS 4</td><td>Gas plant ring main with solar</td><td>59* winter
52* summer</td><td>8</td></tr>
<tr><td>HWS 5</td><td>Continuous flow electric water heater (CFEWH)</td><td>39 winter
32 summer</td><td>8</td></tr>
</table>

* Heated to 70°C, then tempered to 50 °C with cold water
** Determined with ABS data extrapolations (Australian Bureau of Statistics 2007)
*** Determined with ABS and Federal Government data extrapolations (Australian Bureau of Statistics 2007; Department of the Environment Water Heritage and the Arts 2008)

**** Determined from other studies, and Australian Building Codes Board (Australian Building Codes Board 2006)

The primary function of a HWS is to produce and deliver hot water to residents in a building. The functional unit could therefore be defined as:

"Hot water produced, delivered, used and disposed of by a typical apartment resident over the course of 1 year at 50°C."

For this study however, the goal is to focus upon the whole HWS within the building under investigation, so the reference functional unit was defined as follows:

"Hot water produced, delivered, used and disposed of by the typical apartment residents in a building over the course of 1 year at 50°C."

The potential environmental impacts of the HWSs were evaluated in terms of this unit, in the current Australian market (as of April 2013, where the buildings are constructed with apartment residences, and the hot water is produced, distributed, and consumed in those buildings). In the base case, the consumer is located in Melbourne. The performance characteristics are an important sub function of HWS, and these are explored in Section 3.3. Direct environmental comparisons are only be made for HWSs within the same building, with no quantitative comparisons between the results of the two buildings (nor should this be done by any other party). Qualitative insights however are drawn, i.e. the performance characteristics underpinned by a medium density and high density buildings.

A life cycle inventory (LCI) was developed, where the foreground process and environmental flows for the component materials and processes, HWS use, distribution distances for components and end of life data was collected. In the base case, components are considered to be sent to landfill at end of life. These inventories were developed primarily from data directly from suppliers and from existing life cycle inventories and literature. Packaging and installation impacts were not included, as the environmental impacts of these were considered relatively minor and were similar across the systems. Infrastructure, capital equipment, and supplier administration overheads were also excluded from the study, as they were estimated to reflect a small proportion of total impact, and expected to be similar across life cycles.

The Australian Impact Assessment Method was used to assess the base case options for global warming potential, cumulative energy demand, water use (non-turbine) and solid waste. Results of the assessment are tabulated in Table 2 and 3, and represented graphically in Figure 1 and 2.

Table 2: Impact assessment characterisation values for La Banque HWSs for a year of hot water use. Results are reported per functional unit

Impact category	Unit	Use scenario	HWS 1 Central gas plant	HWS 2 CFEWH point of use
Global warming	kg CO_2 eq	Low	1.20E+05	3.04E+05
		Average	1.40E+05	4.01E+05
		High	1.87E+05	6.23E+05
Cumulative energy demand	MJ LHV	Low	2.05E+06	3.38E+06
		Average	2.40E+06	4.47E+06
		High	3.21E+06	6.95E+06
Water use	kL H_2O	Low	5.21E+03	5.80E+03
		Average	6.90E+03	7.65E+03
		High	1.08E+04	1.19E+04
Solid waste	kg	Low	4.91E+02	5.04E+03
		Average	549.87	6.61E+03
		High	687.87	1.02E+04

Table 3: Impact assessment characterisation values for Brahe Place HWSs for a year of hot water use. Results are reported per functional unit

Impact category	**Unit**	**Use scenario**	**HWS 3 Central gas plant**	**HWS 4 Central gas plant & solar**	**HWS 5 CFEWH point of use**
Global warming	kg CO_2 eq	Average	7.17E+03	6.36E+03	9.46E+03
		High	8.45E+03	7.61E+03	1.57E+04
Cumulative energy demand	MJ LHV	Average	1.14E+05	9.87E+04	1.05E+05
		High	1.37E+05	1.20E+05	1.75E+05
Water use	kL H_2O	Average	167.75	169.00	180.82
		High	275.93	277.24	299.54
Solid waste	kg	Average	57.56	70.82	156.77
		High	61.26	75.01	257.39

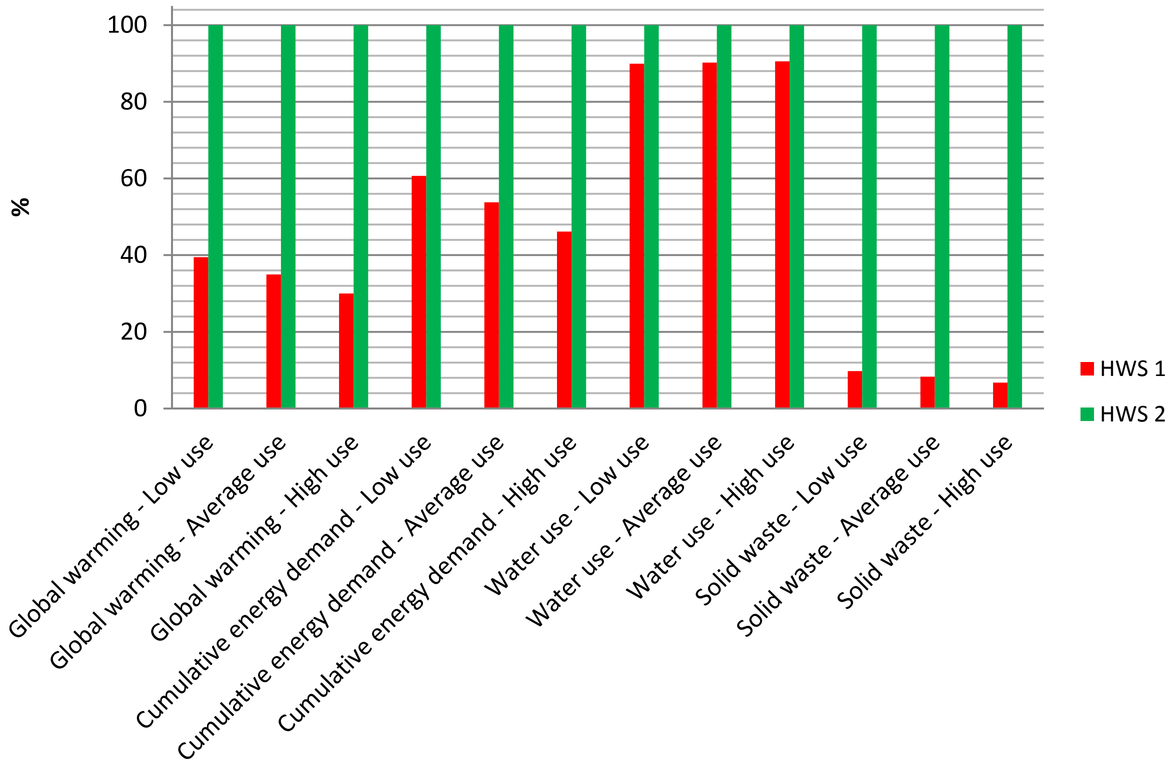

Figure 1: Relative summary of characterised results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

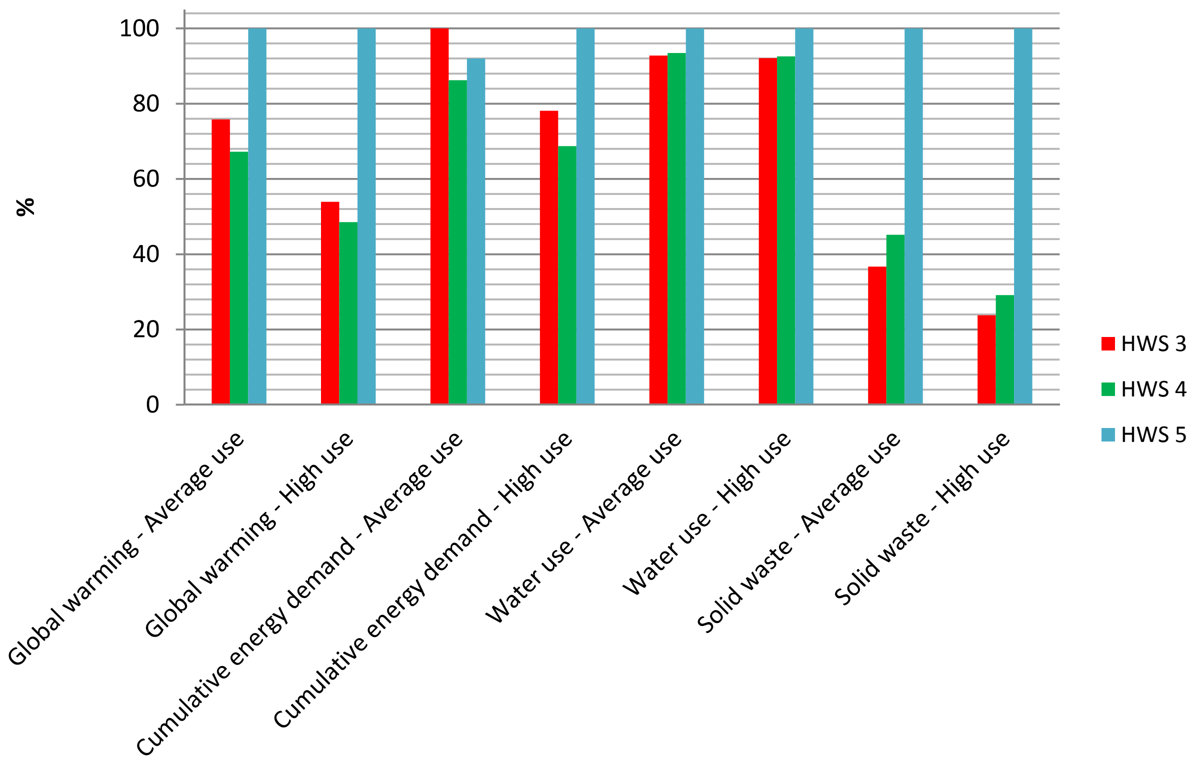

Figure 2: Relative summary of characterised results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS5

These characterised results were disaggregated to determine what the drivers of impacts were. Seven sensitivity analyses were undertaken to test these results including:

- Region for HWS use, based in major Australian capital cities
- Occupancy and vacancy
- Component replacement, component materials, and building life
- CFEWH and solar boosting (substitute electric HWS 4)
- Extra centralised system losses in ring main
- Victorian electricity grid changes
- Green power purchasing

The results of the sensitivity analyses confirmed that the base case study has taken a more conservative approach when comparing HWSs within the La Banque building, with all alterations resulting in the same directional results favouring the centralised HWS 1, albeit at a different quantum.

The results for the smaller building Brahe Place shifted directionally for a number of altered assumptions, including:

- The alteration of region for HWS use resulting in favourable cumulative energy demand results for CFEWH HWS 5 over HWS 3 and HWS 4 in every assessed capital city, global warming potential and for CFEWH HWS 5 over HWS 3 in every assessed capital city, and global warming potential for CFEWH HWS 5 over HWS 4 in Adelaide.
- CFEWH with solar boosting performing better in global warming potential and cumulative energy demand results than HWS 3 and HWS 4 (only marginally in global warming potential).
- The projected Victorian electricity grid changes selected resulting in favourable cumulative energy demand results for CFEWH HWS 5 over HWS 3 and HWS 4 by the 2035 scenario, and favourable global warming potential for CFEWH HWS 5 over HWS 3 and HWS 4 by the 2050 scenario.
- Renewable electricity purchasing for all HWSs results in favourable cumulative energy demand results for CFEWH HWS 5 over HWS 3 and HWS 4 in the 25% and 50 % renewable electricity contribution scenarios, and favourable global warming potential for CFEWH HWS 5 over HWS 3 and HWS 4 in the 50 % renewable electricity contribution scenario.

The results of the sensitivity analyses for Brahe Place show that for this type of building, where standby energy in a centralised system is of a higher proportion of total energy demand, significant opportunities exist today (with renewable electricity, CFEWH solar boosting, and in state capitals where lower grid emissions and lower heating requirements where higher ambient water temperatures exist) and in the future (with Victorian grid emission reductions) for CFEWH to perform better than gas and solar boosted gas systems in global warning potential and cumulative energy demand.

This demonstrates that context is the key to selection of environmentally better HWsS, and that policy makers should consider a systems approach in regulating HWSs rather than product-specific rules of thumb. It also highlights that, although not environmentally better in the base case, CFEWHs are in some circumstances a choice of resilience and future-proofing, where efficiency and electricity grid emission reductions can compound to affect more desirable environmental outcomes.

Limitations

Currently the HWS components are produced in Australia, Asia, USA and Europe. In assessing potential environmental impacts, the study does not differentiate between local and global impacts. For certain environmental indicators, such as water use, this can be important because water may be scarce locally, but not scarce at foreign locations (although there is a growing body of evidence suggesting water is becoming a global issue). Other environmental impacts, such as global warming potential, can be considered of equal importance both locally and internationally.

The life cycle impact assessment (LCIA) results are relative expressions and do not predict impacts on category end points, the exceeding of thresholds or safety margins. Comparison of the results of this study to other LCA studies should be treated with caution, given that there can be differences in LCA methodology, including but not limited to:

- Functional unit
- System boundaries, including the exclusion of life-cycle stages, e.g. use and end-of-life (cradle-to-gate).
- The application of different characterisation factors in the impact assessment (e.g. for global warming potential, the use of IPCC 1996 vs. IPCC 2007 factors).
- The application of CO_2 eq credits for the use of fossil-fuel derived electricity by the purchase of Renewable Energy Certificates (RECs).

Inventory items for which MicroHeat and suppliers provided primary data included manufacturing processes (with associated energy consumption), materials, part masses, shipping and transport locations, and some energy consumption data not contained in existing data sets currently.

Some inventory items required secondary data that derived from a region other than the origin of the specific inventory item. No materials or processes contributed to more than 5% of a particular impact category (apart from the inventory measure of solid waste for HWS 3 and HWS 4 in Brahe Place), so the electricity grids were not modified for materials sourced by MicroHeat or manufacturers from countries other than those in the data source to reflect the electricity grid profiles of those regions.

Developing marketing claims from this study is only relevant for the products and building scenarios considered. The claims do not apply to all current or future circumstances for all buildings, for all regions and for all technologies. It is therefore important for MicroHeat to monitor life cycle system changes and adapt claims to suit.

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Glossary

Below is a list of useful definitions referred to in this study.

Cumulative energy demand (CED) – All energy use including fossil, electrical and feedstock (energy incorporated into materials such as plastic). Renewable energy is not included.

Elemental flow – Input or output from the environment, in a unit process, that can be used to assess environmental impacts in an impact assessment in an LCA.

End of life (EOL) – The end of product or service life cycle, culminating in a ceased function and generally a form of waste flow such as recycling or landfill.

Environmental impact category - A discreet measure of impact to the environment related to the elemental flows through the course of product or service life cycle.

Functional unit – Unit of measure of the function delivered by a particular product or service under investigation in an LCA.

Global warming potential – Climate change effects resulting from the emission of global warming gases into the atmosphere – this indicator is represented in CO_2 equivalents, but covers the six Kyoto protocol gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6).

Heating value – Heat released during the combustion of a substance.

Impact assessment – Identification and establishment of a link between the product's life cycle and the potential environmental impacts associated with it. The impact assessment includes characterisation of the inventory results, assigning the elemental flows to impact categories, and calculating their contribution to that impact.

Reference unit – Unit of measure for a particular product or service that aligns to the functional unit of an LCA.

Life cycle – The life stages of a product or service, from raw material extraction, materials processing, manufacture, distribution, use, and end of life.

Life cycle assessment (LCA) – The process of evaluating the potential environmental impacts that a product, process or service has on the environment over the entire period of its life cycle.

Life cycle inventory (LCI) – Inputs and outputs of a product or service system. Includes a process flow chart and a list of all emissions and raw material & energy inputs (inventory table) that are associated with the product system under study.

Lower heating value (LHV) – Defined as heat from the products of combustion without returning to the pre-combustion temperature (i.e. direct heat from combustion without heat recovered from condensed vapours). This is as opposed to upper heating value (UHV), or heat from the products of combustion when returned to the pre-combustion temperature (in particular condensing any vapour produced).

System boundary – Boundary of product or service system, defining what is included and excluded for a discreet functional unit in an LCA.

Solid waste – Net solid waste generated. Total of all solid waste generated by the processes considered.

Unit process – Discreet process within a product or service system.

Water scarcity (or stress) – Scarcity of water available for use in a regionally specific context.

Water use – Gross fresh water use within a system. Total of all non-turbined water used by the processes considered (i.e. turbined water in hydropower excluded).

1 Introduction

This life cycle assessment (LCA) study was undertaken by the Centre for Design (CfD) at RMIT University for MicroHeat Technologies (MicroHeat) to support decision making for hot water systems (HWS) in the built environment with respect to environmental impacts. The decision making context was specifically related potential HWS specifications as advised by engineering firm Wood and Grieve for two apartment buildings in Melbourne, Australia.

MicroHeat has been in the process of commercialising technology that provides an alternative to the way water is heated (disruptive technology). The MicroHeat Continuous Flow Electrical Water Heater (CFEWH) is a "point-of-use" electric water heater. In developing this product, MicroHeat become aware that there is very little 'in context' comparative analysis or literature of HWS options for multi dwelling built environments, particularly in regard to life cycle impacts of products relative to building use, building life, and hot water demand (rather than exclusively supply) considerations of residents within apartment buildings. This study aims to contribute to this gap, by measuring the potential impacts of HWS within an apartment building context, specifically global warming potential, cumulative energy demand, water use and solid waste.

Initial analysis by MicroHeat showed that CFEWHs installed at the point-of-use had the potential to save energy within apartment buildings based on superior efficiencies to centralised, reticulated hot water systems. The "point-of-use" nature of the product is established to match resident based demand. However, in order to support decision making for hot water systems (HWS) in the built environment, MicroHeat wanted to compare the full product life cycle of HWS options to understand what opportunities for CFEWHs if any existed, and where CFEWHs specification may be appropriate.

1.1 Study alignment

This study is aligned with ISO 14040:2006 (International Organization for Standardization 2006a) and ISO 14044:2006 (International Organization for Standardization 2006b). It was also peer reviewed, as per Section 3.10.

2 Goal of the study

2.1 Reasons for carrying out the study – intended application

This study has been conducted to support MicroHeat internal decision making processes with respect to communications to key stakeholders regarding global warming potential, water use, cumulative energy demand and solid waste in relation to HWSs within multi dwelling buildings. The study utilises Life Cycle Assessment (LCA) to evaluate and compare potential environmental impacts of HWSs, for the reasons outlined in Section 1. A description of the LCA process is provided in Appendix H.

2.2 Goal of the study

The primary goal of this LCA study was to quantify and compare the potential environmental impacts of 5 HWSs within two chosen buildings, one medium density, the other high density, over the full life cycle.

2.3 Involved parties

The study was undertaken with the involvement of the following parties:

- *Commissioning party*: MicroHeat Technologies Pty Ltd (MicroHeat) is an Australian private business focusing on the research and development of highly-advanced systems in the field of rapid fluid heating technology for both domestic and industrial applications. The technology is proprietary (patent protected in over 52 countries). The global market potential has been recognised by the Australian Government through funding grants (Climate Ready 2008). MicroHeat enjoys strategic alliances with world class suppliers, manufacturers, toolmakers, OEM's, and multinational consortiums.

- *Participating study parties*: Advice on the potential HWS specification for the two buildings was provided by Wood and Grieve engineering consultancy. The CFEWH technology operating performance and energy use within buildings was tested, validated and modelled by the Energy CARE Group at RMIT School of Aerospace, Mechanical and Manufacturing Engineering (SAMME), as per Section 4.16.2 to Section 4.16.5, and Appendix E and Appendix F.

- *Participating manufacturing parties*: Primary component manufacturers engage for potential HWS included MicroHeat (CFEWHs), Bosch (instantaneous gas plant and storage tanks), Rheem (instantaneous gas plant, storage tanks, and solar collectors), Armacell (insulation), Wefa Plastic (polymer hot water pipes), Auspex (polymer cold water pipes), Crane (copper hot water pipes), Grundfos (pumps), Lowara (pumps), Reliance Worldwide (cold water bulk meters, hot water remote meters, check valves, tempering valves and isolation valves), TA Hydronics (balancing valves), Prysmian (electrical wiring), and Promat (fire collars).

- *Peer reviewer*: As will be discussed in Section 3.10 a peer review was undertaken for this study conducted by Dr. Wahidul Biswas from Curtin University, an expert in energy systems and LCA.

2.4 Intended audience

The audience for this study is intended to be MicroHeat employees, HWS suppliers, HWS specifiers, manufacturing industry participants and the general public.

2.5 Statement about comparative assertions intended for public disclosure

The results of this study are intended to be used as a basis for comparative assertions which are to be disclosed to the public. This is another reason why a critical review process was undertaken (as will be described in Section 3.10).

3 Scope of study

3.1 Description of product system(s) under investigation

The two buildings used as case studies for the HWSs were;

1. An existing high-density apartment complex, La Banque building, located in the Melbourne CBD at 380 Little Lonsdale Street and consisting of 257 apartments on 35 levels.

2. A proposed medium-density apartment complex, the Brahe Place building located in East Melbourne at 18 Brahe Place, and consisting of eight apartments on three levels.

Table 3-1 provides a description of the HWSs under review.

Table 3-1: Hot water systems under study (base case scenario)

Building	HWS No.	Type of hot water system	Household size profiles (people)**	Annual hot water per residence (kL)***	Temp. rise for 50°C water (°C)	Number of residences	Building life (years)****
La Banque	1	Gas plant ring main	257 (low) 382 (average) 643 (high)	20.1 (low) 26.8 (average) 40.2 (high)	59* winter 52* summer	257	50
	2	Point of use electric instantaneous			39 winter 32 summer	257	
Brahe Place	3	Gas plant ring main	8 (average) 16 (high)	20.1 (average) 33.6 (high)	59* winter 52* summer	8	
	4	Gas plant ring main with solar			59* winter 52* summer	8	
	5	Point of use instant electric			39 winter 32 summer	8	

* Heated to 70°C, then tempered to 50 °C with cold water

** Determined with ABS data extrapolations (Australian Bureau of Statistics 2007)
*** Determined with ABS and Federal Government data extrapolations (Australian Bureau of Statistics 2007; Department of the Environment Water Heritage and the Arts 2008)
**** Determined from other studies, and Australian Building Codes Board (Australian Building Codes Board 2006)

3.2 Functional unit

The primary function of a HWS is to produce and deliver hot water to residents in a building. The functional unit could therefore be defined as:

"Hot water produced, delivered, used and disposed of by a typical apartment resident over the course of 1 year at 50°C."

For this study however, the goal is to focus upon the whole HWS within the building under investigation, so the reference functional unit was defined as follows:

"Hot water produced, delivered, used and disposed of by the typical apartment residents in a building over the course of 1 year at 50°C."

The potential environmental impacts of the hot water systems were evaluated in terms of this unit, in the current Australian market (as of August 2012, where the buildings are constructed with apartment residences, and the hot water is produced, distributed, and consumed in those buildings). The water is treated as delivered at an apartment level, rather than a room or appliance level in this study. In the base case the consumer is based in Melbourne. The performance context is an important sub function of HWS, and is explored in Section 3.3. **It must be made clear that direct comparisons will only be made for HWSs within the same building, with no quantitative comparisons between the results of the two buildings (nor should this be done by any other party). Qualitative insights however may be drawn, i.e. the performance characteristics underpinned by a medium density and high density context.**

3.3 Performance characteristics

The water heating market (domestic and commercial) is one which has come under increasing scrutiny, with government and regulatory bodies tightening the constraints on water and energy efficiency. Water heaters are highly regulated, and subject to limitations through the National Construction Code (NCC, formerly Building Code of Australia, or BCA), in conjunction with standard tests through relevant Australian Standards, such as:

- AS1056:1991 - Storage water heaters - General requirements
- AS3500:2003 - Plumbing and drainage Set
- AS4234:2008 - Heated water systems - Calculation of energy consumption
- AS4445:1997 - Solar heating - Domestic water heating systems - Performance rating procedure (indoor test)
- AS4552:2005 - Gas fired water heaters for hot water supply and/or central heating
- AS4692.1:2005 - Electric water heaters - Energy consumption, performance and general requirements
- AS4692.2:2005 - Electric water heaters - Minimum Energy Performance Standard requirements / energy labelling

One major move by government has been to phase out greenhouse intensive water heaters with the 2010 provisions in the NCC. The recommendations put forward to the Australian Government (Wilkenfeld 2009) have now been adopted and state the following regarding efficiency and greenhouse factors (Australian Building Codes Board 2012):

> ***2.6.3 Verification for a heater in a hot water supply system[1]***
>
> *(a) Compliance with P2.6.2 for a heater in a hot water supply system is verified when the annual greenhouse gas intensity of the water heater does not exceed*

[1] With various state variations

100 g CO2-e/MJ of thermal energy load determined in accordance with AS/NZS 4234.

(b) The annual greenhouse gas intensity of the water heater in (a) is the sum of the annual greenhouse gas emissions from each energy source in g CO2-e divided by the annual thermal energy load of the water heater.

(c) The annual greenhouse gas emission from each energy source in (b) is the product of—

(i) the annual amount of energy consumed from that energy source; and

(ii) the emission factor of—

(A) if the energy source is electricity, 272 g CO2-e/MJ; or

(B) if the energy source is liquefied petroleum gas, 65 g CO2-e/MJ; or

(C) if the energy source is natural gas, 61 g CO2-e/MJ; or

(D) if the energy source is wood or biomass, 4 g CO2-e/MJ.

These energy source factors derive from the domestic energy mix. Eastern seaboard coal fired electricity generation plants, which dominate the electricity market, are some of the most greenhouse intensive in the world (hence 272 g of CO_2 eq released per MJ delivered to heat water). Gas, although a fossil fuel, is less greenhouse intensive (61-65 g of CO_2 eq released per MJ delivered to heat water). The tests and methodology used to determine the efficiency of a water heater in Australian Standards concentrate exclusively on the delivery of energy to heat water at a product level, rather than in the context of an installed system where standby losses (i.e. centralised ring main energy consumption) 'dead water' losses (from flushing water that has cooled in water pipes) or on-going energy requirements of a system (i.e. pumping, heat tracing, etc.) would be included.

In the amendments above, the NCC effectively bans electric water heaters in most residential contexts, no matter how efficient they are stand alone are or incorporated into a highly efficient building wide HWS. There is however another section to the amended NCC that opens opportunities for CFEWHs:

3.12.5.6 Water heater in a hot water supply system[2]

(a) A water heater in a hot water supply system must be—

(i) a solar heater complying with (b); or

(ii) a heat pump heater complying with (b); or

(iii) a gas water heater complying with (c); or

[2] With various state variations

(iv) an electric resistance heater only in the circumstances described in (d).

(b) A solar heater and a heat pump heater must have the following performance:

(i) For a building with 1 or 2 bedrooms—

(A) at least 14 Small-scale Technology Certificates for the zone where it is being installed; or

(B) an energy saving of not less than 40% in accordance with AS/NZS 4234 for a "small" load system.

(ii) For a building with 3 or 4 bedrooms—

(A) at least 22 Small-scale Technology Certificates for the zone where it is being installed; or

(B) an energy saving of not less than 60% in accordance with AS/NZS 4234 for a "medium" load system.

(iii) For a building with more than 4 bedrooms—

(A) at least 28 Small-scale Technology Certificates for the zone where it is being installed; or

(B) an energy saving of not less than 60% in accordance with AS/NZS 4234 for a "large" load system.

(c) A gas heater must be rated at not less than 5 stars in accordance with AS 4552.

(d) An electric resistance water heater with no storage or a hot water delivery of not more than 50 L in accordance with AS 1056.1 may be installed when—

(i) the building has—

(A) not more than 1 bedroom; and

(B) not more than 1 electric resistance water heater installed; or

(ii) the building has—

(A) a water heater that complies with (b) or (c); and

(B) not more than 1 electric resistance water heater installed; or

(iii) the greenhouse gas emission intensity of the public electricity supply is low.

Other applications are permitted for electrical water heaters, above and beyond the greenhouse factors referred to in the BCA section 2.6.3. Of particular interest are low 'water use' scenarios, such as dwellings with one bedroom, apartment complexes, commercial buildings with kitchenettes, hotel rooms, etc.

It also opens the possibility to electrical water heaters being used as boosters, or top-up products on less greenhouse intensive systems such as gas and solar, which may be a highly efficient way to manage water and energy consumption, based on the highly controlled CFEWHs.

It must also be stated, that if Australian targets on greenhouse emissions are enacted by government, CFEWH technology may become more viable for standard hot water services, as the greenhouse gas intensity of the electricity grid diminishes and/or carbon offset mechanisms become more widely used, which may require further attention within the NCC.

3.4 System description and boundary

This study endeavours to encompass all unit processes associated with the supply of the functional unit.

The system boundary for the hot water delivery is shown in Figure 3-1 which describes the unit processes considered, as well as processes excluded from the study. This system boundary is explored in more detail for the HWSs described in the inventory in Section 4.

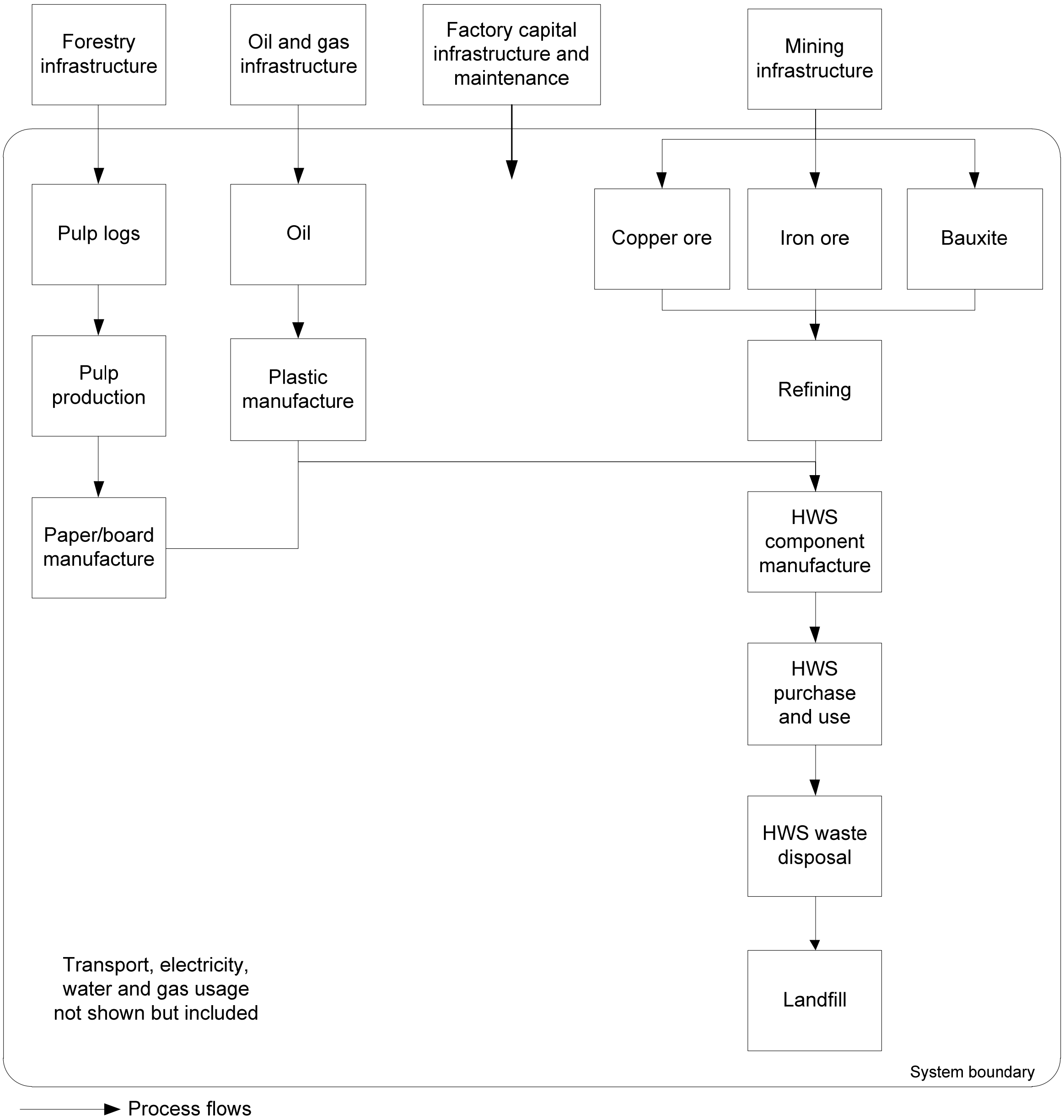

Figure 3-1: System boundary for the hot water systems

3.4.1 *Key assumptions and system boundary rationale*

The system boundary includes the raw and ancillary materials, energy and fuel inputs associated with production of materials and components, distribution and the subsequent end-of-life disposition of the HWS components. Table 3-2 shows the included and excluded processes within the base case scenario.

Table 3-2 : System boundary constituents for the base case scenario

Included	Excluded
• Material manufacture (raw materials) • Component manufacture • HWS use (water, electricity, gas, etc.) o Victorian electricity grid and fuel profile o Australian natural gas production and combustion at industrial facility o Melbourne (Australia) tap water • End-of-life management o Landfill • Component transport to supplier • Component transport to building • Component transport to end of life	• Capital equipment and maintenance • Internal transportation of materials (i.e. warehouse transport, forklifts, etc.) • Transportation of employees • Overheads (heating, lighting) of supplier facilities • Testing, assembly and packaging • Installation of HWSs • Maintenance/operation of support equipment • Human labour • Appliances

Infrastructure impacts have been excluded from the study (although some background inventory items may include minor impacts elementary flows). The capital equipment directly involved in the production of the HWS is assumed to contribute minimally to the life cycle, with the contribution to impacts per unit of product negligible due to high production volumes coupled with the infrastructure life span. Infrastructure involved in the production of each HWS component is also estimated to be relatively similar, so to differentiate the two processes would also be negligible. The water is treated as delivered at an apartment level, rather than a room or appliance level in this study, and as such appliance component and use impacts are excluded, considered part of another life cycle.

Similarly component testing, assembly, packaging and installation impacts were not included, as these were considered minor compared to the component and particularly the use phase impacts, and similar across the various systems. Replacement components were considered over the life of the building, and tested in sensitivity analyses in Section 6.2.3, where inclusion of packaging could also be assumed in these increases.

In addition, supplier administration overheads are excluded from the study as it is also estimated to reflect a small proportion of total impact, and expected to be similar across both HWS system life cycles.

3.5 Limitations

The data used is limited by the quality of primary data collected from industry and the quality of secondary data sets utilised in existing Life Cycle Inventories (LCIs).

Inventory items for which MicroHeat and suppliers provided primary data included materials, manufacturing processes, component masses, shipping and transport locations, and some energy consumption data not currently contained in existing data sets.

Currently the HWS components are produced in Australia, Asia, USA and Europe. The HWS use phases occur in Australia. In assessing potential environmental impacts, the study does not differentiate between local and global impacts. For certain environmental indicators, such as water use, this can be important because water may be scarce locally, but not scarce at foreign locations. For example, there is a growing body of evidence suggesting water is becoming a global issue (Ridoutt and Pfister 2009). Other environmental impacts, such as global warming, can be considered of equal importance both locally and at foreign locations. So the results may have different sensitivity if the product were produced and used in another global region.

Some inventory items required secondary data that derived from a region other than the origin of the specific inventory item. No component manufacturing or manufacturing contributed to more than 2 % of a particular impact category (apart from the inventory measure of solid waste), so it was deemed appropriate not to modify the electricity grids for materials or processes sourced by MicroHeat or other manufacturers from countries other than those in the data source.

3.6 Data quality requirements

A data quality assessment was undertaken for the HWSs being analysed. Data quality was assessed as described by ISO 14044:2006 (International Organization for Standardization 2006b). Table 3-3 presents the data quality requirements of the study.

Table 3-3: Data quality requirements

Aspect	Requirement
Timeframe	Post 2003 (within 10 years)
Geography	Country of unit process origin
Technology	Manufacturer specific
Precision	80%
Completeness	80%
Representativeness	Good
Consistency	Good
Reproducibility	Good
Uncertainty	Low

It is acknowledged that some primary and secondary data may fall outside these requirements. Section 4.19 details the data quality assessment and summaries any areas of issue to be further investigated in the sensitivity analyses.

3.7 Cut-off criteria

Based upon the scope of the study, a cut-off criterion was applicable for small mass contributions or non-reported items (such as adhesives and inks). All foreground mass flows have attempted to be captured back to the manufacturer provenance, however it can be assumed that some minor background mass flows may have been omitted, so it is estimated that a cut-off criterion of 2% by mass (or impact) has been applied. The majority of energy data is to the second order (cradle to gate and transmission losses). Although some background European data includes the third order (capital equipment), this was switched off for the impact assessment.

3.8 Allocation procedures

Allocation relates to the methods of ascribing environmental impacts of related processes. ISO 14044:2006 outlines a hierarchy to deal with allocation. These hierarchal steps are to:

1. Avoid allocation by expanding the system or dividing the unit process into sub-processes.
2. Partition (allocate) by using underlying physical relation.
3. Partition (allocate) by using other relationship (e.g. economic value).

In general, allocation was avoided in the study by ensuring that unit processes were directly related to the production, processing, distribution and use of the products involved. On the rare occasion where direct metering or data measurement was not possible within the manufacturing environment, mass allocation was applied for the unit process under consideration. A consistency check was undertaken to ensure aggregate manufacturing impacts were reasonable.

No foreground multi-output processes were present. Traditional multi-input processes, such as waste treatment in landfill, have been modelled for specific material types, with emissions linked to the associated emissions profiles. The impacts of transport tasks have been allocated based on the mass of the materials being transported.

3.9 Life Cycle Impact Assessment methodology

This LCA study investigates the potential environmental impacts relating to a range of characterised impact and inventory indicators from the Australian Impact Assessment Method developed by the CfD. The environmental indicators investigated in line with the goal of the project are presented in Table 3-4. It should be noted that characterisation of water use is problematic in most LCA studies, particularly when addressing water scarcity. The impact category – water scarcity - was not included.

Table 3-4: Environmental impact indicators of importance to the goal of the study

Indicators	Unit	Description
Global Warming Potential	kg CO_2 eq	Climate change effects resulting from the emission of carbon dioxide (CO_2), methane or other global warming gases into the atmosphere – this indicator is represented in CO_2 equivalents. Factors applied to convert emissions of greenhouse gas emissions into CO_2 equivalents emissions are taken from the IPCC Fourth Assessment Report (2007). The values used are based on a 100 year time horizon.
Cumulative energy demand (CED)	MJ LHV	All energy use including fossil, electrical and feedstock (energy incorporated into materials such as plastic). Renewable energy is not included. The energy measure is at the lower heating value (LHV).
Water use	kL H_2O	Gross water use. Total of all water used by the processes considered. The use of water in hydropower plant is excluded.
Solid waste	kg	Net solid waste generated. Total of all solid waste generated by the processes considered.

Lower heating value (LHV) is used for cumulative energy demand in the Australian Impact Assessment Method, as well as many European Assessment Methods. LHV is appropriate as much of the systems assessed are not condensing the vapour from fuel combustion to reclaim the latent heat. This is appropriate for Australasian Unit Process LCI (AUPLCI), where the majority of the LCI is derived from.

3.9.1 Data requirements

Data requested from MicroHeat was required to align with the processes included in the product system, and the impact assessment method. These included material flows, energy consumption, and emissions (to air, water and land).

3.10 Peer review

ISO 14044:2006 (International Organization for Standardization 2006b), defines the framework and requirements of an LCA, under which it is necessary to:

a) conduct a third part review of the LCA report, and;
b) engage interested parties in the review of LCA studies that are intended to be used in comparative assertions, ISO 14044:2006 (International Organization for Standardization 2006b): paragraph 4.2.3.7.

An independent, external peer reviewer was engaged for the study. Their comments and the considerations based on this feedback are contained in Appendix B.

ISO14044:2006 implies that this review is a requirement when comparative results are to be used in the public domain (International Organization for Standardization

2006b): paragraph 4.2.3.7. A concerted attempt was also made to involve interested parties throughout the study, by talking to suppliers, manufacturers and recyclers. See Section Appendix H for more details of the LCA methodology.

3.11 Type and format of the report required for the study

This report was structured to document the outcomes of the study in a format which included results required by MicroHeat. The report was required to be peer reviewed to be compliant with the ISO ISO 14040:2006 and 14044:2006 standards.

4 Life Cycle Inventory

The life cycle inventory (LCI) documents the foreground process, elemental and environmental flows for the base case scenario hot water systems within the system boundary (refer Section 3.4).

4.1 Data collection procedures

The inventories presented in Table 4-1 were compiled in order to assemble the LCI.

Table 4-1: Data collection details

Data	Data source/s
Material manufacture	Literature
HWS manufacturing	Manufacturers and literature
HWS layout and use	SAMME, Wood and Grieve, manufacturers and literature
Transport	MicroHeat, manufacturers and literature
Landfill waste treatments	Manufacturers and literature
Energy processes, including electricity and natural gas use	Literature
Environmental Emissions	Literature
Notes: Details on specific 'literature' and manufacturer data sources are documented in each inventory table presented in the following sub-sections	

These inventories were developed from various sources, including data directly from suppliers (the majority of data), existing LCIs and publically available literature. Existing unit processes were sourced primarily from European ecoinvent 2.2 inventory datasets, with any Australian based processes sourced from the AUPLCI. No data had a significant influence on impact categories of interest (more than 5%) from ecoinvent 2.2 (apart from solid waste for HWS 3 and HWS 4), as these were primarily materials and processes, where use phase Australian based energy drove most impacts. The remainder of this section details these inventories. All references in the tables within the LCI that refer to 'unit process', are referring to the specific unit process used in the SimaPro software, and are stated as per the grammatical convention used within the names of such processes.

4.2 Top level summary

Table 4-2 summarises the key inventory data and assumptions for the study.

Table 4-2: Summary of key inventory assumptions for hot water systems under study (base case)

	Building 1 - Melbourne CBD		Building 2 - East Melbourne		
	1. La Banque HWS 1	**2. La Banque HWS 2**	**3. Brahe Place HWS 3**	**4. Brahe Place HWS 4**	**5. Brahe Place HWS 5**
Type of hot water system	Gas plant ring main	Point of use instant electric	Gas plant ring main	Gas plant ring main & solar	Point of use instant electric
Number of residences	257	257	8	8	8
Household occupancy profiles (people)	257 (1 per residence, low) 382 (1.5 per residence, average) 643 (2.6 per residence, high)		9 (1 per residence, average) 18 (2 per residence, high)		
Residence bedroom split (1 or 2 bedroom)	154 x 2br 103 x 1br	154 x 2br 103 x 1br	8 x 1br	8 x 1br	8 x 1br
Vacancy (%)	0	0	0	0	0
Annual useful hot water per residence (kL)	20 (55 L per day, low) 27 (73.3 L per day, average) 42 (110 L per day, high)		20 (55 L per day, average) 34 (92 L per day, high)		
Annual building hot water direct heating energy (GJ)**	1,164 (low) 1,482(average) 2,209 (high)	792 (low) 1,052 (average) 1,644 (high)	53 (average) 73 (high)	35 (average) 54 (high) With solar contribution	25 (average) 41 (high)
Annual building hot water standby heating energy (GJ)**	712 (low) 716 (average) 723 (high)	0	40 (average) 40 (high)	40 (average) 40 (high)	0
Non heating energy inputs to the hot water system	Electronic pumps, gas standby & fans	Electronic standby	Electronic pumps, gas standby & fans	Electronic pumps, gas standby & fans	Electronic standby
Heater efficiency (average %)	80	98	80	80 + solar	98
Ambient cold water inlet temperature (°C)	8 (winter average) 20 (summer average)				
Delivered hot water temperature (°C)	Heated to 70, then tempered to 50	50	Heated to 70, then tempered to 50		50
Building life (years)	50				
Hot water system component replacement schedule (years)	10 - Pumps, water heaters and valves 25 – Hot water tanks and solar collectors 50 – Pipes, insulation and other miscellaneous				
Hot water system component end of life	Landfill				

As household size profiles is dynamic in any building (based on churn and market factors), this was determined as a range of possibilities with ABS data extrapolations (Australian Bureau of Statistics 2007) as per Section 4.13, and cross checks with available building managers. Demand side annual hot water consumption metering per residence was not feasible, so this was determined in combination with the household size profiles and Federal Government hot water use extrapolations (Australian Bureau of Statistics 2007; Department of the Environment Water Heritage and the Arts 2008) as per Section 4.14. Building life was determined from other studies and Australian Building Code Board data (Australian Building Codes Board 2006) as per Section 4.9, tested with sensitivity analyses variations in Section 6.2.3. The component replacement schedule for the HWSs was determined using manufacturer advice as per Section 4.10, tested with sensitivity analyses variations in Section 6.2.3. The following sections describe the inventory of the two buildings selected for analysis and potential hot water systems related to those buildings.

4.3 La Banque (Melbourne CBD)

Figure 4-1: La Banque building, Melbourne CBD (image courtesy: Paragon Real Estate)

The first building selected by Wood and Grieve to analyse was a high density apartment complex La Banque, located in the Melbourne CBD at 380 Little Lonsdale Street. It consists of 257 apartments. As regional context is of interest, Section 6.2.1 details a sensitivity analysis of the effect on results of the building being located in other Australian capital cities.

Wood and Grieve specified two potential HWS specifications for comparison, being:

- Hot water via a centralised gas boosted plant (HWS 1)
- Hot water via individual continuous flow electric water heaters in each apartment (HWS 2)

The building currently houses the second of these specifications. The following is the main specification excerpt supplied by Wood and Grieve:

Installation of individual continuous flow electric hot water heaters will typically entail providing space within the apartment to house the individual hot water unit. Metering can be provided on an apartment by apartment basis as electricity and cold water *consumption to each apartment is already metered. Hot water temperature would be set to 50 °C outlet, hence eliminating the need for tempering valves.*[3]

Installation of a central plant will consist of gas boosters, hot water storage tanks and hot water flow and return pumps. Note, due to the plant located at rooftop (i.e. 100 metres above ground) a cold water booster pump set is required for the supply of water to plant as town main supply pressure is insufficient. A spatial allocation on the roof for housing all equipment is required. Individual apartment metering would be achieved through the use of a proprietary Origin energy remote hot water metering solution that would meter the hot water consumption of each apartment and accordingly apportion the associated gas costs.

<u>Centralised Gas Boosted Hot Water Plant (High Rise)</u>

A centralised gas boosted hot water plant that would be adequate to serve a high rise building containing 257 apartments consists of:

- *Bosch Hot water System consisting of:*
  - *Free standing continuous flow gas heater manifold (10 x heaters)*
  - *1 x Hot water flow and return pump*
  - *2 No X 315L Storage Tanks*
- *Flow and return hot water pumps*
- *Gas pipework and bulk meter*
- *Hot water meters*

A centralised hot water system relies on a main hot water flow and return loop being constantly circulated throughout the building from which each individual apartment will draw from. A plant spatial is required at roof level with an approximate area of 20m^2.

A plant spatial will be required at ground floor of 4 m^2 to accommodate the constant pressure domestic cold water pump set.

Note: hot water plant outlet temperature would be set at 70°C. Pipework will be a combination of copper tube and Wethatherm. All pipework will be lagged with 25 mm Armaflex insulation or equivalent. (Wood and Grieve Engineers 2011a)

4.4 La Banque system components

Wood and Grieve provided a bill of materials (BOM) of components that were unique to the two potential systems. Details of common system elements were not considered, due the comparative nature of the study. Table 4-3 and Table 4-4 detail the alternative BOMs.

[3]It is assumed that the MicroHeat continuous flow water heater will comply with AS3498 and be clearly marked “THIS APPLIANCE DELIVERS WATER NOT EXCEEDING 50°C IN ACCORDANCE WITH AS 3498” As required by AS3500.4, Clause 1.9.3.(b).(iii)

Table 4-3: BOM of La Banque CFEWH HWS under study (Wood and Grieve Engineers 2011a)

Item	Quantity
CFEWH (Supply and Installation)	257
Electrical Per apartment	
-Additional apartment electrical Infrastructure	257

Table 4-4: BOM of La Banque centralised gas plant HWS under study (Wood and Grieve Engineers 2011a)

Item	Quantity
Hot Water Plant	1
Tempering Valves	257
Remote Read Hot Water Meters	257
Hot water Flow & Return Pump	1
Bulk Cold Water Meter Assembly & BFPD	1
Gas pipework to Hot water plant, 150 dia	200m
Gas Meter for Bulk Hot water plant	1
75 dia Hotwater flow – lagged (Wefatherm)	150m
40 dia Hotwater flow – lagged (wefatherm)	1,400m
40 dia Hotwater flow – lagged (copper)	50m
20 dia Hotwater flow – lagged (copper)	75m
Isolation valves, balancing valves, check valves	
Fire Collars	

Wood and Grieve was actively engaged about this specification. Originally (as per the excerpt in Section 4.3) a cold water booster pump set was specified for only the gas plant. After discussion with Wood and Grieve, it was decided this would be required for both systems to supply of water as town main supply pressure is insufficient. As such, the booster pump set was not included in the BOMs, due to the analysis being a comparison. Isolation valve, balancing valve, check valve and fire collar numbers were not originally specified, but estimated with the collaboration with Wood and Grieve. Figure 4-2 describes the BOM above in pictorial form.

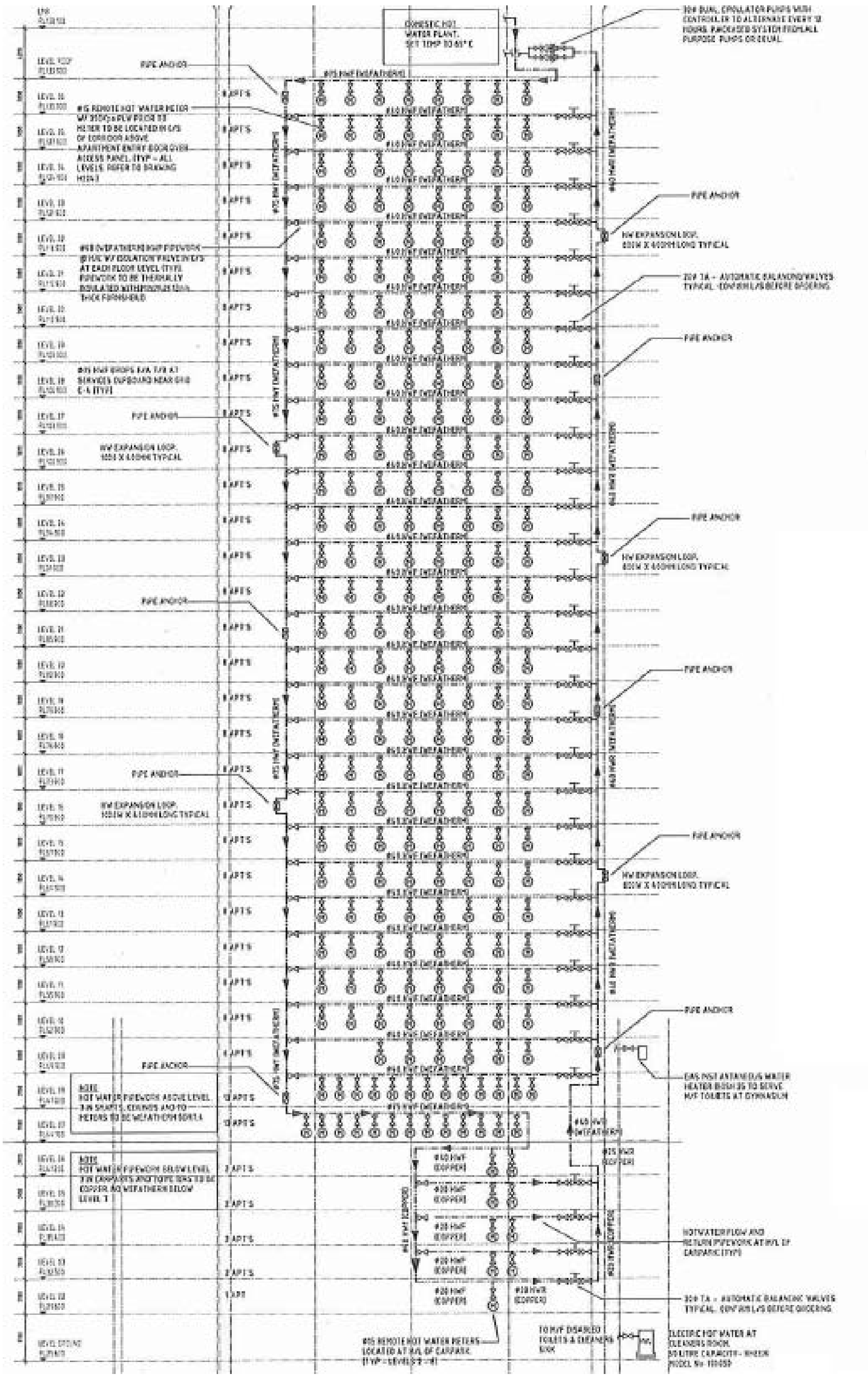

Figure 4-2: La Banque building HWS elevation schematic (Wood and Grieve Engineers 2011a)

Sections 4.7 to 4.11 describe the inventory of the materials and processes of components summarised in Sections 4.3 and 4.4. It is noted that the engineers did not specify a solar option for the La Banque building, and as such it is not included in this study.

4.5 Brahe Place (East Melbourne)

Figure 4-3: Proposed Brahe Place building, East Melbourne (Sheppard 2011)

The second building selected by Wood and Grieve to analyse was a proposed medium density apartment complex located in East Melbourne at 18 Brahe Place. It consists of 8 apartments. As regional context is of interest, Section 6.2.1 details a sensitivity analysis of the effect on results of the building being located in other Australian capital cities.

The proposed building is still at a planning stage and Wood and Grieve specified three potential HWSs for comparison, being:

- Hot water via a centralised gas boosted plant (HWS 3)
- Hot water via a centralised gas boosted solar arrangement (HWS 4)
- Hot water via individual continuous flow electric water heaters in each apartment (HWS 5)

The following is the main specification excerpt supplied by Wood and Grieve:

Installation of individual continuous flow electric hot water heaters will typically entail providing space within the apartment to house the individual hot water unit. Metering can be provided on an apartment by apartment basis as electricity and cold water consumption to each apartment is already metered. Hot water temperature would be set to 50°C outlet, hence eliminating the need for tempering valves.[4]

Installation of a central plant consisting of gas boosters, hot water storage tanks, solar panels and solar storage tanks will typically entail providing a space external to the building for housing. The equipment may be located at ground level or at roof top. A spatial allocation on the roof for solar collectors will be required. Individual apartment metering would be achieved through the use of a proprietary Origin energy remote hot water metering solution that would meter the hot water consumption of each apartment and accordingly apportion the associated gas costs. Note, this

[4] It is assumed that the Microheat continuous flow water heater will comply with AS3498 and be clearly marked “THIS APPLIANCE DELIVERS WATER NOT EXCEEDING 50˚C IN ACCORDANCE WITH AS 3498” As required by AS3500.4, Clause 1.9.3.(b).(iii)

applies to developments with more than 20 apartments. Developments with less than 20 apartments may be installed with body corporate hot water meters for internal system monitoring of hot water plant by the body corporate. These meters will not be read by a gas retailer for billing purposes, the will be read by the body corporate who will then appropriately apportion the gas costs to apartment tenants.

<u>Continuous Flow Electric Hot Water Heaters (Low Rise and High Rise Buildings)</u>

A CFEWH would be of adequate size to serve an apartment with 1 bathroom. A CFEWH would be of adequate size to serving an apartment with a maximum of 2 bathrooms. Note, these units are selected based on setting a outlet temperature of 50°C and the use of low flow fixture 'Wels' rating tapware. The units could be located within the joinery beneath the kitchen sink or at bathroom of each apartment.

It should be noted that the electric hot water option does not include allowances for solar contribution. We are not aware of any planning permit requirements at this stage, but the Council may impose a solar hot water requirement which would make this option potentially difficult (and expensive) to configure to suit. Given this, we have not considered any solar contribution to this option.

<u>Centralised Gas Boosted Hot Water Plant and Solar Storage (Low Rise)</u>

A centralised gas boosted solar hot water that would be adequate to service 18 Brahe Place, consists of:

- *Rheem MPE02K consisting of:*
  - *Free standing continuous flow gas heater manifold (2 x heaters)*
  - *1 x Hot water flow and return pump*
- *Solar pre heat plant:*
  - *4 x Rheem or equivalent NPT200 Collectors*
  - *2 x Double Variable pitch roof Frames*
  - *2 x 410L Storage tanks*
  - *1 x Solar Controller*
- *Flow and return hot water pumps*
- *Gas pipework and bulk meter*
- *Hot water meters*

A centralised hot water system relies on a main hot water flow and return loop being constantly circulated throughout the building from which each individual apartment will draw from. A plant spatial will be required at ground floor with an approximate area of 6m^2. A roof top plat spatial area of approximately 15m^2 is required for the solar collectors. This area includes access for personnel maintenance.

Note, hot water plant outlet temperature would be set at 65°C. All pipework will be of copper tube material and be lagged with 25mm Armaflex insulation or equivalent (Wood and Grieve Engineers 2011b)

It was decided to change the output temperature of the gas plant to 70°C, to make the output temperature of the two buildings consistent.

4.6 Brahe Place system components

Wood and Grieve provided a bill of materials (BOM) of components that were unique to the three potential systems. Details of common system elements were not considered, due the comparative nature of the study. Table 4-5 and Table 4-6 detail the alternative BOMs.

Table 4-5: BOM of Brahe Place CFEWH HWS under study (Wood and Grieve Engineers 2011a)

Item	Quantity
CFEWH (Supply and Installation)	8
Electrical Per apartment	
-Additional apartment electrical Infrastructure	8

Table 4-6: BOM of Brahe Place centralised gas/solar and gas plant HWSs under study (Wood and Grieve Engineers 2011a)

Item	Quantity
Hot water Booster Plant	1
Hot water Flow & Return Pump	1
Hot water Solar Plant	1
Hot water plant enclosure – Plinth & Chain Wire Mesh	1
Bulk Cold Water Meter Assembly	1
Tempering valves	8
Gas pipework to Hot water plant, 100 dia approx. (copper)	30m
Gas Meter for Bulk Hot water plant	1
32 dia hot water flow – lagged, (copper)	25m
25 dia hot water flow – lagged, (copper)	75m
25 dia cold water flow (poly)	35m
Isolation valves, balancing valves	1
15mm dia hot water meters (body corporate)	8
Fire Collars	12
Optional deletion of solar panels	

Wood and Grieve was actively engaged about this specification. Figure 4-4 describes the BOM above in pictorial form.

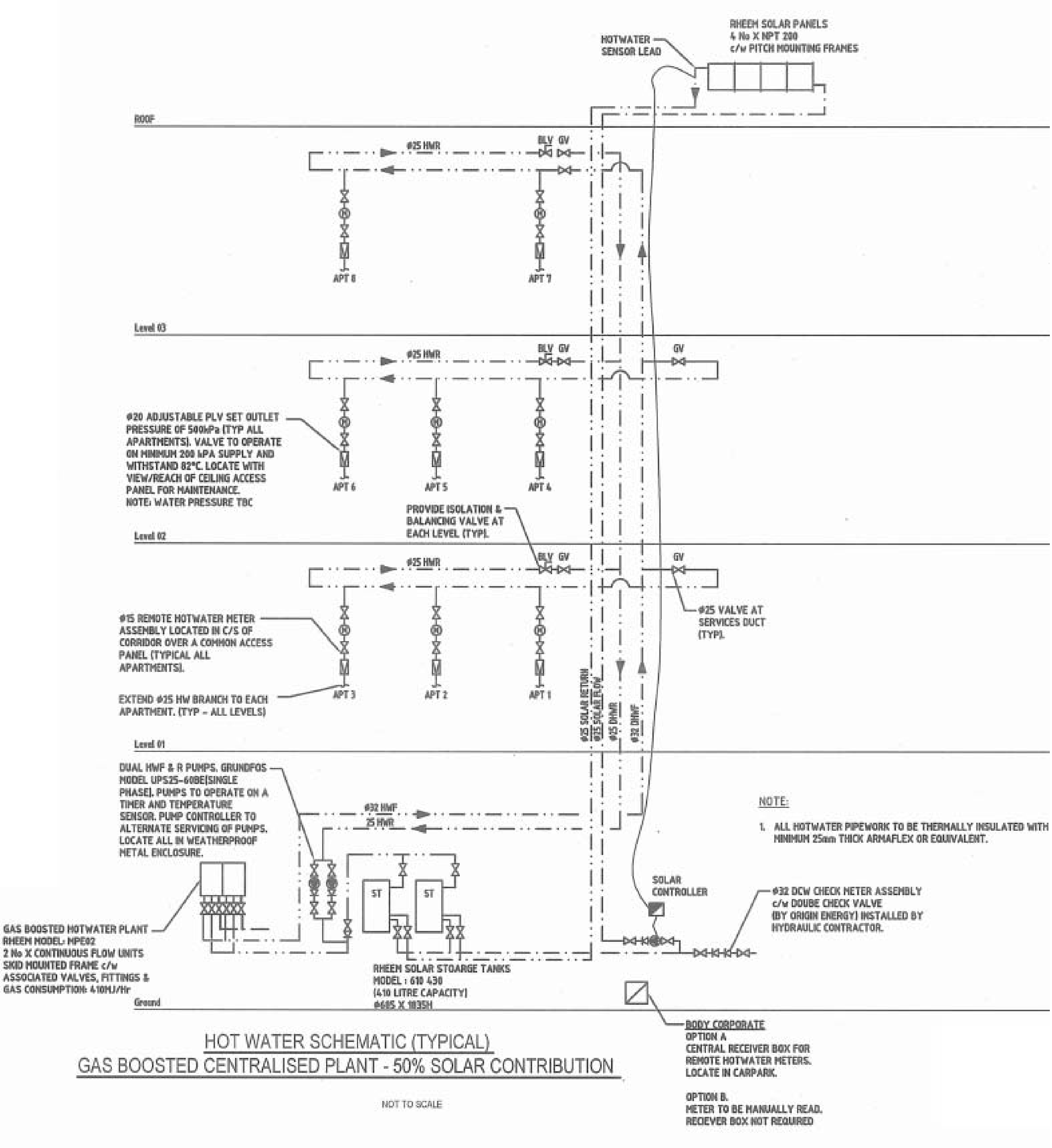

Figure 4-4: Brahe Place building elevation HWS schematic (Wood and Grieve Engineers 2011a)

Sections 4.7 to 4.11 describe the inventory of the materials and processes of components summarised in Sections 4.3 and 4.4 4.6.

4.7 HWS component materials

The inventory data for materials for the proposed HWSs components in the two buildings were either derived from manufacturing data sources, direct manufacturer correspondence or estimated from the best component supplier literature source available. This data was combined with appropriate material unit processes from ecoinvent 2.2 inventory datasets and any Australian based materials sourced from the AUPLCI for Australian manufacture.

Most materials were estimated (from a total component mass or non-disclosure of specific materials), so estimated masses and proxy materials were used from ecoinvent 2.2 or AUPLCI. For any data derived from ecoinvent 2.2 where the materials are manufactured in a different region to Europe, it is assumed that production is similar globally so relative changes to the environmental impacts would be negligible. In addition to this, ***the combined materials and manufacturing processes (including replacement schedules over the building life) contributed no more than 3% of a particular impact category for both buildings in reference to the functional unit,*** so it was deemed unnecessary to modify materials used by manufacturers from countries other than the sourced LCI data to reflect the electricity grid profiles of those regions (apart from solid waste for HWS3 and HWS 4, which is discussed in Section 6.1.8). This, coupled with the fact that this is a comparative LCA, makes these sources appropriate. Packaging materials were not included as details were often not available from manufacturers, considered similar across all systems, and deemed a small proportion of component mass. All of these assumptions were tested with a sensitivity analysis in Section 6.2.3 by increasing the replacement frequency by 5 and 10 fold respectively, effectively increasing the material masses by these factors, to see if the results changed.

Table 4-7 and Table 4-8 summarise the material inputs and data sources for the HWSs respectively. The material input amount relative to the functional unit is reported in Section 4.11. Proxy materials or masses (where specified materials were not in existing LCIs, or component masses within assemblies were not published or provided by manufacturers) are denoted by an asterix (i.e. *).

Table 4-7: Inventory of all materials in the La Banque HWS components

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
1. Gas plant ring main	Polymer pipe Ø = OD (Wefatherm, 1400m - Ø40mm, 150m – Ø75mm)	PP	1163	Polypropylene, granulate, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope.
	Copper pipe Ø = OD (Crane, 75m – Ø20mm, 50m – Ø40mm, 200m – Ø150mm)	Copper	1818	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
	Insulation Ø = ID	PU*	2079	Polyurethane, flexible foam, at	Model from ecoinvent 2.2. Details in “ Life

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
	(Armaflex, 75m – Ø20mm, 1450m – Ø40mm, 150m – Ø75mm)			plant	Cycle Inventories of Packaging and Graphical Paper, 2007”
	Tempering valve (Reliance Heatguard U-15) 0.50 kg each 257 units	Stainless steel	21*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Brass	103*	Brass, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		PP*	2.6*	PP, Polypropylene, at plant	Model from AUPLCI. Developed from Kemcor Resins and Montell data.
		Synthetic rubber	2.6*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
	Hot water flow and return pump (Grundfos UPS 32-80 N 180) 16.3 kg each 2 units	Stainless steel	3.0*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Cast iron (includes process)	20*	Cast iron, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Copper	5.0*	Copper, at regional storage	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Aluminium	2.0*	Aluminium, primary, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Nylon (glass)*	1.6*	Nylon 66, glass-filled, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		PET	0.5*	Polyethylene terephthalate, granulate, amorphous, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Synthetic rubber	0.5*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		Stainless	50*	Chromium steel	Model from ecoinvent

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
		steel		18/8, at plant	2.2. Details in "Life Cycle Inventories of Metals, 2007"
	Gas heater with manifold unit (Bosch series 32, KM3211WHQ) 51 kg (with manifold mass per unit) each 10 units & manifold	Steel	100*	Steel, low-alloyed, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Copper	100*	Copper, at regional storage	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Synthetic rubber	10*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007"
		PP	10*	Polypropylene, granulate, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		ABS	20*	Acrylonitrile-butadiene-styrene granulate (ABS), production mix, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		PVC	20*	Polyvinylchlorid e, at regional storage	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Electronics (process included)	10*	Electronics for control units	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Chemicals, 2007"
	315L storage tank (Bosch 315C232LR) 75 kg each 2 units	Stainless steel	92*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Brass	2*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		PU*	18*	Polyurethane, flexible foam, at plant	Model from ecoinvent 2.2. Details in " Life Cycle Inventories of Packaging and Graphical Paper, 2007"
		HDPE	38*	Polyethylene, HDPE, granulate, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
	Water heater cycle pump	Stainless steel	17.6*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
	(Grundfos CHI-4-20) 9.6 kg each 2 units				Cycle Inventories of Metals, 2007”
		Brass	0.8*	Brass, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Synthetic rubber	0.4*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		PP*	0.4*	Polypropylene, granulate, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
	Hot water remote meter (Reliance WM201HWM - DN20) 2.3 kg each 1 unit	PS*	0.3*	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
		Copper	1.5*	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
		Brass	0.5*	Brass, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007
	Cold water bulk meter (Reliance DN40 Endurance Multijet) 5.7 kg each 1 unit	PS*	0.7*	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
		Cast iron (includes process)	4.5*	Cast iron, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Brass	0.5*	Brass, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007
	Balancing valve (TA Hydronics 52 265-040) 2.9 kg each 40 units	Stainless steel	4.0*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Copper	80*	Copper, at regional storage	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Nylon (glass)	20*	Nylon 66, glass-filled, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Synthetic rubber,	12*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
					Packaging and Graphical Paper, 2007".
	Isolation Valve (Reliance N175 - DN20) 0.53 kg each 590 units	Brass	59*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Stainless steel	59*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Cast iron (includes process)	177*	Cast iron, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Synthetic rubber	3.0*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007"
		PP*	12*	PP, Polypropylene, at plant	Model from AUPLCI. Developed from Kemcor Resins and Montell data.
	Check Valve (Reliance N7B200 - DN20) 0.25 kg each 1 unit	Brass	0.2*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		PP*	0.05*	PP, Polypropylene, at plant	Model from AUPLCI. Developed from Kemcor Resins and Montell data.
	Fire collar Ø = OD (Promat Unicollar 180 x Ø90mm, 20 x Ø125mm)	Graphite	1.5*	Graphite, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007"
		PVC	1.2*	PVC, Polyvinyl Chloride	Model from AUPLCI. Developed from Australian Vinyls data.
		Stainless steel	1.2*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
	Gas meter (Actaris Gallus 2000) 2 kg each	Aluminium	0.3*	Aluminium, at plant	Model from AUPLCI. Developed from AAC data.
		Brass	1.5*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
	1 units	PS*	0.2*	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
Total HWS 1 component mass in building			6168.25 kg		
2. Point of use instant electric	CFEWH (MicroHeat Series 1 - 27kW assembly) 4.5 kg each 257 units	Stainless steel	201	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Steel	45	Steel, low-alloyed, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		PS	314	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
		Nylon (glass)*	189	Nylon 66, glass-filled, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Synthetic rubber	4.4	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007".
		ABS	215	ABS, Acryloniril butastyrene, at plant	Model from AUPLCI. Developed from PWMI data.
		Printed circuit board (process included)	173	Printed wiring board, mixed mounted, unspec., solder mix, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Electric and Electronic Equipment - Production, Use & Disposal, 2007"
		Copper	6	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
		Tinplate*	0.1	Tinplate, at plant	Model from AUPLCI. Developed from Tellus data
		Brass	143	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007
		HDPE	3.1	HDPE, high density polyethylene, at plant	Model from AUPLCI. Developed from Qenos data.
		PVC	4.0	PVC, Polyvinyl Chloride	Model from AUPLCI. Developed from

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
					Australian Vinyls data.
		Aluminium	.005	Aluminium, at plant	Model from AUPLCI. Developed from AAC data.
		Zinc oxide	0.005	Zinc oxide, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Electric and Electronic Equipment - Production, Use & Disposal, 2007"
	Electric cables 10 kg per apartment 257 apartments	PVC	643	PVC, Polyvinyl Chloride	Model from AUPLCI. Developed from Australian Vinyls
		Copper	1928	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
Total HWS 2 component mass in building			3868.61 kg		

Table 4-8: Inventory of all materials in the Brahe Place HWS scenarios

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
3. Gas plant ring main	Copper pipe Ø = OD (Crane, 75m – Ø25mm, 25m – Ø32mm, 30m – Ø100mm)	Copper	226	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
	Insulation Ø = ID (Armaflex, 75m – Ø25mm, 25m – Ø32mm)	PU*	96	Polyurethane, flexible foam, at plant	Model from ecoinvent 2.2. Details in " Life Cycle Inventories of Packaging and Graphical Paper, 2007"
	Poly pipe Ø = OD (Auspex, 35m – Ø25mm)	HDPE	23	HDPE, high density polyethylene, at plant	Model from AUPLCI. Developed from Qenos data.
	Tempering valve (Reliance Heatguard U-15) 0.50 kg each 8 units	Stainless steel	0.7*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Brass	3.2*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		PP	0.1*	PP, Polypropylene, at plant	Model from AUPLCI. Developed from Kemcor Resins and Montell data.

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
	Hot water flow and return pump (Grundfos UPS 25-60 130) 2.6 kg each 2 units	Stainless steel	1.0*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Cast iron (includes process)	3.0*	Cast iron, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Copper	0.4*	Copper, at regional storage	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Aluminium	0.4*	Aluminium, primary, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Nylon (glass)*	0.2*	Nylon 66, glass-filled, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		PET	0.1*	Polyethylene terephthalate, granulate, amorphous, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Synthetic rubber	0.1*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
	Gas heater with manifold unit (Rheem MPE02K) 47.5 kg (with manifold mass per unit) each 2 units & manifold	Stainless steel	8*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Steel	63*	Steel, low-alloyed, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Copper	14*	Copper, at regional storage	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Synthetic rubber	2*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		PP	2*	Polypropylene, granulate, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		ABS	2*	Acrylonitrile-butadiene-	Model from ecoinvent 2.2. Developed from

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
				styrene granulate (ABS), production mix, at plant	PlasticsEurope data.
		PVC	2*	Polyvinylchloride, at regional storage	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Electronics (process included)	2*	Electronics for control units	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Chemicals, 2007”
	410 L storage tank (Rheem 610 430) 111 kg each 2 units	Stainless steel	136*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Brass	3*	Brass, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		PU*	27*	Polyurethane, flexible foam, at plant	Model from ecoinvent 2.2. Details in “ Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		HDPE*	56*	Polyethylene, HDPE, granulate, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
	Water heater cycle pump (Lowara 4HMS3) 6.8 kg each 2 units	Stainless steel	12*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Brass	0.8*	Brass, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Synthetic rubber	0.4*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		PP*	0.4*	Polypropylene, granulate, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
	Hot water remote meter (Reliance WM201HWM - DN20)	PS	0.3*	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
		Copper	1.5*	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
	2.3 kg each 1 unit	Brass	0.5*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007
	Cold water bulk meter (Reliance DN40 Endurance Multijet) 5.7 kg each 1 unit	PS	0.7*	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
		Copper	4.5*	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
		Brass	0.5*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007
	Balancing valve (TA Hydronics 52 265-040) 2.9 kg each 4 units	Stainless steel	0.4*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Copper	8.0*	Copper, at regional storage	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Nylon	2.0*	Nylon 66, glass-filled, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Synthetic rubber	1.2*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007".
	Isolation Valve (Reliance N175 - DN20) 0.53 kg each 30 units	Brass	3.0*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Stainless steel	3.0*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Cast iron	9.0*	Cast iron, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Synthetic rubber	0.2*	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007"
		PP	0.6*	PP, Polypropylene,	Model from AUPLCI. Developed from Kemcor Resins and Montell

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
				at plant	data.
	Fire collar Ø = OD (Promat Unicollar 12 x Ø90mm)	Graphite	0.08*	Graphite, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007"
		PVC	0.07*	PVC, Polyvinyl Chloride	Model from AUPLCI. Developed from Australian Vinyls data.
		Stainless steel	0.07*	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
	Gas meter (Actaris Gallus 2000) 2 kg each 1 units	Aluminium	0.3*	Aluminium, at plant	Model from AUPLCI. Developed from AAC data.
		Brass	1.5*	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007
		PS	0.2*	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
	Hot water plant enclosure	Steel Sheet (process included)*	115*	Steel Sheet, at regional store	Model from AUPLCI. Developed from Strezov & Herbertson, and Tellus data.
Total HWS 3 component mass in building			837.82 kg		
4. Solar plant**	Solar collector (Rheem NPT200) 40 kg each 4 units	Steel Sheet (process included)	60*	Steel Sheet, at regional store	Model from AUPLCI. Developed from Strezov & Herbertson, and Tellus data.
		Glass (process included)	60*	Glass, flat, at plant	Model from AUPLCI. Developed from Pilkington data.
		PET	12*	PET, polyethylene terephthalate, amorphous resin, at plant	Model from AUPLCI. Developed from BERGH, PEMS and Tellus data.
		Aluminium	28*	Aluminium, at plant	Model from AUPLCI. Developed from AAC data.
	Solar collector frame	Steel Sheet (process included)	81*	Steel Sheet, at regional store	Model from AUPLCI. Developed from Strezov & Herbertson, and Tellus data.

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
	(Rheem 12106871) 86 kg each 1 unit	Aluminium	5*	Aluminium, at plant	Model from AUPLCI. Developed from AAC data.
	Solar controller (Rheem 052104) 1 kg each 1 unit*	PP*	0.4*	PP, Polypropylene, at plant	Model from AUPLCI. Developed from Kemcor Resins and Montell data.
		Electronics (process included)*	0.6*	Electronics for control units	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Chemicals, 2007”
Total HWS 4 component mass in building			247 + 837.82 = 1084.82 kg		
5. Point of use instant electric	CFEWH (MicroHeat Series 1 - 27kW assembly) 4.5 kg each 8 units	Stainless steel	6.3	Chromium steel 18/8, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Steel	1.4	Steel, low-alloyed, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		PS	12.7	Polystyrene, general purpose, at plant	Model from AUPLCI. Developed from PWMI data.
		Nylon	2.9	Nylon 66, glass-filled, at plant	Model from ecoinvent 2.2. Developed from PlasticsEurope data.
		Synthetic rubber	0.1	Synthetic rubber, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”.
		ABS	6.7	ABS, Acryloniril butastyrene, at plant	Model from AUPLCI. Developed from PWMI data.
		Printed circuit board (process included)	5.4	Printed wiring board, mixed mounted, unspec., solder mix, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Electric and Electronic Equipment - Production, Use & Disposal, 2007”
		Copper	0.2	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
		Tinplate	0.004	Tinplate, at plant	Model from AUPLCI. Developed from Tellus data

HWS	Part, specific. units	Material in	Mass in building (kg)	Unit Process	Data source & comments
		Brass	4.5	Brass, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007
		HDPE	0.1	HDPE, high density polyethylene, at plant	Model from AUPLCI. Developed from Qenos data.
		PVC	0.1	PVC, Polyvinyl Chloride	Model from AUPLCI. Developed from Australian Vinyls data.
		Aluminium	0.0002	Aluminium, at plant	Model from AUPLCI. Developed from AAC data.
		Zinc oxide	0.0002	Zinc oxide, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Electric and Electronic Equipment - Production, Use & Disposal, 2007"
	Electric cables 10 kg per apartment 8 apartments	PVC	20*	PVC, Polyvinyl Chloride	Model from AUPLCI. Developed from Australian Vinyls
		Copper	60*	Copper, at plant	Model from AUPLCI. Developed from Norgate and Rankin data.
Total HWS 5 component mass in building			120.40 kg		

**Components for solar plant, the remainder of HWS 4 are the same as HWS 3 (Gas plant ring main). No mass available on solar controller, so mass estimated by Rheem, processes estimated for study.

4.8 HWS component manufacturing

The inventory data for manufacturing processes for the proposed HWSs components in the two buildings were either derived from manufacturing data sources, direct manufacturer correspondence or estimated from the best component supplier literature source available. This data was combined with appropriate processing unit processes from ecoinvent 2.2 inventory datasets and any Australian based manufacturing sourced from the AUPLCI for Australian manufacture.

Most processing masses were estimated (from a total component mass or non-disclosure of specific materials), so estimated masses and proxy manufacturing processes were used from ecoinvent 2.2 or AUPLCI. For any data derived from ecoinvent 2.2 where the manufacturing occurs in a different region to Europe, it is assumed that production is similar globally so relative changes to the environmental impacts would be negligible. In addition to this, ***the combined materials and manufacturing processes (including replacement schedules over the building life) contributed no more than 3% of a particular impact category for both buildings in reference to the functional unit,*** so it was deemed unnecessary to modify processes used by manufacturers from countries other than the sourced LCI data to reflect the electricity grid profiles of those regions (apart from solid waste for HWS3 and HWS 4, which is discussed in Section 6.1.8). This, coupled with the fact that this is a comparative LCA, makes these sources appropriate. Packaging manufacturing was not included as details were often not available from manufacturers, considered similar across all systems, and deemed a small proportion of component mass. All of these assumptions were tested with a sensitivity analysis in Section 6.2.3 by increasing the replacement frequency by 5 and 10 fold respectively, effectively increasing the processing masses by these factors, to see if the results changed.

Table 4-9 and Table 4-10 summarise the manufacturing process inputs and data sources for the HWSs respectively. The manufacturing input amount relative to the functional unit is reported in Section 4.11. Proxy processes or masses (where specified processes were not in existing LCIs, or component masses within assemblies were not published or provided by manufacturers) are denoted by an asterix (i.e. *).

Table 4-9: Inventory of all manufacturing processes in the La Banque HWS components

HWS	Part	Process	Mass in building (kg)	Unit Process	Data source & comments
1. Gas plant ring main	Polymer pipe	Extrusion	1163	Extrusion, plastic pipes	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper,2007”
	Copper pipe	Cold transforming*	1818	Cold transforming aluminium	Model from AUPLCI. Developed from Kemna data.
	Insulation	Foaming	2079	Foaming, expanding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
	Tempering valve	Casting	124*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	5.2*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
	Hot water flow and return pump	Sheet rolling	3.0*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Cast iron (includes material)	20*	Cast iron, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”

HWS	Part	Process	Mass in building (kg)	Unit Process	Data source & comments
		Wire drawing	5.0*	Wire drawing, copper	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Casting*	2.0*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	2.6*	Injection moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”.
	Gas heater with manifold unit	Sheet rolling	50*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Steel working	100*	Steel product manufacturing, average metal working	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
		Wire drawing	100*	Wire drawing, copper	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	60*	Injection moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		Electronics (includes material)	10*	Electronics for control units	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Chemicals, 2007”
	315L storage tank	Sheet rolling	92*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Casting	2*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Foaming	18*	Foaming, expanding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and

HWS	Part	Process	Mass in building (kg)	Unit Process	Data source & comments
					Graphical Paper, 2007”
		Blow moulding	38*	Stretch blow moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
	Water heater cycle pump	Casting	18.4*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	0.8*	Injection moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
	Hot water remote meter	Injection moulding	0.3*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Casting*	1.5*	Casting, bronze	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Casting	0.5*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Milling*	2.0*	Milling, cast iron, small parts	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
	Cold water bulk meter	Injection moulding	0.7*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Cast iron (includes process)	4.5*	Cast iron, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Brass	0.5*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Milling*	5.0*	Milling, cast iron, small parts	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
	Balancing valve	Wire drawing	4.0*	Wire drawing, steel	Model from ecoinvent 2.2. Details in “Life

HWS	Part	Process	Mass in building (kg)	Unit Process	Data source & comments
					Cycle Inventories of Metals, 2007"
		Copper	80*	Casting, bronze	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Injection moulding	32*	Injection moulding	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007".
	Isolation Valve	Casting	59*	Casting, brass	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Sheet rolling	59*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Wood as Fuel and Construction Material, 2007"
		Cast iron (includes material)	177*	Cast iron, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Injection moulding	15*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
	Check Valve	Casting	0.2*	Casting, brass	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Injection moulding	0.05*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
	Fire collar	Foaming	2.7*	Foaming, expanding	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007"
		Sheet rolling	1.2*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Wood as Fuel and Construction Material, 2007"
	Gas meter	Casting*	1.8*	Casting, brass	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Injection	0.2*	Injection	Model from AUPLCI.

HWS	Part	Process	Mass in building (kg)	Unit Process	Data source & comments
		moulding		moulding	Developed from Kemna data.
2. Point of use instant electric	CFEWH	Sheet rolling	201	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Wood as Fuel and Construction Material, 2007"
		Sheet rolling	45	Sheet rolling, steel	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Wood as Fuel and Construction Material, 2007"
		Injection moulding	725.5	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Printed circuit board (material included)	173	Printed wiring board, mixed mounted, unspec., solder mix, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Electric and Electronic Equipment - Production, Use & Disposal, 2007"
		Wire drawing	6	Wire drawing, copper	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Cold impact stroke	198	Cold impact extrusion, steel, 2 strokes	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007"
		Milling	43	Milling, chromium steel, average	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007"
		Bar rolling	0.5	Section bar rolling, steel	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Wood as Fuel and Construction Material, 2007"
		Casting	143	Casting, brass	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Extrusion	4.0	Extrusion, plastic pipes	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and

HWS	Part	Process	Mass in building (kg)	Unit Process	Data source & comments
					Graphical Paper,2007"
	Electric cables	Extrusion	643	Extrusion of PVC pipe	Model from AUPLCI. Developed from SPIN Plastics data
		Wire drawing	1928	Wire drawing, copper	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"

Table 4-10: Inventory of all manufacturing processes in the Brahe Place HWS scenarios

HWS	Part, specific. units	Process	Mass in building (kg)	Unit Process	Data source & comments
3. Gas plant ring main	Copper pipes	Cold transforming*	226	Cold transforming aluminium	Model from AUPLCI. Developed from Kemna data.
	Insulation	Foaming	96	Foaming, expanding	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper, 2007"
	Poly pipe	Extrusion	23	Extrusion, plastic pipes	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Packaging and Graphical Paper,2007"
	Tempering valve	Casting	3.9*	Casting, brass	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Injection moulding	0.1*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
	Hot water flow and return pump	Sheet rolling	1.0*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Wood as Fuel and Construction Material, 2007"
		Cast iron (includes material)	3.0*	Cast iron, at plant	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Wire drawing	0.4*	Wire drawing, copper	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"
		Casting*	0.4*	Casting, brass	Model from ecoinvent 2.2. Details in "Life Cycle Inventories of Metals, 2007"

HWS	Part, specific. units	Process	Mass in building (kg)	Unit Process	Data source & comments
		Injection moulding	0.4*	Injection moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”.
	Gas heater with manifold unit	Sheet rolling	8*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Steel working	63*	Steel product manufacturing, average metal working	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
		Wire drawing	14*	Wire drawing, copper	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	8*	Injection moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		Electronics (includes material)	2*	Electronics for control units	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Chemicals, 2007”
	410 L storage tank	Sheet rolling	136*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Casting	3*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Foaming	27*	Foaming, expanding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		Blow moulding	56*	Stretch blow moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper,

HWS	Part, specific. units	Process	Mass in building (kg)	Unit Process	Data source & comments
					2007”
	Water heater cycle pump	Casting	12.8*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	0.8*	Injection moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
	Hot water remote meter	Injection moulding	0.3*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Casting	1.5*	Casting, bronze	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Casting	0.5*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Milling*	2.0*	Milling, cast iron, small parts	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
	Cold water bulk meter	Injection moulding	0.7*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Cast iron (material included)	4.5*	Cast iron, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Casting	0.5*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Milling*	5.0*	Milling, cast iron, small parts	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
	Balancing valve	Stainless steel	0.4*	Wire drawing, steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Casting*	8.0*	Casting, bronze	Model from ecoinvent 2.2. Details in “Life

HWS	Part, specific. units	Process	Mass in building (kg)	Unit Process	Data source & comments
					Cycle Inventories of Metals, 2007”
		Nylon	3.2*	Injection moulding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”.
	Isolation Valve	Casting, brass	3.0*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Sheet rolling, chromium steel	3.0*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Cast iron (material included)	9.0*	Cast iron, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	0.8*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
	Fire collar	Foaming	0.15*	Foaming, expanding	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper, 2007”
		Sheet rolling	0.07*	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
	Gas meter	Casting	1.8*	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Injection moulding	0.2*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
	Hot water plant enclosure	Steel Sheet (material included)*	115*	Steel Sheet, at regional store	Model from AUPLCI. Developed from Strezov & Herbertson, and Tellus data.
4. Solar plant**	Solar collector	Steel Sheet (material included)	60*	Steel Sheet, at regional store	Model from AUPLCI. Developed from Strezov & Herbertson, and Tellus data.

HWS	Part, specific. units	Process	Mass in building (kg)	Unit Process	Data source & comments
		Glass (material included)	60*	Glass, flat, at plant	Model from AUPLCI. Developed from Pilkington data.
		Injection moulding	12*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Cold transforming	28*	Cold transforming aluminium	Model from AUPLCI. Developed from Kemna and Idemat data.
	Solar collector frame	Steel Sheet (material included)	81*	Steel Sheet, at regional store	Model from AUPLCI. Developed from Strezov & Herbertson, and Tellus data.
		Cold transforming	5*	Cold transforming aluminium	Model from AUPLCI. Developed from Kemna and Idemat data.
	Solar controller	Injection moulding*	0.4*	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Electronics (material included)*	0.6*	Electronics for control units	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Chemicals, 2007”
5. Point of use instant electric	CFEWH	Sheet rolling	6.3	Sheet rolling, chromium steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Sheet rolling	1.4	Sheet rolling, steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Injection moulding	22.5	Injection moulding	Model from AUPLCI. Developed from Kemna data.
		Printed circuit board (material included)	5.4	Printed wiring board, mixed mounted, unspec., solder mix, at plant	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Electric and Electronic Equipment - Production, Use & Disposal, 2007”
		Wire drawing	0.2	Wire drawing, copper	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”

HWS	Part, specific. units	Process	Mass in building (kg)	Unit Process	Data source & comments
		Cold impact strokes	6.2	Cold impact extrusion, steel, 2 strokes	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
		Milling	1.3	Milling, chromium steel, average	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metal Processing and Compressed Air Supply, 2007”
		Section bar rolling	0.02	Section bar rolling, steel	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Wood as Fuel and Construction Material, 2007”
		Casting	4.5	Casting, brass	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”
		Extrusion	0.1	Extrusion, plastic pipes	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Packaging and Graphical Paper,2007”
	Electric cables	Extrusion	20*	Extrusion of PVC pipe	Model from AUPLCI. Developed from SPIN Plastics data
		Wire drawing	60*	Wire drawing, copper	Model from ecoinvent 2.2. Details in “Life Cycle Inventories of Metals, 2007”

**Components for solar plant, the remainder of HWS 4 are the same as HWS 3 (Gas plant ring main). No mass available on solar controller, so mass estimated by Rheem, processes estimated for study.

4.9 Building life

Building-life assumptions are often arbitrary in nature in LCA studies. They are however critical to determining the total impact of building components (such as HWS components) over a building life as well as the comparison of component impacts and impacts associated with operation and the other lifecycle stages. Amongst other studies, a range of building lives has been considered ranging, from 50 to 80 years. Justification for such assumptions was typically limited with most studies acknowledging the arbitrary nature of the building life assumption.

Table 4-11: **Comparison of different LCA studies on residential buildings.**

Study	**LCA applied to the comparative evaluation of single family houses in the French context**	**CORRIM: Life-Cycle Environmental Performance of Renewable Building Materials**	**Sustainability based on LCM of residential dwellings: A case study in Catalonia, Spain**	**LCA Fact Sheet: LCA of clay brick housing, based on a typical project home**	**Comparative LCA of Alternative Construction of a Typical Australian House Design**
Author/s	(Peuportier 2001)	(Lippke *et al.* 2004)	(Ortiz *et al.* 2009)	(Maddox and Nunn 2003)	(Carre 2011)
Functional unit	1 m^2 living area	Total house	1m^2 floor area	Total house	1 m^2 floor area
House size	112-212 m^2	190-200 m^2	160 m^2	127 m^2	202 m^2
Building types	All single storey houses	Both single and double storey houses	Double storey house	Various houses	Single storey house
Building life	80 years	75 years	50 years	60 years	50 years
Country	France	USA	Spain	Australia	Australia
Time frame	2001	2004	2008	2003	2011

Building life for this study has been assumed to be 50 years. This assumption is reflects other studies (refer Table 4-11) as well as Australian Building Codes Board guidance (ABCB 2006) on building life of a normal building. As building life can be considered arbitrary this assumption is also tested as a sensitivity analysis in Section 6.2.3. By an increase in replacement schedules, the analysis simulates a longer building life and the effect on overall impacts from greater component embodied impacts in relation to the functional unit.

4.10 HWS component replacement schedules

The components within the HWSs have defined warranty periods and projected service lives. In consultation with Wood and Grieve, Table 4-12 details replacement schedules that were applied to the components specified for the defined building life.

Table 4-12: **Replacement schedules for HWS components in both Brahe Place and La Banque buildings.**

Years until replacement (schedule)	**Component inclusions**	**Replacements over 50 year building life**
50 years (building life base case)	Copper/ polymer and poly pipes, insulation, and fie collars	1*
25 years	Water storage tanks, solar controller, solar collector frame, gas meter, hot water meters, cold water meter, balancing valves, check valve, and isolation valves	2*
10 years	Pumps, water heaters, tempering valves, and solar collectors	5*

*Including original components

Replacement schedules can be considered arbitrary based on component use (and potentially abuse) in context, so assumptions are also tested as a sensitivity analysis in Section 6.2.3. By an increase in replacement schedules the effect on overall impacts from greater component embodied impacts is tested in relation to the functional unit.

As an example, the building manager of La Banque mentioned that the temping valves for the entire building were replaced twice soon after the building was commissioned before deciding on Reliance valves, based on performance failures of in inferior products in line with the valves. This kind of instance is captured by the sensitivity analysis in Section 6.6.3.

4.11 Component impact amortisation in relation to functional unit

Component materials, processing, transport, end of life and replacement schedules over the building life of 50 years need to be accounted for in relation to a functional unit that has a 1 year time frame. For this reason all of these inventories are divided by 50 to align them with the functional unit. This relates to inventories described in Sections 4.4, 4.6, 4.7, 4.8, 4.10, 4.17 and 4.18.

4.12 Electricity and gas grids

Electricity and gas generation and distribution grids were used within foreground data for the use profile of the HWSs defined in Section 4.16 and regional sensitivities in Section 6.2.1. Table 4-13 and Table 4-14 details the foreground energy grids used (other European and Australian grids may have been used in the background of sourced LCI data), the fuel mix, and the carbon equivalent intensity of the grid. Table 4-15 Details the solar energy input for HWS 4 in Brahe Place.

Table 4-13: Energy grids used and details

Electricity grid	Fuel mix	Greenhouse intensity (kg CO_2 eq/ kWh delivered)	Comment
VIC (Australia)	As per Electricity, low voltage, Victoria, AUPLCI unit process	1.33	91.9 % (94.7 % * 97 %) grid efficiency applied in unit process
NSW (Australia)	As per Electricity, low voltage, NSW average, AUPLCI unit process	0.96	92.6 % (95.5 % * 97 %) grid efficiency applied in unit process
SA (Australia)	As per Electricity, low voltage, South Australia, AUPLCI unit process	0.64	91.4 % (94.2 % * 97 %) grid efficiency applied in unit process
WA (Australia)	As per Electricity, low voltage, Western Australia, AUPLCI unit process	0.78	91.9 % (94.7 % * 97 %) grid efficiency applied in unit process
QLD	As per Electricity, low voltage, Queensland, AUPLCI unit process	0.90	91.2 % (94 % * 97 %) grid efficiency applied in unit process

Note: Carbon equivalent intensities derived from Australian Impact Method and do not necessarily align with factors determined from National Greenhouse and Energy Reporting (NGERS).

Table 4-14: Gas grid used and details

Electricity grid	Fuel mix	Greenhouse intensity (kg CO_2 eq/ kWh delivered)	Comment
Natural gas	As per Energy, from natural gas, AUPLCI unit process	0.21	Average Australian gas grid, with direct and fugitive emissions, etc.

An average Australian gas grid was used, although a variance on the fugitive emissions (i.e. pipe leaks, etc.) for state by state gas grids is acknowledged. This was tested with state based grids in the AUPLCI, and the differences were determined to be outside the cut off criteria for mass (or impact).

Table 4-15: Solar heat used and details

Electricity grid	Fuel mix	Greenhouse intensity (kg CO_2 eq/ kWh delivered)	Comment
Solar heat energy	As per Heat, at flat plate collector, multiple dwelling, for hot water, ecoinvent 2.2 unit process	0.001	Delivery of heat with a solar system including maintenance and electricity use for operation. Excluding the necessary auxiliary heating.

4.13 Occupancy and vacancy

Occupancy details in apartments is dynamic in nature based on the mixture of rentals and owner occupancy, ownership churn (sales), household composition, and the often transient nature of living arrangements (i.e. partners with multiple properties, etc.). For these reasons multiple occupancy scenarios and subsequent hot water use (detailed in Section 4.14) for those occupancies were modelled.

The Australian census and housing data from the Australian Bureau of Statistics (ABS) was used to determine how many people live on average in an apartment, and how many bedrooms an apartment has on average.
Census data (Australian Bureau of Statistics 2007) states that in 2004 the average household was 2.5 people and the average dwelling had 3.0 bedrooms. This could be equated to around 0.8 people per bedroom.

Housing data (Australian Bureau of Statistics 1999) states that in 1999 the average household was 2.6 people and the average dwelling had 3.0 bedrooms. This could be equated to around 0.9 people per bedroom, a slightly higher loading.

Housing data (Australian Bureau of Statistics 1999) breaks this down into a bit more detail, including more relevant flat data. For average people living in an apartment, the data is separated into 798,500 flats in Australia (in 1999) into 1, 2, 3 and 4+ usual residents per household respectively (Table 7, page 28). If a 4+ household is taken as a lower average of 4 people (most 4+ flats at 4 people, rarely above this), then the average people per flat is 1.7. If a 4+ household is taken as an upper average of 5 people (some flats at 4, most at 5, a few more at 5+, and noting flats are typically smaller than houses and less likely to hold larger amounts of residents), then the average people per flat is 1.7.

The same housing data (Australian Bureau of Statistics 1999) also separates a smaller sample of these flats (485,200) in Australia at that time into 11 discreet life cycle groups regarding number of persons in households respectively (Table 5, pages 24-25). The various groups within these flats total 794,900 people, making an average of 1.6 persons per flat.

Based on these investigations, the samples and assumptions from the bedroom composition was selected from housing data (as it was a bigger sample), so an average of 1.7 residents per apartment was therefore assumed.

The same housing data (Australian Bureau of Statistics 1999) separates the 798,500 flats in Australia (in 1999) into 1, 2, 3 and 4+ bedrooms per household respectively in (Table 7, page 28). In terms of how many bedrooms an apartment has on average, if a 4+ household is taken as a lower average of 4 bedrooms (most 4+ flats at 4 bedrooms, rarely above this), then the average people per flat is 1.8. If a 4+ household is taken as an upper average of 5 bedrooms (some flats at 4, most at 5, a few more at 5+), then the average bedrooms is 1.8 also. An average of 1.8 bedrooms was therefore assumed.

The housing data could then be equated to an average of 1.7 persons per apartment which contains an average of 1.8 bedrooms, making around 0.9 people per bedroom, consistent with the average per bedroom from the total households for the same study previously identified. This average resident per bedroom assumption can be used to estimate the average occupancy of both buildings under investigation, and modulated up and down to estimate a range of occupancy scenarios. La Banque has 257 apartments, 154 are 2 bedrooms, and 103 are 1 bedroom, making a total of 411 bedrooms. Brahe Place has 8 apartments all with 1 bedroom. Table 4-16 and Table 4-17 list the occupancy scenarios modelled from the assumptions taken from ABS data for the two buildings.

Table 4-16: Occupancy scenarios for La Banque building.

Scenario	Residents	Residents per bedroom	Bedrooms in building	Residents per residence
Low occupancy	257	0.6	411	1.0
Average occupancy	370	0.9	411	1.5
High occupancy	670	1.6	411	2.6*

*Close to average residents per residence as total housing market in 2004 (Australian Bureau of Statistics 2007), and based on building management advice

Table 4-17: Occupancy scenarios for Brahe Place building.

Scenario	Residents	Residents per bedroom	Bedrooms in building	Residents per residence
Average occupancy	8*	1.0*	8	1.0
High occupancy	16	1.6	8	2.0

*Rounded up to 1 resident per bedroom

A low occupancy scenario for Brahe Place was not deemed necessary as a medium density development with fewer apartments, there was less likelihood of an apartment being empty. The resident per bedroom assumption of 0.9 was also rounded up to 1.0 for Brahe Place based on all apartments being occupied and by at least 1 person. A low occupancy scenario for La Banque was deemed necessary as a high density development with more apartments, with more likelihood of some apartments being empty.

Being a development in planning these occupancy scenarios could not be cross checked with building management at the time of this study for Brahe Place. In regards to La Banque, the building management estimated occupancy of around 670 people at the time of this study, defined as a high occupancy scenario based on ABS data. This was the used to define the high occupancy scenario for La Banque (but would fluctuate dynamically with time).

Vacancies were also considered to cross check this data. Recent data from SQM Research suggests that there are only 1.8% vacancies amongst rental properties (van Onselen 2012) in Australia, which would be diluted further by owner occupier dwellings, so a 0% vacancy level for the base case of this study is appropriate. The same data suggests that Melbourne is higher at 3.1% vacancy, and another report from id Consulting suggests that inner city Melbourne will have a higher vacancy in apartments and homes of 10 % by the end of 2013 (Danckert 2012). For this reason the base case occupancies in Table 4-16 and Table 4-17 were tested with lower vacancies in a sensitivity analysis in Section 6.2.2 to see what bearing this had on results.

4.14 HWS hot water use

Direct hot water use was not available from La Banque due to building management not having access to this data, and the inability to get a response from the body corporate accounts staff. Clearly as Brahe Place is still in development this is the same also. Literature was therefore used to determine HWS hot water use for the buildings, in conjunction with occupancy scenarios from Section 4.13.

Various studies estimate the hot water use of Australian households, summarised in Table 4-18.

Table 4-18: **Comparison of different studies estimating Australian domestic hot water use.**

Study	RIS: Proposed National System of Mandatory Water Efficiency Labelling for Selected Products	Estimated Household Water Heater Energy Use, Running Costs and Emissions, Victoria	Energy use in the provision and consumption of urban water in Australia and New Zealand	Energy Use in the Australian Residential Sector: 1986 – 2020	Take Action on Electric Hot Water and Air-Conditioning
Author	(Wilkenfeld 2004)	(Wilkenfeld 2005)	(Kenway *et al.* 2008)	(Department of the Environment Water Heritage and the Arts 2008)	(Moreland Energy Foundation Limited 2009)
Institution	George Wilkenfeld and Associates	George Wilkenfeld and Associates	CSIRO & Water Services Association of Australia (WSAA)	Department of the Environment Water Heritage and the Arts (DEWHA)	Moreland Energy Foundation & Sustainability Victoria
Hot water per day per household	171 L	120 – 300 L	90 L	55 L – 110 L	40 -119 L
Estimate/ measured	Estimate	Estimate	Estimate	Estimate	Measured
Measured	Average Australian	Average Australian	Average Australian	Average Australian	5 Moreland households
Timeframe	2004	2005	2008	2008	2009

The 2004 study from Wilkenfeld and Associates bases 171 L per day per household on WSSA data as an average of hot water use by households in Perth, Sydney and Melbourne (Wilkenfeld 2004).

In a 2005 study Wilkenfeld and Associates bases a range of 120 - 300 L per day per household scenarios around the average household draw off Australian Standard draw off of 200 L per day (Wilkenfeld 2005).

A more recent 2008 CSIRO report uses per capita residential water demand derived from data supplied by utilities with the assistance of WSSA where the total volume of residential water supplied has been divided by population served, this is then combined with the proportion of water used for appliances in households proposed by the earlier 2004 Wilkenfeld and Associates study (Kenway *et al.* 2008).

A comprehensive 2008 study by DEWHA (assisted by Wilkenfeld and Associates) details figures on domestic hot water use. A base level of 110 L per day for the average Australian household is proposed, which drops as the household gets smaller, with 55 L of the water use fixed (Department of the Environment Water Heritage and the Arts 2008). A small measured study in Moreland, Victoria was reasonably consistent with this, with households ranging from multi-level townhouses to weatherboards with extensions benchmarking at 40 - 119 L per day per household (Moreland Energy Foundation Limited 2009). This trail of studies have been progressively downgraded estimates of the average hot water use of Australian households, with a range of reasons detailed in each as to what has driven this consumption drop (i.e. drought related water saving campaigns, cost considerations, water saving devices, clothes washing using inlet cold water, etc.), and that it will reduce further in the future. As an example, the author of the earlier studies identified higher consumption levels, and has more recently been involved in a study with lower estimates. The approach of a range of hot water consumptions for different types of households is consistent with the occupancy approach of this study. This, as well as timeliness, methodology and the parties involved, meant the DEWHA (assisted by Wilkenfeld) approach has been selected for this study. It was also reasonably consistent with the more recent studies as per Table 4-18.

The consumption of an average household of 2.5 people is set at of 110 L hot water per day, which drops off to the fixed minimum of 55 L for a household of 1.0 people (Assuming there is at least 1 person for the base limit). For this study, based on estimated occupancy for apartments in Section 4.13, an average household of 2.5 people represents the high end of occupancy for La Banque (being 1 and 2 bedroom apartments), and above the high 2.0 person occupancy estimate for Brahe Place (being 1 bedroom apartments). When combined with occupancy scenarios (often lower than 2.5 people being apartments rather than the average Australian home) from Section 4.13, Table 4-19 and Table 4-20 detail hot water consumption profiles for the buildings in this study.

Table 4-19: HWS hot water use scenarios for La Banque building (257 apartments).

Scenario	Residents	Residents per residence	Hot water per apartment per day (L)	Hot water per apartment per annum (kL)	Building hot water per annum (kL)
Low occupancy	257	1.0	55	20	5,159**
Average occupancy	370	1.5	73	27	6,847**
High occupancy	670	2.6*	114	42	10,699**

*Close to average residents per residence as total housing market in 2004 (Australian Bureau of Statistics 2007), and based on building management advice
** Aligned with TRNSYS modelling be SAMME (Paul and Andrews 2013)

Table 4-20: HWS hot water use scenarios for Brahe Place building (8 apartments).

Scenario	Residents	Residents per residence	Hot water per apartment per day (L)	Hot water per apartment per annum (kL)	Building hot water per annum (kL)
Average occupancy	8*	1.0	55	20	161**
High occupancy	16	2.0	92	34	269**

*Rounded up to 1 resident per bedroom
** Aligned with TRNSYS modelling be SAMME (Paul and Andrews 2013)

It is assumed that significant building hot water use is only from residential draw off. Another important point is the generally held view that hot water use and the behaviour related to it are poorly understood, summarised in the statement;

'Despite powerful tools for modelling of energy consumption of water heaters being available (eg AS4234 and TRNSYS), data on actual use of hot water in households is generally poor. Traditional utility data for controlled loads, which are mostly off-peak hot water, are not generally available in the public domain any more. Very few studies have monitored hot water loads in households. It is known that there is a wide distribution of actual hot water consumption across households, but the factors that drive this variation are not known. There is also some anecdotal evidence that households with water heaters such as gas instantaneous can effectively supply unconstrained amounts of hot water, but have a much higher hot water consumption (BRANZ 2005). So while such systems may be more efficient, they may result in an overall increase in total energy consumption.
There is also very poor data on key parameters such as cold water supply temperatures by time of year and the number of draw-offs per day, which is important for instantaneous gas systems (due to start-up losses).

End-use metering of hot water loads is generally more complex than simple electrical appliances and may require insertion of equipment in gas and/or water supply systems in households. But a targeted program would be very worthwhile to establish some of these patterns. Some information on usage patterns of mains powered instantaneous gas systems can be inferred from electrical metering with a short sampling duration.' (Department of the Environment Water Heritage and the Arts 2008)

This concern is addressed by modelling a range of water use scenarios based on occupancy, and rigorously detailing energy related to HWS use in Section 4.16. Hot water use was split monthly as per TRNSYS modelling (Paul and Andrews 2013), by seasonal variations throughout the year shown in Table 4-21.

Table 4-21: Seasonal hot water load profile (Standards Australia 2008)

Seasonal load profile for Australia	
Month	**Load multiplier Zones 1 to 4**
Jan	0.7
Feb	0.8
Mar	0.85
Apr	0.9
May	0.95
Jun	1
Jul	1
Aug	1
Sep	1
Oct	0.95
Nov	0.9
Dec	0.8

Maximum daily hot water demand along with seasonal load multipliers were applied to give the variation in total daily hot water demand over a year. Hot water demand also varies hour by hour through each day. The hourly variation assumed in the TRNSYS modelling (Paul and Andrews 2013), is provided in Table 4-22:

Table 4-22: Hourly hot water load profile (Standards Australia 2008)

Hourly load profile for Australia	
Time	**Load Multiplier Zones 1 to 4**
07:00	0.15
08:00	0.15
11:00	0.1
13:00	0.1
15:00	0.125
16:00	0.125
17:00	0.125
18:00	0.125

The hourly hot water demand in any given hour can then be found as follows:

Hourly load = maximum daily hot water demand × hourly load multiplier for that hour × seasonal load multiplier (Paul and Andrews 2013).

It must be noted that a discreet hourly Victorian load profile was not used, as the Australian Standard amalgamates all regional zones into one hourly load profile, and as such may be viewed as a limitation.

4.14.1 Dead water losses

It must be noted that this study does not include any dead water losses and 'start-up' losses that can be particularly significant in centralised systems. This can occur when water is tempered at the door, and then cools down in pipes into the apartment hot water tap outlets after use. This study assumes that one CFEWH sits at the door of each apartment, around the same spot that the tempering takes place for a centralised alternative, thus much the same cooling occurs for HWS options.

If this were to change, so that a CFEWH were at each tap outlet in the apartment (around 3 units, at an on cost to installation) we could potentially see significant water saving occur from reduced dead water being flushed before hot water use by residents. As an example, if the apartments from the HWS scenarios in Section 4.14 were to include 10 meters of 20 mm pipes to the hot water tap outlets, the pipes hold around 3 litres of water at any time after use. If the 3 litres were flushed on an increasing scale with occupancy rates, once for low occupancy (i.e. one shower, basins once each), twice for average occupancy (i.e. two showers, basins twice each), and three times for high occupancy (i.e. three showers, basins three times each), Table 4-23 and Table 4-24 summarise the increase in hot water use (including hot water heated up, then cooled down and flushed before use) for centralised options in the buildings under review.

Table 4-23: Centralised HWS hot water use scenarios for La Banque with potential dead water loss

Scenario	Residents	Hot water per apartment per day (L)	Hot water per apartment per annum (kL)	Building hot water per annum (kL)	Building hot water increase per annum (kL)
Low occupancy	257	55+3=68	20+1.1=21	5,442	283
Average occupancy	370	73+6=98	27+2.2=36	7,413	566
High occupancy	670	114+9=152	42+3.3=56	11,542	843

*Close to average residents per residence as total housing market in 2004 (Australian Bureau of Statistics 2007), and based on building management advice

Table 4-24: Centralised HWS hot water use scenarios for Brahe Place with potential dead water loss

Scenario	Residents	Hot water per apartment per day (L)	Hot water per apartment per annum (kL)	Building hot water per annum (kL)	Building hot water increase per annum (kL)
Average occupancy	8*	55+6=61	20+2.2=29	179	18
High occupancy	16	92+9=101	34+3.3=48	295	26

*Rounded up to 1 resident per bedroom

Assuming none of this dead water loss from a multi CFEWH installation, Table 4-23 and Table 4-24 provide examples of between 5 to 10 % increases on annual hot water use based on various assumptions of dead water flushing from low to high occupancy in the two buildings. This would also equate to an energy increase in initially heating this water before it cooled. Although not considered in this study any further, this point may be relevant for further research or considerations of potential water and energy efficiency gains on whole building HWS resource use.

4.15 Ambient cold water delivery temperature

Cold water is delivered at various temperatures throughout the year depending on the season, and climatic zone. AS4234:2008 provides guidance on this delivery temperature, described in Figure 4-5 and Figure 4-6.

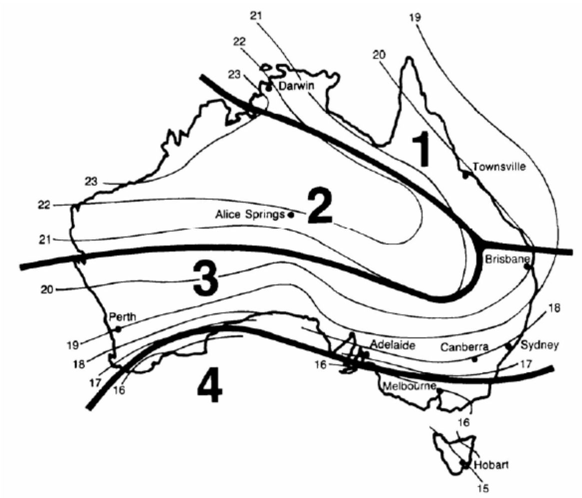

Figure 4-5: Australian climatic zones (Standards Australia 2008)

COLD WATER TEMPERATURE (°C)

Month	Zone 1	Zone 2	Zone 3	Zone 4
January	28	29	23	20
February	28	27	23	20
March	27	24	21	18
April	25	20	18	15
May	23	14	15	11
June	20	11	12	9
July	20	9	11	8
August	21	12	12	10
September	24	18	15	12
October	26	23	19	15
November	28	26	21	17
December	28	28	22	19

Figure 4-6: Monthly cold water ambient delivery temperature for Australian climatic zones (°C) (Standards Australia 2008)

The La Banque building is located in Melbourne, which is in zone 4. So column 4 temperatures in Figure 4-6 were used for the cold water temperature profile in each month. These were used in all energy calculations for hot water heating from in Section 4.16.

4.16 HWS energy use

The potential HWSs specified by Wood and Grieve utilise various components to heat and distribute water throughout the buildings at La Banque and Brahe Place. Table 4-25 details these components, including what energy source they use (not including components that perform the same, as in booster pump sets).

Table 4-25: HWS components that heat and distribute hot water to the buildings.

Building	Type of hot water system	Components using electricity	Components using gas
La Banque	Gas plant ring main	Hot water flow and return pump, water heater cycle pump.	Gas heaters (x 10)
La Banque	Point of use electric instantaneous	CFEWH units (x 257)	N/A
Brahe Place	Gas plant ring main	Hot water flow and return pump, water heater cycle pump.	Gas heaters (x 2)
Brahe Place	Gas plant ring main & solar collectors	Hot water flow and return pump, water heater cycle/ solar pump, solar controller.	Gas heaters (x 2)
Brahe Place	Point of use electric instantaneous	CFEWH units (x 8)	N/A

The following sub sections explore the use phase of these components in line with the hot water consumption scenarios modelled in the SAMME report in Appendix F, summarised in Section 4.14.

The following thermostatic equation underpin calculations within TRNSYS of energy required to heat water from ambient to heated temperature of 70° C:

1. $Q = (c_p V \rho_{water} dT) / EF$ (J)

   Q = energy (kJ)
   c_p = specific heat of water (kJ/kg)
   V = volume (m^3)
   ρ_{water} = density of water (kg / m^3)
   dT = change of temperature (°C)
   EF = efficiency fraction of the water heater

Wood and Grieve advised that a 5°C drop in hot water temperature in one cycle around ring main HWSs is considered acceptable by designers. Bosch confirmed that this is a common specification, but in reality often worse due to under specification of insulation, valve joints, installation issues, etc. For the base case a 5°C drop in hot water temperature was used, and tested at larger temperature drops in a sensitivity analysis in Section 6.2.5

Stand by heating energy is additional energy in order to keep the water heated in a ring main HWS at a set temperature all year round. It is assumed that the direct draw off heated water is consumed, and water at 65°C - 70°C temperature within the ring main is circulated and topped up intermittently when required (measured by a thermostat in the storage tanks). Wood and Grieve provided details on how they calculate ring main heat loss and specify pump flow rate illustrated in Figure 4-7.

The following is a table giving the approximate heat emissions from secondary hot water flow and return pipework in watts per metre run of pipe.

The information is based on 40°C difference mean water to air W/m run for copper tubes. Air surrounding hot water flow pipes is assumed to be 20°C. Heat emission from insulated surfaces will vary for different types and thicknesses of insulation.

TABLE OF HEAT EMISSIONS FROM SECONDARY HOT WATER FLOW AND RETURN PIPEWORK

Copper Tube Size, mm	Bare Tube, W/m run/hour	Insulated Tube, W/m run/hour	13mm Armaflex Insul
15	28	8	11
20	39	11	13
25	48	13	15
32	58	16	17
40	68	17	19.5
50	88	20	24
65	106	24	29
80	120	26	34
100	160	35	41

Heat losses given for insulated pipework are based on magnesia-type insulation 25mm thick or equivalent type of insulation.

WATER FLOW FROM SECONDARY HOT WATER RETURN CIRCULATING PUMPS

The flow from hot water return pumps is obtained by calculating the total watts emission from the pipework system, both flow and return pipelines.

Water flows are measured in volume per unit time, in this case litres per second.

The flow of hot water return is obtained from the formula:

$$\ell = \frac{W \times 10^{-3}}{kJ/kg \times {}^{o}C}$$

where: ℓ = flow in litres per second.

W = watts emitted per metre run of insulated and uninsulated pipework per hou

kJ/kg = specific heat of water, 4187 joules, say 4.2 kilojoules per kilogram. (Water at 4°C has a density of 1000 kilograms per cubic metre).

°C = temperature difference between seconday hot water flow and secondary ho water return in °C.

Figure 4-7: Wood and Grieve pipe heat loss and hot water flow and return pump literature

The advice for insulation in Figure 4-7 assumes a 40°C air to hot water temperature difference.

The temperature differential is most likely larger than 40°C due to the assumption the air temperatures are sub 25°C - 30°C (particularly for pipes outside or in non-heated areas of the building) in most parts of the ring main hot water, which set to a temperature range of 65°C - 70°C. Therefore a 50°C air to hot water temperature difference assumption (or ambient air temperature being 15-20°C within and around the buildings, around the ring main, etc.) is used in the base case of this study and the referenced TRNSYS report in Appendix F. This is within the Melbourne annual range of mean maximum air

temperatures 19.9°C and mean minimum temperatures of 10.2°C compared to the ring main hot water set to a temperature range of 65°C - 70°C (Bureau of Meteorology 2012).

It is acknowledged this may still treat the centralised system heat loss conservatively (based on the minimum Melbourne annual mean temperature). For this reason Section 6.2.5 explores a sensitivity analysis where larger temperature losses around the ring main occur, and the energy implications that follow are quite substantial.

25 mm insulation is specified for both buildings, the relevant Figure 4-7 information for 25 mm insulation is a magnesia type (not closed cell foam like Armaflex), the hand written column is for 13mm Armaflex (not 25mm). 25 mm Armaflex would have higher insulation properties than the 13 mm, but potentially lower than the magnesia type at 25 mm. For this reason tables from a Thermotec catalogue were used, where the heat loss per meter is detailed for a similar insulation type to Armaflex (0.036 W/(m.K)) and foil covered (as observed on site). Relevant details the performance characteristics of this insulation are in Figure 4-8:

WATER TEMP °C		65			
AMBIENT TEMP °C		10	12	15	20
PIPE O.D. (mm)	INSULATION THICKNESS				
13	Nil	35.9	34.5	32.4	28.9
	15	9.7	9.4	8.8	7.9
	20	9.0	8.6	8.1	7.2
	25	8.3	7.7	6.8	6.4
	30	7.7	7.1	6.2	5.7
15	Nil	40.9	39.3	36.8	32.8
	15	10.7	10.5	10.2	9.8
	20	10.2	9.7	8.8	7.6
	25	9.6	8.5	7.0	6.7
	30	8.6	7.8	6.6	6.0
20	Nil	51.5	49.5	46.5	41.5
	15	12.4	11.9	11.2	10.1
	20	11.3	10.8	10.0	8.8
	25	10.1	9.5	8.7	7.5
	30	9.2	8.7	8.0	6.9
25	Nil	62.1	59.7	56.2	50.2
	15	14.1	13.3	12.2	10.2
	20	12.4	11.9	11.2	10.0
	25	10.6	10.5	10.4	9.8
	30	9.8	9.6	9.4	9.0
32	Nil	76.6	73.7	69.3	61.9
	15	16.5	15.5	14.1	13.5
	20	14.4	13.9	13.2	11.7
	25	13.1	12.5	11.6	10.5
	30	11.8	11.3	10.5	9.2

WATER TEMP °C		65			
AMBIENT TEMP °C		10	12	15	20
PIPE O.D. (mm)	INSULATION THICKNESS				
39	Nil	90.6	87.1	81.9	73.3
	15	23.2	21.2	18.3	15.5
	20	16.3	16.2	16.1	13.4
	25	14.8	14.5	14.1	12.1
	30	13.3	13.2	13.0	10.9
51	Nil	113.8	109.5	103.0	92.3
	15	22.9	21.5	19.5	18.7
	20	19.5	18.8	17.8	16.0
	25	17.6	17.0	16.1	14.5
	30	15.7	15.1	14.3	12.9
60	Nil	130.7	125.8	118.4	106.1
	15	25.8	24.2	21.8	21.0
	20	21.9	21.1	19.9	17.9
	25	19.7	19.0	17.9	16.2
	30	17.5	16.8	15.8	14.4
76	Nil	160.2	154.2	145.2	130.2
	15	30.8	29.7	28.0	25.2
	20	26.1	25.1	23.7	21.4
	25	23.3	22.5	21.2	19.1
	30	20.5	19.8	18.7	16.9
102	Nil	206.4	198.7	187.2	168.0
	15	38.9	37.5	35.3	31.7
	20	32.7	31.4	29.5	26.3
	25	26.5	25.8	24.7	22.9
	30	24.3	23.5	22.2	20.0

Figure 4-8: Heat loss (W/m) in pipes for Thermotec 4-Zero/ Sealed Tube Pipe insulation (Thermotec 2007)

The following heat loss values were used for the relevant pipe diameters at a 45°C temperature differential and 25 mm insulation:

20 mm pipes – 8.7 W/m
25 mm pipes – 10.4 W/m
32 mm pipes – 11.6 W/m
40 mm pipes – 14.1 W/m
75 mm pipes – 21.2 W/m

These values are slightly lower than the values in Figure 4-7, based on different assumptions (i.e. 40°C temperature difference) and different insulation types, however deemed in this case more appropriate.

Engineers Toolbox was cross referenced (see the region between the 40°C and 60°C temperature difference curve) as per Figure 4-9 for metal pipes insulated with a thermal conductivity 0.036 W/(m.K) (same as Armaflex and Thermotec):

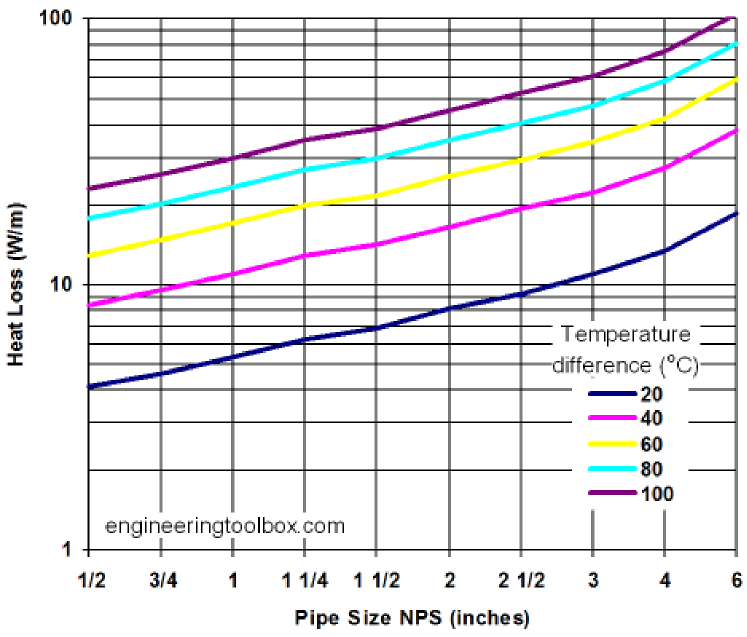

Figure 4-9: Heat loss in pipes for insulation 25 mm thick (The Engineering ToolBox 2012)

Again this was directionally consistent with the Thermotec data, however higher that modelling parameters include outdoor condition with moderate wind 9 m/s, and a safety factor of 10% is included.

It is therefore noted that using the selected pipe heat losses may be generous to centralised systems. [5]

[5] The insulation performance data in Section 4.16 assumes copper pipes delivering the hot water. The R value of plastic pipes could be assumed 0.04 compared with the copper pipes at 0.004. However comparatively to insulation with R0.6 and an air film of R0.15, the difference is minor. Clearly this makes a difference if there is no insulation, but as there is reasonable insulation installed it is a small factor. For example, with R0.6 insulation and an air film of 0.15, the ratio is 0.79/0.754=1.05 so there would be about 5% difference in heat flow. As conservative values for heat loss have been selected, this assumption has been deemed adequate.

4.16.1 HWS 1 - La Banque gas plant ring main energy use

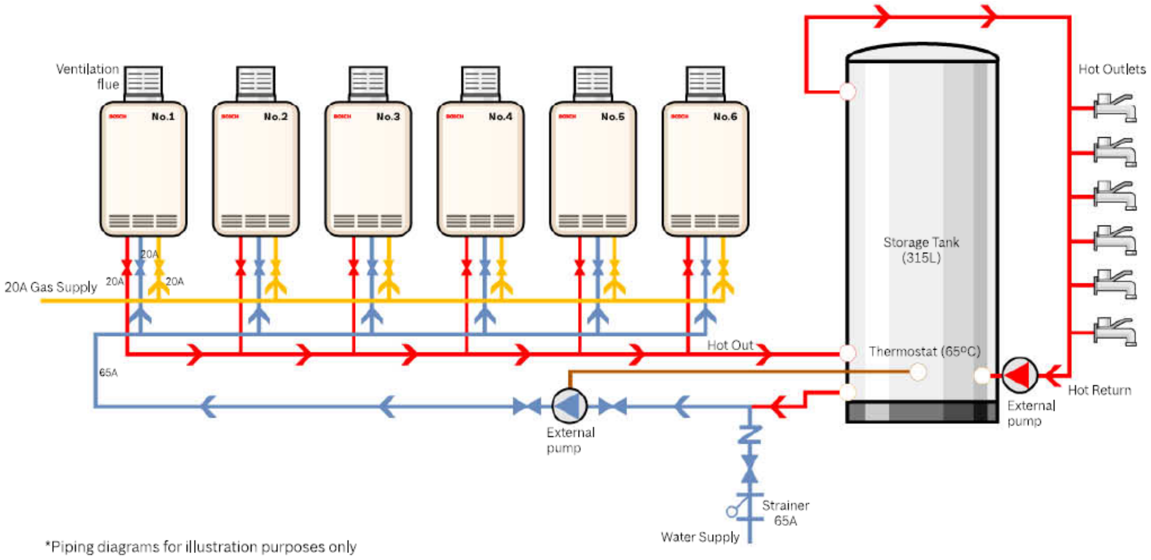

Figure 4-10: Typical ring main setup (Bosch 2011)

La Banque has a gas plant and ring main set up currently, one of the two potential systems specified by Wood and Grieve. The current system was also inspected on site. Figure 4-10 (courtesy of Bosch) illustrates a typical ring main. The main water heating source is 10 instantaneous gas heater units on a manifold on the roof. These units are Bosch series 32 heaters (KM3211WHQ), and teamed up with 2 x 315 L storage tanks. Bosch state and national technical sales managers were engaged to explain the way that these systems operate in detail.

Water is originally supplied cold (booster pump sets outside this energy modelling), and heated up to the specified 70°C through the heaters and transferred to storage tanks via Grundfos water heater cycle pumps (CHI 4-20 with 0.59 kW input power, 1 for each tank/ bank of 5 heaters at 4.5 m^3/h). Figure 7-3 in Appendix I shows the performance curves of this pump.

The tanks are connected to a ring main throughout the building, through which water is circulated constantly (24 hours a day, 7 days a week), using a Grundfos hot water flow and return pump (UPS 32-80 N 180, 2 units alternating periodically). Figure 7-4 shows the performance curves of this pump. The tank thermostats activate water heater cycle pumps to heat the system back up to 70°C once temperature drops to 65°C.

Assuming average air to water temperature differential of 50°C through 75 m of diameter 20 mm tube, 1450 m of diameter 40 mm tube, and 150 m of diameter 75 mm tube, the calculated heat loss is around 24 kW (for a pipe fluid volume of 2.5 kL) based on the guidance from Figure 4-8. From the pump flow equation in Figure 4-7 this is consistent with the specified Grundfos hot water flow and return pump at speed 2 (or 4.2 m^3/h) running at 200 W annually (with a head of 2.5 m) as per Figure 7-4 in Appendix I.

Bosch confirmed that each storage tank loses 4.8 kWh of energy per day, so both tanks lose 9.6 kWh on average (for 630 L stored in the tanks). For the two tanks this equates to 0.4 kW heat loss, and a combined on-going heat loss of around 25 kW for the ring main system. This is captured in the TRNSYS model by SAMME.

When hot water is drawn off by residents, cold water mixes with hot water circulated through the ring main through tempering valves located at each apartment at a delivery temperature of 50°C to the user. Annual hot water heating energy can be categorised into two discrete classifications;

1. Direct draw off hot water heating energy and distribution
2. Stand by hot water heating energy and distribution

In this case direct draw off heating energy is defined as enough water heated to 70°C mixed with cold water (at ambient temperature) to deliver the annual building hot water draw off for residents at 50°C.

The average efficiency of the Bosch 32 series heaters is specified as 80% in literature (Bosch 2011) for various temperature changes, which was confirmed by sales staff for all flows and temperature changes (gas input modulates for different water flow and temperature change requirements, other units such as the 32C series can deliver up to 94%). The Bosch 32 series run a fan and electronics when heating at 85 W per unit, and standby electricity consumption is 8 W per unit (as advised by Bosch).
When direct draw heating occurs, the water heater cycling pumps operate with booster pumps (not accounted for in this modelling) and the water heaters run a fan and electronics.

The HWS uses stand by energy to counter ring main heat loss on an on-going basis. The change in temperature across the top to bottom of the tanks is an interesting phenomenon to note in regards to standby heating. As described by the installing plumber, the system is optimised for the ring main temperature required and temperature range, however the thermostat is located at the base of the tanks, and set to a range of 45-50°C (as observed on site, see Figure 4-11). This is where heated water, cold water and the end ring main entry points are located (see Figure 4-12). This ring main outlet is at the top of the tank, so there is effectively a 20°C drop from the top to the bottom of the tank (70°C to 50°C). This relates to convection (hot water rising to the top of the tank), the end ring main and cold water entering at the base of the tank, ring main cycling, and heat loss (ambient conditions, etc.).

Figure 4-11: Thermostat on tanks in La Banque gas ring main plant

Figure 4-12: Heater and hot flow and return pipe tank connections in La Banque gas ring main plant

The implication here is that the water is taken from the base of the tanks at 45-50°C, so the temperature change through the heaters is around 35-30°C (consuming 700 kW or 2519 MJ/h of gas), which matches the pumps specified at top flow for that change. For modelling this means that the ring main is still assumed to run at the 65-70°C range. The combined hot water ring main of 3.1 kL (pipes and tanks) loses around 25 kW of energy. The tanks are set to heat the system back up to 70°C once the thermostat drops 5°C (the system at 65°C).

At this point the Grundfos pumps cycle tank and pipe water through the Bosch water heaters to heat the total system from 65°C to 70°C, where they again turn off. Based on Bosch data, this can occur at a total flow of around 14 m^3/h (or 7 m^3/h per pump as per Figure 7-3, the heaters consuming 700 kW or 2519 MJ/h of gas which also accounts for efficiency) through the 10 gas heaters for a total rise of around 35°C (below boiling at in inlet temperature from water taken from the tanks at 45-50°C). Table 4-26 summarises the performance characteristics of HWS 1 components.

Table 4-26: HWS1 Gas heating system components for La Banque building (Paul and Andrews 2013).

System component	Specifications
Storage tank	Bosch (315C232LR), volume 315 L, height 1.97 m, 2 units
Cycle pump	Grundfos CHI 4-20, input power 0.59 kW, flow rate 4.5 m^3/h*, 2 units
Gas heater	Bosch series-32 (KM3211WHQ), gas input 350 MJ/h, efficiency 80%, 10 units**
Hot water flow pipe	Wefatherm polymer pipe, 1375 m long – 40 mm dia. (29 mm inner dia.), 150 m long – 75 mm dia. (55 mm inner dia.)

System component	Specifications
Hot water return pipe	Wefatherm polymer pipe, 150 m long – 40 mm dia. (29 mm inner dia.)
Pipe Insulation	Armaflex insulation, thickness 25 mm, loss coefficient 8.8 kJ/hm^{2}K for 75 mm pipe, and 11.2 kJ/hm^{2}K for 40 mm pipe (based on inner surface area of the pipe)
Flow/return pump	Grundfos UPS 32-80 N 180, input power 0.2 kW, flow rate 4.2 m^3/h, 1 unit operating

*It is acknowledged that SAMME chose the pump rated flow of 4.5 m^3/h, resulting in a total flow of m^3/h. This would likely be tuned up to the top total flow of around 14 m3/h (or 7 m3/h per pump) to ensure that the temperature change across the heaters is lowered enough so the water does not boil due to a faster flow rate, with a total rise of around 35°C. This will not affect the time the heaters are on, the electricity used by the pumps (constant at 0.59 kW per pump) or the energy dosed to the water (constant at 2519 MJ/h of gas).
**The Bosch 32 series gas heater unit runs a fan and electronics when heating at 85 W per unit, and standby electricity consumption is 8 W per unit (as advised by Bosch).

From this specification, SAMME set up an annual water and energy consumption model in TRNSYS which is described in detail in Appendix F. The simulation results for the gas ring-main water heating system (HWS 1) in the La Banque building is summarised in Table 4-27:

Table 4-27: HWS 1 TRNSYS simulation results for the gas ring-main water heating system in the La Banque building (Paul and Andrews 2013).

Occupancy	Annual hot water demand (kL)	Annual gas consumption (GJ)	Piping annual heat loss (GJ)	Storage tank annual heat loss (GJ)	Cycle pump annual electricity consumption (kWh)	Flow/return pump annual electricity consumption (kWh)	Cycle and flow/return pump combined annual electricity consumption (kWh)
Low	5,159	1,876.1	703.8	8.5	1,227	1,752	2,979
Average	6,847	2,198.1	707.6	8.6	1,359	1,752	3,111
High	10,699	2,931.9	714.2	8.8	1,730	1,752	3,482

The simulation results for the gas ring-main water heating system stand by operation and electrical performance in the La Banque building is summarised in Table 4-28.

Table 4-28: HWS 1 Gas heating system heating and standby mode electricity consumption for La Banque building (Paul and Andrews 2013).

Occupancy	Cycle pump annual electricity consumption (kWh)	Two cycle pumps combined rated power consumption (kW)	Heating mode annual operation of cycle pump and gas heater (hrs)	No. of Bosch gas heater units	Yearly total heating operation hours (hrs)	Yearly total standby operation hours (hrs)	Annual total electricity consumption by heaters in heating and standby mode (kWh)
Low	1,227	1.18	1,040	10	10,400	77,200	1,502
Average	1,359	1.18	1,152	10	11,520	76,080	1,588
High	1,730	1.18	1,466	10	14,663	72,937	1,830

Table 4-29 summarises the total energy consumption annually and per apartment for HWS 1 based on energy inputs from Table 4-27 and Table 4-28.

Table 4-29: HWS 1 La Banque gas ring main annual heating energy inputs (Paul and Andrews 2013).

Occupancy	Annual total water heating gas consumption including losses (GJ)	Hot water system annual total electricity consumption by all pumps and heaters (kWh)	Annual gas consumption per apartment (GJ)	Hot water system annual total electricity consumption per apartment (kWh)
Low	1,876.1	4,481	7.3	17
Average	2,198.1	4,699	8.6	18
High	2,931.9	5,312	11.4	21

4.16.2 HWS 2 - La Banque CFEWH energy use

The alternative for La Banque is a point of use hot water system as specified by Wood and Grieve. **The main water heating source is 257 CFEWH units, one for each apartment, set to 50°C at the door.** These units are MicroHeat Series 1 three phase heaters, with cold water inlets. MicroHeat technical managers were engaged to explain the way that these systems operate in detail.

Water is supplied cold to the apartments (by booster pump sets not included in this modelling, as they are required for all system options studied), and heated up to the specified 50°C with modulating electrical power based on inlet temperature and flow rate. Annual hot water heating energy can be categorised into one discrete classification;

1. Direct draw off hot water heating energy and distribution

Direct draw off heating energy can be assumed as enough water heated to 50°C to deliver the annual building hot water draw off for residents. The average efficiency of the MicroHeat Series 1 three phase heaters is promoted as 98% by MicroHeat (based on standby energy use, etc. and confirmed through testing at the RMIT School of Aerospace, Mechanical and Manufacturing Engineering (SAMME) in Appendix E (this includes 'start-up' energy requirements tested under a range of usage patterns, showing the 98% is a conservative approximation). The MicroHeat Series 1 three phase heaters run at a standby electricity consumption of 1.3 W per unit (as advised by MicroHeat), when no water is being drawn.

When direct draw heating occurs, mains pressure and booster (not accounted for in this modelling) pumps run cold water to the apartments to heat water. Annual hot water consumption derives from Table 4-19, with monthly and time based fluctuations accounted for as per Table 4-21 and Table 4-22.

From this specification, SAMME set up an annual water and energy consumption model in TRNSYS which is described in detail in Appendix F. The simulation results for the CFEWH system (HWS 2) in the La Banque building is summarised in Table 4-30.

Table 4-30: HWS 2 TRNSYS simulation results for CFEWH system for La Banque building (Paul and Andrews 2013).

Occupancy	Annual hot water demand (kL)	Annual electricity consumption (MWh)
Low	5,159	220.1
Average	6,847	292.2
High	10,699	456.6

The simulation results for HWS 2 stand by operation and electrical performance in the La Banque building is summarised in in Table 4-31.

Table 4-31: HWS 2 CFEWH system standby mode total electricity consumption for La Banque building (Paul and Andrews 2013).

Occupancy	Cycle pump annual electricity consumption (kWh)	Two cycle pumps combined rated power consumption (kW)	Heating mode annual operation of cycle pump and gas heater (hrs)	No. of Bosch gas heater units	Yearly total heating operation hours (hrs)	Yearly total standby operation hours (hrs)	Annual total electricity consumption by heaters in heating and standby mode (kWh)
Low	1,227	1.18	1,040	10	10,400	77,200	1,502
Average	1,359	1.18	1,152	10	11,520	76,080	1,588
High	1,730	1.18	1,466	10	14,663	72,937	1,830

Table 4-32 summarises the total energy consumption annually and per apartment for HWS 2 based on energy inputs from Table 4-30 and Table 4-31.

Table 4-32: HWS 2 La Banque building CFEWH system annual total energy inputs (Paul and Andrews 2013).

Occupancy	Annual water heating electricity consumption (MWh)	Annual standby electricity consumption by heater units (kWh)	Building hot water system total annual electricity consumption (MWh)	Hot water system annual total electricity consumption per apartment (kWh)
Low	220.1	1,951	222.1	864
Average	292.2	1,951	294.1	1,145
High	456.6	1,951	458.5	1,784

4.16.3 HWS 3 – Brahe Place gas plant ring main energy use

The first of the three potential systems specified by Wood and Grieve for Brahe Place is a gas plant and ring main. Figure 4-13 illustrates a typical Rheem Multipak. The main water heating source is 2 instantaneous gas heater units on a manifold. These units are the Rheem Multipak (MPE02K), and teamed up with 2 x 410 L storage tanks. Rheem literature and sales managers were engaged to explain the way that these systems operate in detail.

Figure 4-13: Typical Multipak setup (Rheem 2007)

Water is originally supplied by cold (booster pump sets not included in this modelling), and heated up to the specified 70°C through the heaters and transferred to the storage tanks via a Lowara water heater cycle pump (4HMS3 with 0.51 kW input power, one pump operates for both tanks to the bank of 2 heaters). Figure 7-5 in Appendix I shows the performance curves of this pump.

The tanks are connected to a ring main throughout the building, through which water is circulated constantly (24 hours a day, 7 days a week); using a Grundfos hot water flow and return pump (UPS 25-60 130, 2 units alternating periodically). Figure 7-6 shows the performance curves of this pump. The tank thermostats would activate the water heater cycle pump to heat the system back up to 70°C once temperature drops to 65°C (as per La Banque).

Assuming average air to water temperature differential of 50°C through 75 m of diameter 25 mm tube, and 25 m of 32 mm diameter tube, the calculated heat loss is 1.1 kW (for a calculated pipe volume of 57 L) based on the guidance from Figure 4-8. From the pump flow equation in Figure 4-7 this is consistent with the specified Grundfos hot water flow and return pump rating at speed 1 (or flow 0.2 m^3/h) running at 100 W annually (with a head of 5 m) as per Figure 7-6 in Appendix I.

Rheem confirmed that each storage tank loses 10 MJ of heat per day, so both tanks lose 20 MJ on average (for 630 L stored in the tanks). For the two tanks this equates to 0.23 kW heat loss, and a combined on-going heat loss of around 1.1 + 0.23 = 1.3 kW for the ring main system. This is captured in the TRNSYS model by SAMME.

When hot water is drawn off by residents, cold water is mixed with the hot water being circulated through the ring main with tempering valves, to a

delivery temperature of 50°C to the door. Annual hot water heating energy can be categorised into two discrete classifications;

1. Direct draw off hot water heating energy and distribution
2. Stand by hot water heating energy and distribution

In this case direct draw off of heating energy can be assumed as enough water heated to 70°C mixed with cold water (at ambient temperature) to deliver the annual building hot water draw off for residents.

Based on literature (Rheem 2007), the average efficiency of the Rheem Multipak series heaters is 80% for various temperature changes (410 MJ/h heat for a change in temperature of 25°C at 52.8 L/min, and 410 MJ/h heat for a change in temperature of 50°C at 26.4 L/min), which was confirmed by sales staff for all flows and temperature changes (gas input modulates for different water flow and temperature change requirements, other units such as the Raypak series can deliver up to 83%). The Rheem Multipak series run a fan and electronics; however the details were not available. The Bosch 32 series specifications were used as a proxy, when heating at 85 W per unit, and standby electricity is 8 W per unit (as advised by Bosch).

The methodology applied in this scenario for the use phase is the same as for HWS 1 at Banque building, but with input values changed to suit the smaller building.

When direct draw heating occurs, the cycling pumps operate and the water heaters run a fan and electronics. The heaters must also counter system heat losses of around 1.3 kW (consuming 114 kW or 410 MJ/h of gas, which also accounts for efficiency losses). The HWS uses stand by energy to counter heat loss on an on-going basis. The combined hot water ring main of 877 L (pipes and tanks) loses 1.3 kW of energy. The tanks are set to heat the system back up to 70°C once the ring main drops to 65°C. The change in temperature across the tanks locally is assumed to be the same as the phenomenon observed at La Banque.

At this point the Lowara pump cycles tank and pipe water through the Rheem water heaters to heat the total system from 65°C to 70°C. Based on Rheem data (Rheem 2011), this can occur at around 4 m^3/h (a head of 13 m as per Figure 7-5, the heaters consuming 114 kW or 410 MJ/h of gas, which also accounts for efficiency) for a total rise of 35°C through the 2 gas heaters (below boiling at in inlet temperature from water taken from the tanks at 45-50°C). Table 4-33 summarises the performance characteristics of HWS 3 components.

Table 4-33: HWS 3 Gas heating system components for Brahe Place building (Paul and Andrews 2013).

System component	Specifications
Storage tank	Rheem (610 430), volume 410 L, height 1.64 m, 2 units
Cycle pump	Lowara (4HMS3), input power 0.51 kW, flow rate 4.0 m^3/h, 1 unit
Gas heater	Rheem Multipak (MPE02K), gas input 410 MJ/h, efficiency 80%, 2 units*

System component	Specifications
Hot water flow pipe	Copper pipe, 50 m long – 25 mm dia. (22.2 mm inner dia.), 25 m long – 32 mm dia. (28.6 mm inner dia.) (Standard Australia 2004)
Hot water return pipe	Copper pipe, 25 m long – 25 mm dia. (22.2 mm inner dia.)
Pipe Insulation	Armaflex insulation, thickness 25 mm, loss coefficient 9.3 kJ/hm^2K for 32 mm pipe, and 10.7 kJ/hm^2K for 25 mm pipe (based on inner surface area of the pipe)
Flow/return pump	Grundfos (UPS 25-60 130), input power 0.1 kW, flow rate 0.2 m^3/h, 1 unit operating

* The Rheem Multipak series run a fan and electronics; however the details were not available. The Bosch 32 series specifications were used as a proxy, when heating at 85 W per unit, and standby electricity is 8 W per unit (as advised by Bosch).

From this specification, SAMME set up an annual water and energy consumption model in TRNSYS which is described in detail in Appendix F. The simulation results for the gas ring-main water heating system (HWS 3) in the Brahe Place Building is summarised in Table 4-34:

Table 4-34: HWS 3 TRNSYS simulation results for the gas ring-main water heating system in the Brahe Place building (Paul and Andrews 2013).

Occupancy	Annual hot water demand (kL)	Annual gas consumption (GJ)	Piping annual heat loss (GJ)	Storage tank annual heat loss (GJ)	Cycle pump annual electricity consumption (kWh)	Flow/return pump annual electricity consumption (kWh)	Cycle and flow/return pump combined annual electricity consumption (kWh)
Average	161	92.7	30.3	9.4	104	876	980
High	269	113.0	30.4	9.4	112	876	988

The simulation results for the HWS 3 stand by operation and electrical performance in the Brahe Place building is summarised in Table 4-35.

Table 4-35: HWS 3 Gas heating system heating and standby mode electricity consumption for the Brahe Place building (Paul and Andrews 2013).

Occupancy	Cycle pump annual electricity consumption (kWh)	Cycle pump rated power consumption (kW)	Heating mode annual operation of cycle pump and gas heater (hrs)	No. of Rheem gas heater units	Yearly total heating operation hours (hrs)	Yearly total standby operation hours (hrs)	Annual total electricity consumption by heaters in heating and standby mode (kWh)
Average	104	0.51	205	2	409	17,111	172
High	112	0.51	220	2	441	17,079	174

Table 4-36 summarises the total direct heating and standby energy consumption for HWS 3 based on energy inputs from Table 4-34 and Table 4-35.

Table 4-36: HWS 3 Brahe Place building ring-main gas heating system annual total energy inputs (Paul and Andrews 2013).

Occupancy	Annual total water heating gas consumption including losses (GJ)	Hot water system annual total electricity consumption by all pumps and heaters (kWh)	Annual gas consumption per apartment (GJ)	Hot water system annual total electricity consumption per apartment (kWh)
Average	92.7	1,152	11.6	144
High	113	1,162	14.1	145

4.16.4 HWS 4 – Brahe Place gas plant ring main with solar energy use

The second of the three potential systems specified by Wood and Grieve for Brahe Place is a gas plant and ring main as per Section 4.16.3, supplemented by a solar plant. The main water heating source is 2 instantaneous gas heater units on a manifold. These units are the Rheem Multipak (MPE02K), and teamed up with 2 x 410 L storage tanks. From the SAMME TRNSYS report in Appendix F, HWS 4 is completed with the following:

> *There are four Rheem solar collectors (NPT200) on a frame, with a solar controller (052104) and a pump (Grundfos UPS 25-60 130 with 100 W input power, flow rate 0.2 m^3/h) connected to the storage tanks in a separate loop. The solar controller will turn on the solar pump and draw water from bottom of the tanks and will pass through the collectors to preheat the water, if the output temperature of the collectors is above 50°C. This will supplement the gas required by the gas heater to meet the hot water demand of the building. Then water is heated up to the specified 70°C through the heaters and transferred to the storage tanks via Lowara hot water heater cycle pumps (4HMS3 with 0.51 kW input power, flow rate 4.0 m^3/h, 1 operates for both tanks).*
>
> *It needs to be noted here that we have not investigated whether the solar system is optimised in terms of collector area and solar fraction within the present study; we have simply assumed the specifications of the solar system for this building provided by the building designers, Wood and Grieve. However, in the TRNSYS model the collectors are assumed to be installed facing North, tilted at the Melbourne latitude angle (38°) to receive optimum solar radiation for the year round application.*
>
> *In the water draw-off loop (demand side) the tanks are connected to the main hot water flow pipes (32 mm and 25 mm dia.) and return pipes (25 mm dia.) throughout all the floors of the building. Water is circulated through this ring main constantly (24 hours a day, 7 days a week), using a Grundfos hot water flow and return pump (UPS 25-60 130 with 100 W input power, flow rate 0.2 m^3/h, and two identical pumps alternately in use periodically). The hot water flow and return pipes are interconnected at each level to minimise the pressure drop when there is draw off (Figure 23). When hot water is drawn off by residents, cold water is mixed with the hot water within each apartment to yield a delivery temperature of 50°C. Table 22 lists of all the components and their detailed specifications in the*

overall solar-boosted gas ring-main water heating system (Paul and Andrews 2013).

The NPT200 panels are also noted in the literature as having an average annual efficiency of 57% (Rheem 2007). Table 4-37 summarises the performance characteristics of HWS components.

Table 4-37: HWS 4 Solar-boosted gas heating system components for Brahe Place building (Paul and Andrews 2013).

System component	Specifications
Storage tank	Rheem (610 430), volume 410 L, height 1.64 m, 2 units
Cycle pump	Lowara (4HMS3), input power 0.51 kW, flow rate 4.0 m^3/h, 1 unit
Gas heater	Rheem Multipak (MPE02K), gas input 410 MJ/h, efficiency 80%, 2 units*
Hot water flow pipe	Copper pipe, 50 m long – 25 mm dia. (22.2 mm inner dia.), 25 m long – 32 mm dia. (28.6 mm inner dia.) (Standard Australia 2004)
Hot water return pipe	Copper pipe, 25 m long – 25 mm dia. (22.2 mm inner dia.)
Pipe Insulation	Armaflex insulation, thickness 25 mm, loss coefficient 9.3 kJ/hm^2K for 32 mm pipe, and 10.7 kJ/hm^2K for 25 mm pipe (based on inner surface area of the pipe)
Flow/return pump	Grundfos (UPS 25-60 130), input power 0.1 kW, flow rate 0.2 m^3/h, 1 unit operating
Solar collector	Rheem (NPT200), aperture area 1.86 m^2, black polyester absorber (0.92 absorptance coefficient), 4 units
Solar pump	Grundfos (UPS 25-60 130), input power 0.1 kW, flow rate 0.2 m^3/h, 1 unit

** The Rheem Multipak series run a fan and electronics; however the details were not available. The Bosch 32 series specifications were used as a proxy, when heating at 85 W per unit, and standby electricity is 8 W per unit (as advised by Bosch).

Rheem literature (Figure 4-14) and sales managers were engaged to explain the way that these systems operate in detail.

S200 COLLECTOR TECHNICAL DATA		
Overall Dimensions H x W x D	mm	1937 x 1022 x 65
Aperture Area	m^2	1.86
Weight (empty /full)	kg	35/37
Fluid Capacity	Litres	2
Number of Risers		33
Absorber Material		Black Polyester Steel
Insulation		Polyester
Glazing		Tempered
Tray Material		Zincalume®

Figure 4-14: Rheem solar collector specification (Rheem 2011)

The key difference between the HWS 3 from Section 4.16.3 and HWS 4 is that the latter produces hot water during off peak time (during the day) to supplement the standby hot water, effectively making the gas heaters a booster plant. From the SAMME TRNSYS report in Appendix F, HWS 4 solar performance is modelled as per the following:

> *The average solar radiation values on the collector surface tilted at the angle of 38° (Melbourne latitude) and facing north found from the simulation was 16.6 MJ/m^2/day. This value is consistent with daily average solar radiation data on an inclined surface in Melbourne, which is 17.1 MJ/m^2/day (BOM 2008).*

From this specification, SAMME set up an annual water and energy (gas and solar) consumption model in TRNSYS which is described in detail in Appendix F. The simulation results for the gas ring-main water heating system (HWS 4) in the Brahe Place Building is summarised in Table 4-38. It must be noted that the peak time of water use in not the peak time of solar gain for the system, and as such the solar contribution is not optimal. Based on Melbourne solar gain potential, solar contribution represents a small proportion of the energy required to heat and maintain direct draw off hot water and standby around the Brahe centralised HWS4):

Table 4-38: HWS 4 TRNSYS simulation results for the solar-gas ring-main water heating system in the Brahe Place building (Paul and Andrews 2013).

Occupancy	Annual hot water demand (kL)	Annual gas consumption (GJ)	Annual energy supplied by solar collectors (GJ)	Piping annual heat loss (GJ)	Storage tank annual heat loss (GJ)	Cycle pump annual electricity consumption (kWh)	Flow/return pump annual electricity consumption (kWh)	Solar pump annual electricity consumption (kWh)	Cycle, flow/return and solar pump combined annual electricity consumption (kWh)
Average	161	74.6	14.8	30.5	9.5	102	876	107	1,085
High	269	93.9	15.5	30.6	9.3	125	876	111	1,112

The simulation results for HWS 4 stand by operation and electrical performance in the Brahe Place building is summarised in Table 4-39.

Table 4-39: HWS 4 Solar-gas heating system heating and standby mode electricity consumption for Brahe Place building (Paul and Andrews 2013).

Occupancy	Cycle pump annual electricity consumption (kWh)	Cycle pump rated power consumption (kW)	Heating mode annual operation of cycle pump and gas heater (hrs)	No. of Rheem gas heater units	Yearly total heating operation hours (hrs)	Yearly total standby operation hours (hrs)	Annual total electricity consumption by heaters in heating and standby mode (kWh)
Average	102	0.51	199	2	398	17,122	171
High	125	0.51	245	2	489	17,031	178

Table 4-40 summarises the total energy consumption annually and per apartment for HWS 4 based on energy inputs from Table 4-38 and Table 4-39.

Table 4-40: HWS 4 Brahe Place building solar-boosted ring-main gas heating system annual total energy inputs (Paul and Andrews 2013).

Occupancy	Annual total water heating gas consumption including losses (GJ)	Hot water system annual total electricity consumption by all pumps and heaters (kWh)	Annual gas consumption per apartment (GJ)	Hot water system annual total electricity consumption per apartment (kWh)
Average	74.6	1,256	9.3	157
High	93.9	1,289	11.7	161

Although not specified by Wood and Grieve, a scenario like HWS 4 with CFEWH units substituted for the gas plant is explored in a sensitivity analysis in Section 6.2.4 to see how this affects results.

4.16.5 HWS 5 – Brahe Place CFEWH energy use

The third alternative for Brahe Place is a point of use hot water system as specified by Wood and Grieve. **The main water heating source is 8 CFEWH units, one for each apartment, set to 50°C at the door.** These units are MicroHeat Series 1 three phase heaters, with cold water inlets. MicroHeat technical managers were engaged to explain the way that these systems operate in detail.

Water is supplied cold to the apartments, and heated up to the specified 50°C with modulating electrical power based on inlet temperature and flow rate. Annual hot water heating energy can be categorised into one discreet classification;

1. Direct draw off hot water heating energy and distribution

Direct draw off heating energy can be assumed as enough water heated to 50°C to deliver the annual building hot water draw off for residents. The average efficiency of the MicroHeat Series 1 three phase heaters is promoted as 98% by MicroHeat (based on standby energy use, etc. and confirmed through testing at the RMIT School of Aerospace, Mechanical and Manufacturing Engineering (SAMME) in Appendix E (this includes 'start-up' energy requirements tested under a range of usage patterns, showing the 98% is a conservative approximation). The MicroHeat Series 1 three phase heaters run at a standby electricity consumption of 1.3 W per unit (as advised by MicroHeat), when no water is being drawn.

When direct draw heating occurs, mains pressure and booster (not accounted for in this modelling) pumps run cold water to the apartments to heat water. Annual hot water consumption derives from Table 4-20, with summer and winter period hot water is split, with monthly and time based fluctuations accounted for as per Table 4-21 and Table 4-22.

From this specification, SAMME set up an annual water and energy consumption model in TRNSYS which is described in detail in Appendix F. The simulation results for the CFEWH system (HWS 5) in the Brahe Place building is summarised in Table 4-41.

Table 4-41: HWS 5 - TRNSYS simulation results for CFEWH system for Brahe Place building

Occupancy	Annual hot water demand (kL)	Annual electricity consumption (MWh)
Average	161	6.9
High	269	11.5

The simulation results for HWS 5 stand by operation and electrical performance in the Brahe Place building is summarised in in Table 4-42

Table 4-42: HWS 5: CFEWH system standby mode total electricity consumption for Brahe Place building (Paul and Andrews 2013).

Heating mode (hrs/day)	Standby mode (hrs/day)	No. of CFEWH units	Yearly total standby operation (hrs)	CFEWH standby power consumption (W)	Yearly total standby electrical energy consumption (kWh)
8	16	8	46,720	1.3	61

Table 4-43 summarises the total energy consumption annually and per apartment for HWS 5 based on energy inputs from Table 4-41 and Table 4-42.

Table 4-43: HWS 5: Brahe Place building CFEWH system annual total energy inputs (Paul and Andrews 2013).

Occupancy	Annual water heating electricity consumption (MWh)	Annual standby electricity consumption by heater units (kWh)	Building hot water system total annual electricity consumption (MWh)	Hot water system annual total electricity consumption per apartment (kWh)
Average	6.9	61	6.9	864
High	11.5	61	11.5	1,440

4.16.6 Use phase building comparisons

The following section compares the HWS energy performance of the potential HWS for each building. Table 4-44 summarizes and compares the potential HWSs in the La Banque building.

Table 4-44: La Banque building total annual water and secondary energy use for the different water heating options and occupancy levels (Paul and Andrews 2013).

Hot water use profile	Type of hot water systems for La Banque building					
	Gas ring main (HWS 1)			CFEWH (HWS 2)		
	Low	Average	High	Low	Average	High
Water use (kL/y)	5,159	6,847	10,699	5,159	6,847	10,699
Gas use (GJ/y)	1,876.1 (521,139 kWh)	2,198.1 (610,583 kWh)	2,931.9 (814,417 kWh)	0	0	0
Electricity use (kWh/y)	4,481	4,699	5,312	222,087	294,138	458,516
Total energy use (kWh equivalent/y)	525,620	615,282	819,729	222,087	294,138	458,516

Table 4-45 summarizes and compares the potential HWSs in the La Banque building.

Table 4-45: Brahe Place building total annual water and secondary energy use for the different water heating options and occupancy levels (Paul and Andrews 2013).

Hot water use profile	Type of hot water systems for Brahe Place building					
	Gas ring-main (HWS 3)		Solar gas ring-main (HWS 4)		CFEWH (HWS 5)	
	Average	High	Average	High	Average	High
Water use (kL/y)	161	269	161	269	161	269
Gas use (GJ/y)	92.7 (25,750 kWh)	113.0 (31,389 kWh)	74.6 (20,722 kWh)	93.9 (26,083 kWh)	0	0
Electricity use (kWh/y)	1,152	1,162	1,256	1,289	6,913	11,523
Total energy use (kWh equivalent/y)	26,902	32,551	21,978	27,372	6,913	11,523

One important point to note from these results is that the smaller building Brahe Place runs a larger load of standby energy (to keep the water hot at all times) in proportion to the direct HWS energy used for any water draw off, thus making it less efficient overall as a system as the larger building La Banque.

This can be further explained by Brahe Place having less residents for average and high scenarios being smaller apartments (leading to lower water draw offs, making standby heating a higher proportion of these scenarios than La Banque), and the fact that Brahe Place has almost double the hot water pipe (12.5 m) to deliver hot water per apartment than La Banque (6.5 m) in the centralised HWSs, with the majority of these pipes of similar heat loss (10.4 - 14.1 W/m), resulting in more heat is lost in Brahe Place standby compared to La Banque (apart from 9% of pipes at 75 mm in La Banque losing 21.2 W/m).

Apart from the solar contribution modelling for HWS 4 which changed significantly with the input of SAMME researchers, Table 4-44 and Table 4-45 energy consumption figures are closely aligned with results from a previous report using a simplified modelling methods from first principles (not a dynamic TRNSYS model), Life Cycle Use Phase of Hot Water Delivery (Lockrey 2012). **This instils confidence in the robustness of work completed by SAMME, with the dynamic and simplified methods triangulating with directionally consistent results.**

4.17 Transport

4.17.1 Transport to building site

Based upon on the information provided by MicroHeat and other suppliers on the geographical location of their suppliers respectively, the transport routes and distances of the products within the HWSs was calculated, and applied at a unit process level. The distances calculated are detailed in Table 4-46.

Table 4-46: Transport distances and modes

Route	Distance (km)	Transport mode
Attendorn (Germany) to Rotterdam (Holland)	337	truck
Rotterdam (Holland) to Port Melbourne (VIC)	24,848	ship
Perth (WA) to Melbourne (VIC)	3,269	truck
Rydalmere (NSW) to Melbourne (VIC)	894	truck
Montecchio Maggiore (Italy) to Venice (Italy)	79	truck
Venice (Italy) to Port Melbourne (VIC)	18,257	ship
Bjerringbro (Denmark) to Aalborg (Denmark)	88	truck
Aalborg (Denmark) to Port Melbourne (VIC)	22,700	ship
Wingfield (SA) to Melbourne (VIC)	735	truck
Adelaide (SA) to Melbourne (VIC)	727	truck
Penrith (NSW) to Melbourne (VIC)	866	truck
Eagle Farm (QLD) to Melbourne (VIC)	1,725	truck
Liverpool (NSW) to Melbourne (VIC)	863	truck
Kofu (Japan) to Tokyo, (Japan)	127	truck
Tokyo, (Japan) to Port Melbourne (VIC)	9,006	ship
Mölndal (Sweden) to Gothenburg (Sweden)	15	truck
Gothenburg (Sweden) to Port Melbourne (VIC)	22,659	ship
Conover, NC (USA) to Norfolk, VA (USA)	523	truck
Norfolk (USA) to Port Melbourne (VIC)	18,018	ship
Alexandria (NSW) to Melbourne (VIC)	869	truck
Underdale (SA) to Melbourne (VIC)	730	truck
Jiangsu (China) to Shanghai (China)	149	truck
Shanghai (China) to Port Melbourne (VIC)	9,290	ship
South Minneapolis MN (USA) to New York NY (USA)	1,937	truck
New York NY (USA) to Port Melbourne (VIC)	18,398	ship
Rocherlea (TAS) to Devonport (TAS)	108	truck
Devonport (TAS) to Port Melbourne (VIC)	459	ship
Devon Park (SA) to Port Melbourne (VIC)	728	truck
Rydalmere (NSW) to Port Melbourne (VIC)	876	truck

Route	Distance (km)	Transport mode
Southport (QLD) to Melbourne (VIC)	1,738	truck
Longhua Town (China) to Shenzhen (China)	30	truck
Shenzhen (China) to Port Melbourne (VIC)	9,041	ship
Silverwater (NSW) to Port Melbourne (VIC)	865	truck
Dandenong (VIC) to Port Melbourne (VIC)	37	truck
Mulgrave (VIC) to Port Melbourne (VIC)	27	truck
Bundoora (VIC) to Port Melbourne (VIC)	37	truck
Preston (VIC) to Port Melbourne (VIC)	14	truck
Bayswater (VIC) to Port Melbourne (VIC)	40	truck
Heidelberg (VIC) to Port Melbourne (VIC)	27	truck
Sunshine (VIC) to Port Melbourne (VIC)	16	truck
Port Melbourne (VIC) to supplier DC to building site	50 (estimation)	truck
Supplier factory to port where unknown	50 (estimation)	truck

Shipping distances were calculated from www.portworld.com and road distances from www.googlemaps.com, for HWS components. Shipping distances for materials to suppliers were inherent in the background of generic LCI unit processes. The assumptions used in transport calculations for components inbound to HWS building installations on site are in Table 4-47, with a more detailed supply chain for the CFEWH in Table 4-48.

Table 4-47: Transport assumptions for HWS components inbound to building site

Component/s to be shipped this distance	Route Start from supplier to site	Route Stages	Transport mode distances (km)
Polymer pipe	Attendorn (Germany)	Attendorn to Rotterdam (truck) – Melbourne (ship) – site (truck)	Ship = 24,848 Truck = 337 + 50 =387
Copper pipe	Penrith (NSW)	Penrith (truck) – Melbourne/ site (truck)	Truck = 866
Poly pipe	Dandenong (VIC)	Dandenong (truck) – Melbourne/ site (truck)	Truck = 37
Insulation	Conover (USA)	Conover to Norfolk (truck) – Melbourne (ship) – site (truck)	Ship = 18,018 Truck = 523 + 50 =573
Tempering valve, Hot water remote meter, Cold water bulk meter, Isolation Valve, Check Valve	Eagle Farm (QLD)	Eagle Farm (truck) – Melbourne/ site (truck)	Truck = 1,725
Hot water flow and return pumps	Bjerringbro (Denmark)	Bjerringbro to Aalborg (truck) – Melbourne (ship) – site (truck)	Ship = 22,700 Truck = 88 + 50 =387
Gas heater with manifold unit (Rheem and Bosch), 315L storage tank (Bosch)	Kofu (Japan)	Kofu to Tokyo (truck) – Melbourne (ship) – site (truck)	Ship = 9,006 Truck = 127 + 50 - 177
410 L storage tank (Rheem)	Rydalmere (NSW)	Rydalmere (NSW) – Melbourne/ site (truck)	Truck = 876
Water heater cycle	Montecchio Maggiore	Montecchio Maggiore to Venice (truck) – Melbourne	Ship = 18,257

Component/s to be shipped this distance	Route Start from supplier to site	Route Stages	Transport mode distances (km)
pumps (Italy)	(Italy)	(ship) – site (truck)	Truck = 79 + 50 = 129
Water heater cycle pump (Denmark)	Bjerringbro (Denmark)	Bjerringbro to Aalborg (truck) – Melbourne (ship) – site (truck)	Ship = 22,700 Truck = 88 + 50 =138
Balancing valve	Mölndal (Sweden)	Mölndal to Gothenburg (truck) – Melbourne (ship) – site (truck)	Ship = 22,659 Truck = 15 + 50 = 65
Fire collar	Adelaide (SA)	Adelaide (truck) – Melbourne/ site (truck)	Truck = 727
Gas meter	Wingfield (SA))	Wingfield (truck) – Melbourne/ site (truck)	Truck = 735
Electric cables	Liverpool (NSW)	Liverpool (truck) – Melbourne/ site (truck)	Truck = 863
Hot water plant enclosure	Dandenong (VIC)	Dandenong (truck) – Melbourne/ site (truck)	Truck = 37
Solar collector	Perth (WA)	Perth (truck) – Melbourne/ site (truck)	Truck = 3,269
Solar collector frame	Adelaide (SA)	Adelaide (truck) – Melbourne/ site (truck)	Truck = 727
Solar controller	Sydney (NSW)	Sydney (truck) – Melbourne/ site (truck)	Truck = 895

Table 4-48: Transport assumptions for CFEWH components inbound to building site

Component/s to be shipped this distance	Route Start from supplier to site	Route Stages	Transport mode distances (km)
Decal	Alexandria (NSW)	Alexandria (truck) – Melbourne/ site (truck)	Truck = 869
Earth wire,	Underdale (SA)	Underdale (truck) – Melbourne/ site (truck)	Truck = 730
Electrode plates	Jiangsu (China)	Jiangsu to Shanghai (truck) – Melbourne (ship) – site (truck)	Ship = 9,290 Truck = 149 + 50 =199
Filter washer	South Minneapolis MN (USA)	South Minneapolis to New York (truck) – Melbourne (ship) – site (truck)	Ship = 18,398 Truck = 1,937 + 50 =1,987
Heat sink	Rocherlea (TAS)	Rocherlea to Devonport (truck) – Melbourne (ship) – site (truck)	Ship = 459 Truck = 108 + 50 =158
Membrane	Devon Park (SA)	Devon Park (truck) – Melbourne/ site (truck)	Truck = 728
Labels	Adelaide (SA)	Adelaide (truck) – Melbourne/ site (truck)	Truck = 727
Gland, gaskets, caps, o-rings, washers (rubber)	Rydalmere (NSW)	Rydalmere (truck) – Melbourne/ site (truck)	Truck = 876
Temperature sensor	Southport	Southport (truck) –	Truck = 1,738

Component/s to be shipped this distance	Route Start from supplier to site	Route Stages	Transport mode distances (km)
	(QLD)	Melbourne/ site (truck)	
Cut out switch	Longhua Town (China)	Longhua Town to Shenzhen (truck) – Melbourne (ship) – site (truck)	Ship = 9,041 Truck = 30 + 50 = 80
Thermal paste	Silverwater (NSW)	Silverwater (truck) – Melbourne/ site (truck)	Truck = 865
	Dandenong (VIC)	Dandenong (truck) – Melbourne/ site (truck)	Truck = 37
Flow rate sensor	Mulgrave (VIC)	Mulgrave (truck) – Melbourne/ site (truck)	Truck = 27
Printed Circuit Boards	Bundoora (VIC)	Bundoora (truck) – Melbourne/ site (truck)	Truck = 37
Bracket, pin, mouldings, insulators,	Preston (VIC)	Preston (truck) – Melbourne/ site (truck)	Truck = 14
Bracket, pressure plate	Bayswater (VIC)	Bayswater (truck) – Melbourne/ site (truck)	Truck = 40
Bolts, screws, nuts, washer	Heidelberg (VIC)	Heidelberg (truck) – Melbourne/ site (truck)	Truck = 27
Inlets/ outlets, electrode posts,	Sunshine (VIC)	Sunshine (truck) – Melbourne/ site (truck)	Truck = 16
CFEWH final assembly	Port Melbourne (VIC)	Port Melbourne (truck) – Melbourne/ site (truck)	Truck = 50

4.17.2 Transport modes

Table 4-49 presents the transport models used for this study from ecoinvent 2.2 for European/Asian/US trucking/rail and international shipping routes and AUPLCI for Australian trucking routes. The trucking inventory is an average of urban and rural transport. Australian fuel use data is from (Apelbaum 2001) with greenhouse related emissions based on fuel factors taken from (NGGIC 1997).

Table 4-49: Inventory of transport models used

Transport mode	CO_2 intensity (kg CO_2 eq/ kg.km)	Units	Comments
Truck (Australia)	0.000095	kg.km	Articulated Truck, average, freight task from AUPLCI, developed from (Apelbaum 2001), Average load (28t) with backhaul of 1.2 (truck is empty 40% of the time) is used as default.
Truck (Europe/Asia/USA)	0.00023	kg.km	Transport, lorry 7.5-16t, EURO3 from ecoinvent 2.2. Contained in “Life Cycle Inventories of Transport Services, 2007”
Ship (International)	0.000011	kg.km	Transport, transoceanic freight ship from ecoinvent 2.2. Contained in “Life Cycle Inventories of Transport Services, 2007”

Note: CO_2 equivalent intensities derived from IMPACT 2002+ method and don’t necessarily align with NGERS reporting factors

4.18 End of Life

At the end of the HWS components useful life, parts are assumed to be discarded into construction and demolition waste streams that invariably end up in landfill. It could be argued however that high value items, such as copper pipes and other metals would be collected to be recycled from construction and demolition waste, potentially creating a credit for some impact categories. It is therefore important to check the results to see if material and manufacturing impacts of components could not change the results if recycled, or lie outside of the cut off criteria (as per Section 3.7). If so the landfill assumption is deemed to be reasonable. This is checked in the disaggregated results in Section 6.1.

The effect of having shorter product lives on waste streams for various components is explored in a sensitivity analysis in Section 6.2.3. Recycling was not considered in this study, as parts are generally discarded post replacement or demolition in the Australian context. The sensitivity analysis in Section 6.2.3 is designed to explore whether any change in the material flows of HWS components change the results (only solid waste is expected to be affected significantly), which will give an indication of what recycling may look like relative to the entire life cycle.

MicroHeat has mentioned that there are plans to introduce a product stewardship scheme for the CFEWH units. It follows that expectations over the full life cycle would be minimal effect on environmental impacts due to such a big contribution from use of the HWS, except solid waste measures.

4.19 Data quality assessment

Data quality differs between the processes delivering the functional unit in this study. Generally a high level of completeness and consistency was achieved for the HWS materials, manufacturing processes, use, transport and end of life because the data was either publicly available or directly measured and reported on by suppliers.

The material data sets used are considered the most up to date in light of unavailable primary data from the material manufacturers of MicroHeat or other HWS components.

Overall, the data quality achieved is believed to be sufficient to judge the scale of impacts related to most environmental impacts assessed, particularly the categories important to the goal of this study. The results of the data quality assessment are listed in Table 4-50. Representativeness, consistency and reproducibility are considered qualitative (ranked good, medium or poor) and relate to previous items in Table 4-50 (i.e. region, time frame, precision, and technology) aligned to data in the model, transparency of the inventory, etc.

Table 4-50: Data quality assessment

Inventory item	Time (Year)	Geography (Region for majority data)	Technology	Precision	Completeness (% measured)	Representativeness (Poor/Medium/ Good)	Consistency (Poor/Medium/ Good)	Reproducibility (Poor/Medium/ Good)
Materials	2005-2007	Europe	Industry average	75%	75%	Medium	Good	Good
Manufacturing processes	2005-2010	Europe	Industry average	75%	75%	Medium	Good	Good
Occupancy	2004-2007	Australia	Literature	90%	90%	Good	Good	Good
Building life	2008-2011	Australia	Literature	80%	80%	Good	Good	Good
Insulation properties	2007-2012	Australia	Industry average	80%	80%	Good	Good	Good
Ambient temperature, water and solar conditions	2008	Australia	Literature	90%	90%	Good	Good	Good
Hot water consumption	2005-2009	Australia	Literature	80%	80%	Good	Good	Good
HWS energy consumption	2012-2013	Australia	TRNSYS model	90%	90%	Good	Good	Good
Transport	2005-2009	Australia	Industry average	80%	80%	Good	Good	Medium
Waste treatment	2005-2009	Australia	Industry average	75%	75%	Medium	Good	Good
Gas grids	2005-2009	Australia	Industry average	80%	80%	Good	Good	Good
Electricity grids	2003	Australia	Industry average	80%	80%	Good	Good	Good

Based upon the process of inventory item collection, MicroHeat requirements, and in areas of lower data quality than the requirements, sensitivity analyses were run to test conclusions (refer Section 6.2). Sensitivity analyses of the results, reported in Section 6 included:

- Region for HWS use
- Occupancy and vacancy
- Component replacement, component materials, and building life
- CFEWH and solar boosting (substitute electric HWS 4)
- Extra centralised system losses in ring main
- Victorian electricity grid changes
- Green power purchasing

5 Life Cycle Impact Assessment

5.1 Characterisation results

LCA has been used to evaluate and compare potential environmental impacts of the 5 different HWSs, following a detailed data collection and inventory modelling. A summary of base case Life Cycle Impact Assessment (LCIA) results for the impact categories from the Australian Impact Method developed by the CfD is provided in Table 5-1 (La Banque building) and Table 5-2 (Brahe Place building), comparing the HWSs for the various water use scenarios (based on occupancy). The difference in the impacts between the systems relate to differences in the emissions and resources associated with the production of materials, material conversion for HWS components, distribution of HWS components, HWS use and waste treatment.

Table 5-1: Impact assessment characterisation values for La Banque HWSs for a year of hot water use

Impact category	Unit	Use scenario	HWS 1 Central gas plant	HWS 2 CFEWH point of use
Global warming	kg CO_2 eq	Low	1.20E+05	3.04E+05
		Average	1.40E+05	4.01E+05
		High	1.87E+05	6.23E+05
Cumulative energy demand	MJ LHV	Low	2.05E+06	3.38E+06
		Average	2.40E+06	4.47E+06
		High	3.21E+06	6.95E+06
Water use	kL H_2O	Low	5.21E+03	5.80E+03
		Average	6.90E+03	7.65E+03
		High	1.08E+04	1.19E+04
Solid waste	kg	Low	4.91E+02	5.04E+03
		Average	549.87	6.61E+03
		High	687.87	1.02E+04

Table 5-2: Impact assessment characterisation values for Brahe Place HWSs for a year of hot water use

Impact category	Unit	Use scenario	HWS 3 Central gas plant	HWS 4 Central gas plant & solar	HWS 5 CFEWH point of use
Global warming	kg CO_2 eq	Average	7.17E+03	6.36E+03	9.46E+03
		High	8.45E+03	7.61E+03	1.57E+04
Cumulative energy demand	MJ LHV	Average	1.14E+05	9.87E+04	1.05E+05
		High	1.37E+05	1.20E+05	1.75E+05
Water use	kL H_2O	Average	167.75	169.00	180.82
		High	275.93	277.24	299.54
Solid waste	kg	Average	57.56	70.82	156.77
		High	61.26	75.01	257.39

The results should not be used to compare the potential environmental impact of HWSs other than with those included in the scope of this LCA. The relative results from the two scenarios are provided graphically in Figure 5-1 and Figure 5-2, with the highest of the HWSs for a particular impact set at 100%. For all impact and inventory categories for all scenarios for both buildings (in Melbourne), the CFEWH HWSs (HWS 2 and HWS 5) had higher impacts (apart from cumulative energy demand for average use in Brahe Place, where centralised gas HWS 3 was higher than the other two systems).

Tables 7.1 to 7.5 in Appendix J detail the top five inventory reference flows contributing to impacts in the different HWSs in the base case relative to the functional unit.

It must be made clear that direct quantitative comparisons will only be made for HWSs within the same building with no comparisons between the results of the two buildings (nor should this be done by any other party). Qualitative insights however may be drawn, i.e. the performance characteristics underpinned by a medium density and high density context.

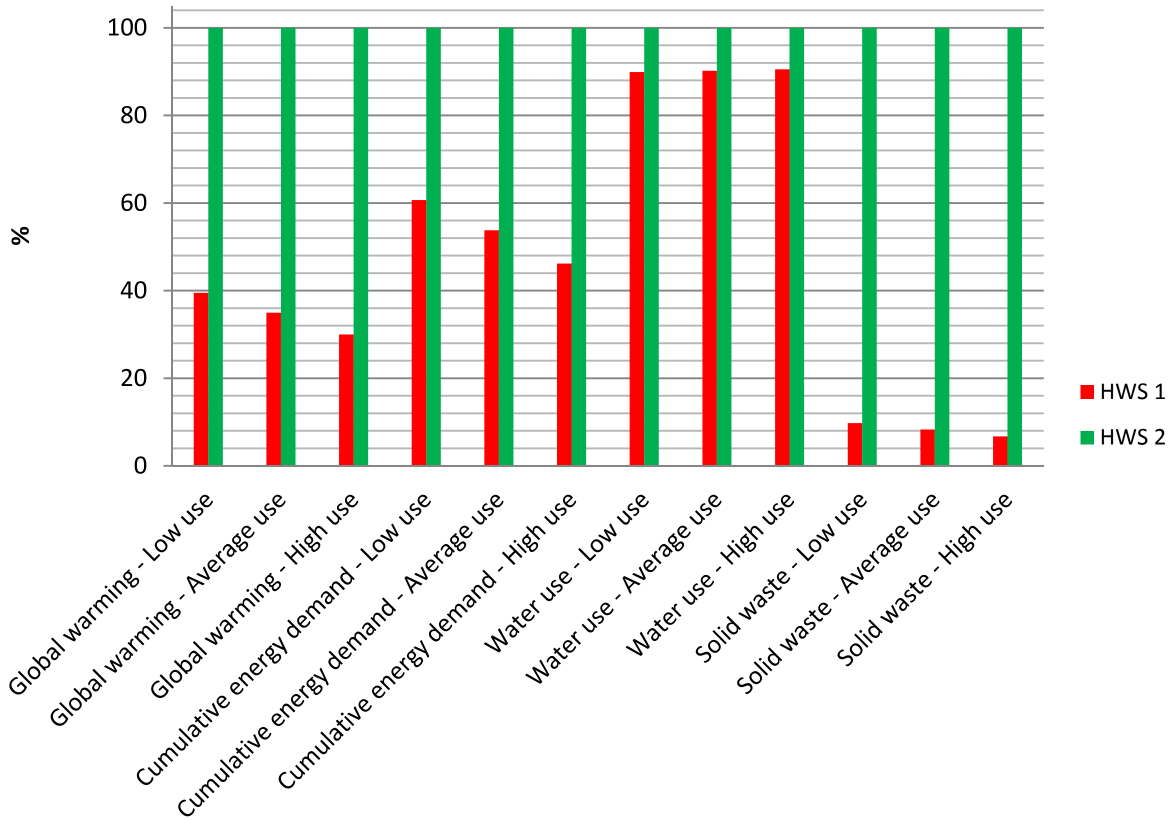

Figure 5-1: Relative summary of characterised results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

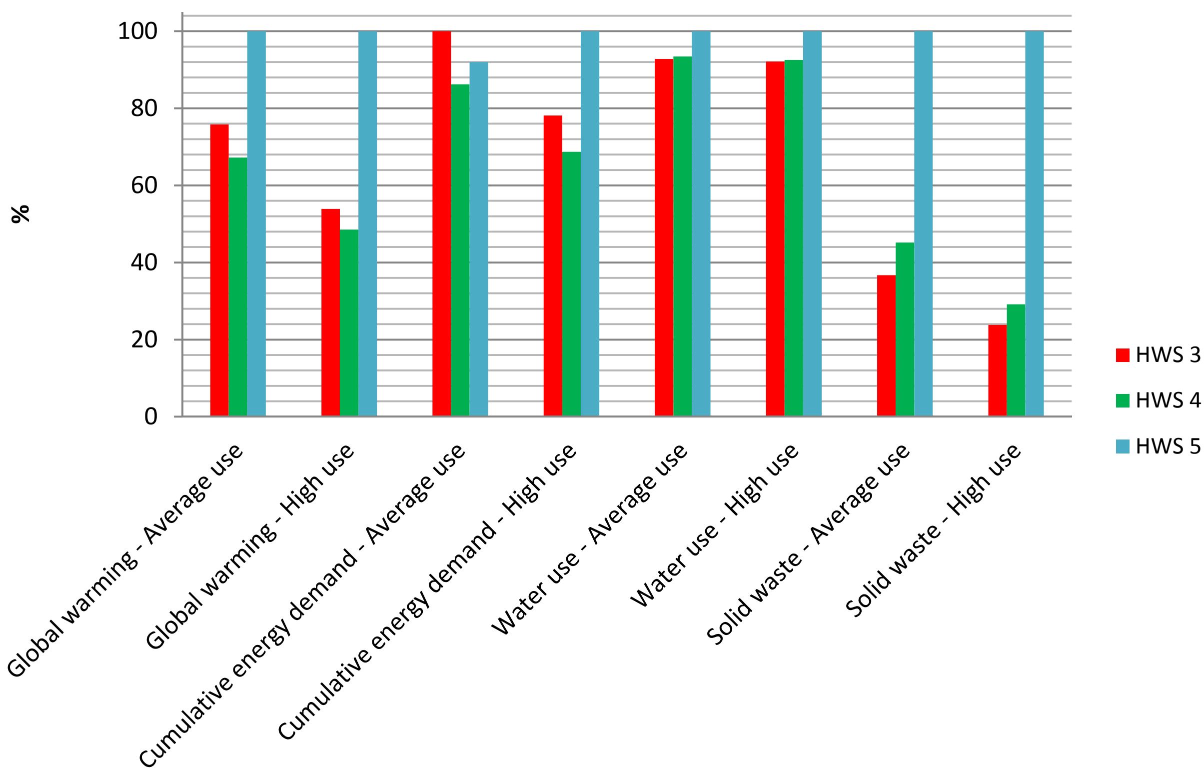

Figure 5-2: Relative summary of characterised results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS5

6 Discussion and interpretation

The following discussion and interpretation of results focuses on the four impact or inventory categories of interest aligned with the goal of the study. A check of contributing and non-assessed flows was completed, and presented in the Appendices.

6.1 Consistency and completeness

The interpretation includes sensitivity and cross-referencing tests to check consistency and completeness of inventory and results, based upon assumptions made in the inventory, and the data quality requirements and assessment. The inventory data was assessed for gaps in reference/ elemental flows and perceived gaps related to the impacts of interest in global warming potential, cumulative energy demand, water use and solid waste in Section 4.19.

6.1.1 Disaggregated results – Global warming potential at La Banque

The global warming potential results presented in Section 5 have been disaggregated into four life cycle categories; materials production and transport; HWS use (auxiliary); HWS use (heating); and end of life (Table 6-1 and Figure 6-1). HWS use (auxiliary) includes any energy used that is not directly heating water, HWS use (heating) any energy that directly heats water as well as the water itself, and end of life includes both disposal of parts and waste water treatment.

Table 6-1: Disaggregated results for global warming potential (kg CO_2 eq for La Banque HWSs per year)

Life cycle stage	Unit	HWS 1 Low use	HWS 1 Average use	HWS 1 High use	HWS 2 Low use	HWS 2 Average use	HWS 2 High use
Materials, production and transport	kg CO_2 eq	971.58	971.58	971.58	4.25E+03	4.25E+03	4.25E+03
HWS use (auxiliary energy)	kg CO_2 eq	5.96E+03	6.17E+03	7.10E+03	2.59E+03	2.59E+03	2.59E+03
HWS use (heating energy and water)	kg CO_2 eq	1.10E+05	1.28E+05	1.71E+05	2.93E+05	3.89E+05	6.08E+05
End of Life (including water treatment)	kg CO_2 eq	3.60E+03	4.77E+03	7.47E+03	3.61E+03	4.81E+03	7.47E+03
Total	kg CO_2 eq	1.20E+05	1.40E+05	1.87E+05	3.04E+05	4.01E+05	6.23E+05

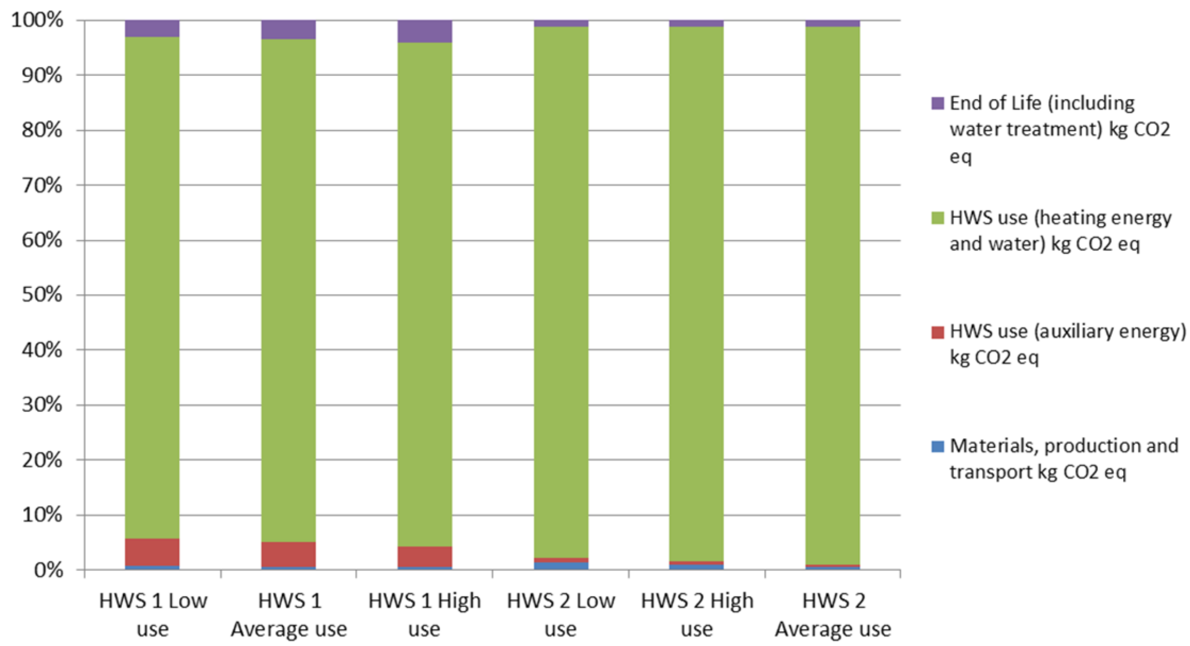

Figure 6-1: Disaggregated % characterisation results for global warming potential for La Banque HWSs

HWS 1 gas fuelled water heating (91-92%) and HWS 2 coal fire generated electricity based water heating (97-98%) drive global warming potential for all use scenarios. Within HWS 1 the auxiliary electrical energy used is a minor driver also at 4-5% across high to low use.

6.1.2 Disaggregated results – Cumulative energy demand at La Banque

The cumulative energy demand results presented in Section 5 have been disaggregated into life cycle stages (Table 6-2 and Figure 6-2).

Table 6-2: Disaggregated results for cumulative energy demand (MJ LHV for La Banque HWSs per year)

Life cycle stage	Unit	HWS 1 Low use	HWS 1 Average use	HWS 1 High use	HWS 2 Low use	HWS 2 Average use	HWS 2 High use
Materials, production and transport	MJ LHV	6.35E+03	6.35E+03	6.35E+03	3.04E+04	3.04E+04	3.04E+04
HWS use (auxiliary energy)	MJ LHV	6.57E+04	6.92E+04	7.86E+04	2.89E+04	2.89E+04	2.89E+04
HWS use (heating energy and water)	MJ LHV	1.93E+06	2.26E+06	3.01E+06	3.27E+06	4.34E+06	6.78E+06
End of Life (including water treatment)	MJ LHV	5.36E+04	7.12E+04	1.11E+05	5.34E+04	7.11E+04	1.11E+05
Total	MJ LHV	2.05E+06	2.40E+06	3.21E+06	3.38E+06	4.47E+06	6.95E+06

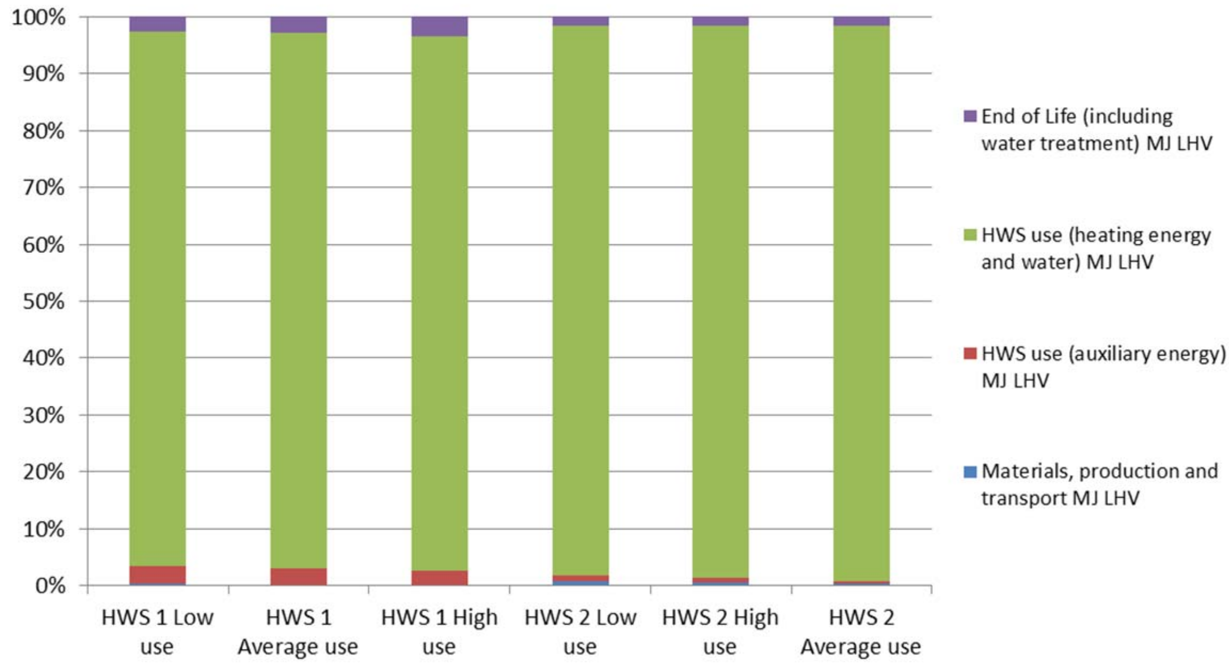

Figure 6-2: Disaggregated % characterisation results for cumulative energy demand for La Banque HWSs

Cumulative energy demand generally tracks global warming potential. HWS 1 gas fuelled water heating (94%) and HWS 2 coal fire generated electricity based water heating (97-98%) drive cumulative energy demand for all use scenarios. Again within HWS 1 the auxiliary electrical energy used is a minor driver at 2-3% across high to low use, with production, materials and transport contributing 2-3% across low to high use scenarios.

6.1.3 Disaggregated results – Water use at La Banque

The water use results have been disaggregated into life cycle stages (Table 6-3 and Figure 6-3).

Table 6-3: Disaggregated results for water use (kL for La Banque HWSs per year)

Life cycle stage	Unit	HWS 1 Low use	HWS 1 Average use	HWS 1 High use	HWS 2 Low use	HWS 2 Average use	HWS 2 High use
Materials, production and transport	kL	34.43	34.43	34.43	120.13	120.13	120.13
HWS use (auxiliary energy)	kL	10.42	10.70	10.76	4.48	4.48	4.48
HWS use (heating energy and water)	kL	5.16E+03	6.85E+03	1.07E+04	5.67E+03	7.50E+03	1.17E+04
End of Life (including water treatment)	kL	5.21	8.97	11.84	5.80	7.65	11.89
Total	kL	5.21E+03	6.90E+03	1.08E+04	5.80E+03	7.65E+03	1.19E+04

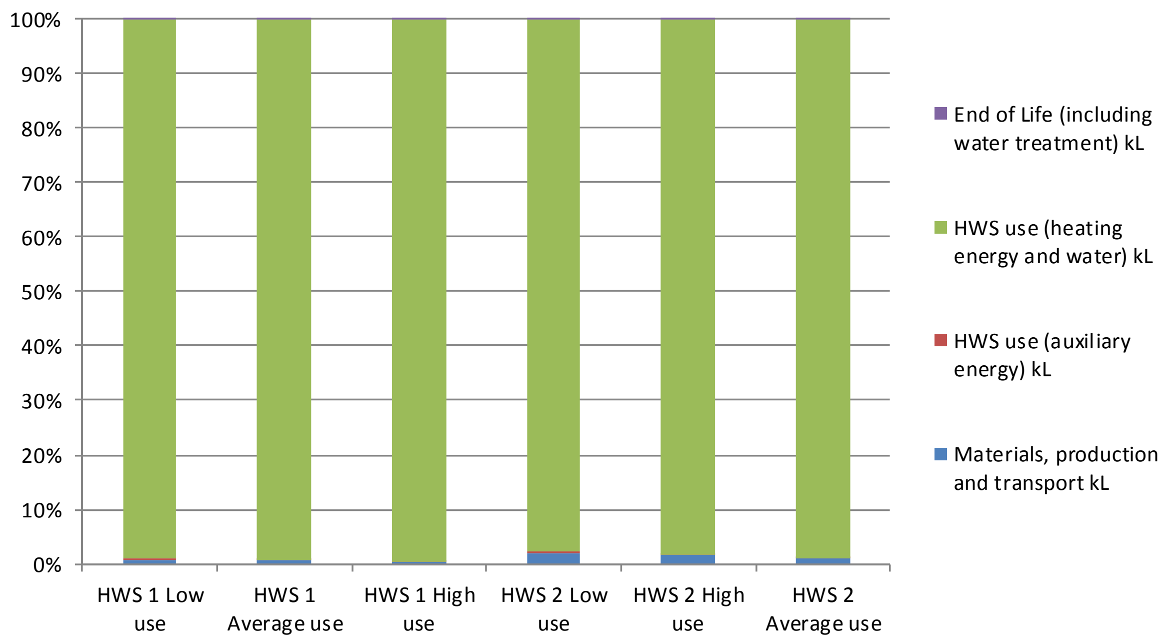

Figure 6-3: Disaggregated % characterisation results for water use for La Banque HWSs

Within HWS use (heating energy and water), HWS 1 water draw off (99%) and HWS 2 water draw off (89-90%) drive water use for all use scenarios. HWS 2 has a minor driver in the water used for cooling at coal fire power station generating the electricity used in water heating (9%) within HWS use too.

6.1.4 Disaggregated results – Solid waste at La Banque

The water use results have been disaggregated into life cycle stages (Table 6-4 And Figure 6-4).

Table 6-4: Disaggregated results for solid waste (kg for La Banque HWSs per year)

Life cycle stage	Unit	HWS 1 Low use	HWS 1 Average use	HWS 1 High use	HWS 2 Low use	HWS 2 Average use	HWS 2 High use
Materials, production and transport	kg	13.07	13.07	13.07	52.87	52.87	52.87
HWS use (auxiliary energy)	kg	94.34	98.98	112.12	41.11	41.11	41.11
HWS use (heating energy and water)	kg	26.83	35.61	56.20	4.64E+03	6.20E+03	9.68E+03
End of Life (including water treatment)	kg	356.24	401.40	505.58	276.94	323.84	428.29
Total	kg	491.37	549.87	687.87	5.04E+03	6.61E+03	1.02E+04

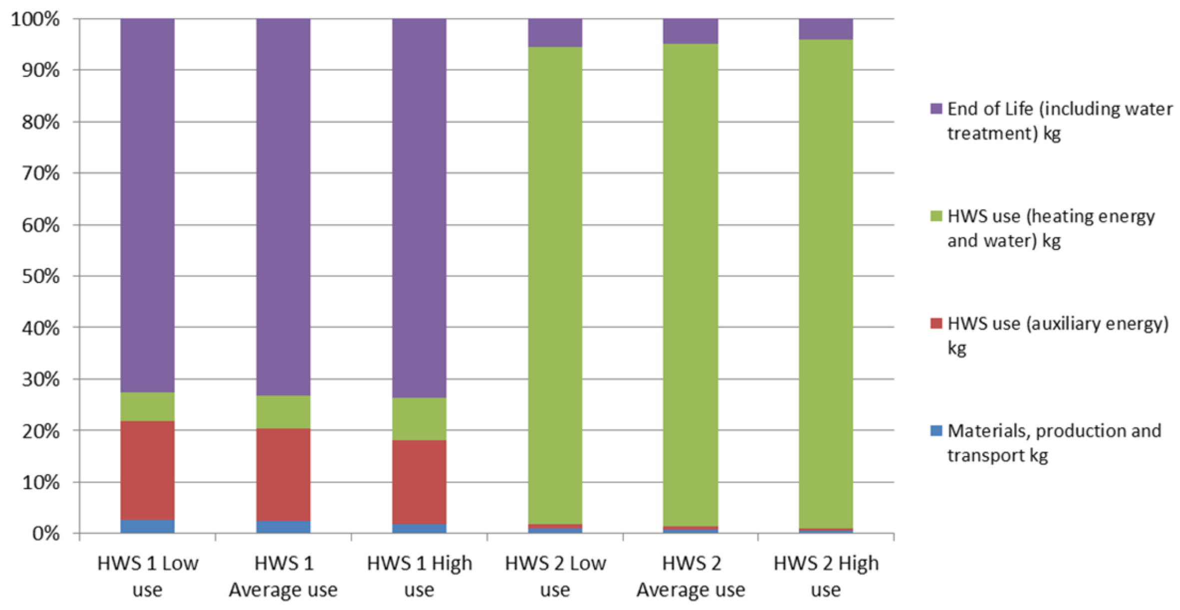

Figure 6-4: Disaggregated % characterisation results for solid waste for La Banque HWSs

HWS 1 component landfill and wastewater treatment (73-74%) drive solid waste for all use scenarios. HWS 2 waste from coal fired electricity generation for water heating (94%) drives solid waste for all use scenarios. HWS 1 the waste from coal fired electricity generation for auxiliary electrical energy used is a minor driver at 16-19% across high to low use, whilst HWS 2 component landfill and wastewater treatment contributing 4-6% across high to low use scenarios.

6.1.5 Disaggregated results – Global warming potential at Brahe Place

The global warming potential results presented in Section 5 have been disaggregated into four life cycle categories; materials production and transport, HWS use (auxiliary), HWS use (heating), and end of life (Table 6-5 and Figure 6-5).

Table 6-5: Disaggregated results for global warming potential (kg CO_2 eq for Brahe Place HWSs per year)

Life cycle stage	Unit	HWS 3 Average use	HWS 3 High use	HWS 4 Average use	HWS 4 High use	HWS 5 Average use	HWS 5 High use
Materials, production and transport	kg CO_2 eq	135.18	135.18	225.98	225.98	132.37	132.37
HWS use (auxiliary energy)	kg CO_2 eq	1.53E+03	1.55E+03	1.67E+03	1.71E+03	81.32	81.32
HWS use (heating energy and water)	kg CO_2 eq	5.40E+03	6.58E+03	4.32E+03	5.48E+03	9.11E+03	1.53E+04
End of Life (including water treatment)	kg CO_2 eq	114.71	185.87	114.42	187.94	112.52	188.07
Total	kg CO_2 eq	7.17E+03	8.45E+03	6.36E+03	7.61E+03	9.46E+03	1.57E+04

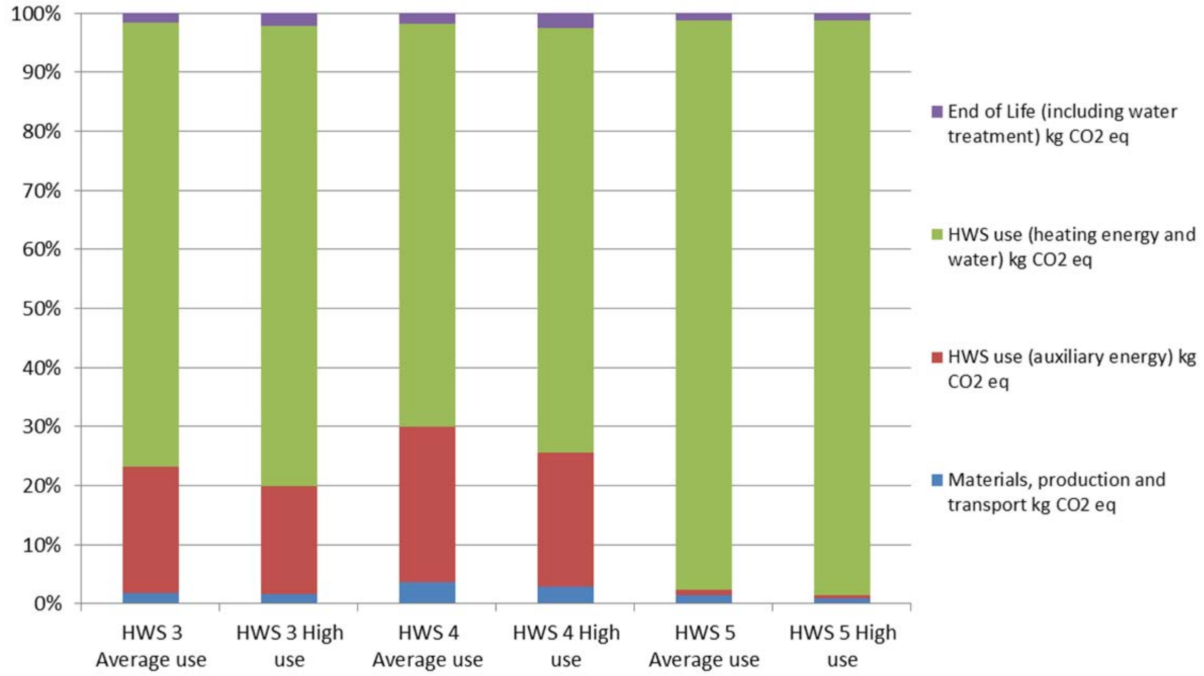

Figure 6-5: Disaggregated % characterisation results for global warming potential for Brahe Place HWSs

HWS 3 gas fuelled water heating (75-78%), HWS 4 gas fuelled water heating (70-74%), and HWS 5 coal fire generated electricity based water heating (96-97%) drive global warming potential for all use scenarios. Within HWS 3 the auxiliary electrical energy used is a minor driver at 18-21% across high to average use, with HWS 4 auxiliary electrical energy used a minor driver also at 23-27% across high to average use.

6.1.6 Disaggregated results – Cumulative energy demand at Brahe Place

The cumulative energy demand results presented in Section 5 have been disaggregated into life cycle stages (Table 6-6 and Figure 6-6). Renewable energy is not included (i.e. solar water heating).

Table 6-6: Disaggregated results for cumulative energy demand (MJ LHV for Brahe Place HWSs per year)

Life cycle stage	Unit	HWS 3 Average use	HWS 3 High use	HWS 4 Average use	HWS 4 High use	HWS 5 Average use	HWS 5 High use
Materials, production and transport	MJ LHV	669.31	669.31	1838.34	1838.34	936.98	936.98
HWS use (auxiliary energy)	MJ LHV	1.70E+04	1.72E+04	1.86E+04	1.91E+04	905.40	905.40
HWS use (heating energy and water)	MJ LHV	9.50E+04	1.16E+05	7.63E+04	9.64E+04	1.01E+05	1.70E+05
End of Life (including water treatment)	MJ LHV	1.72E+03	2.87E+03	1.68E+03	2.76E+03	1.68E+03	2.80E+03
Total	MJ LHV	1.14E+05	1.37E+05	9.87E+04	1.20E+05	1.05E+05	1.75E+05

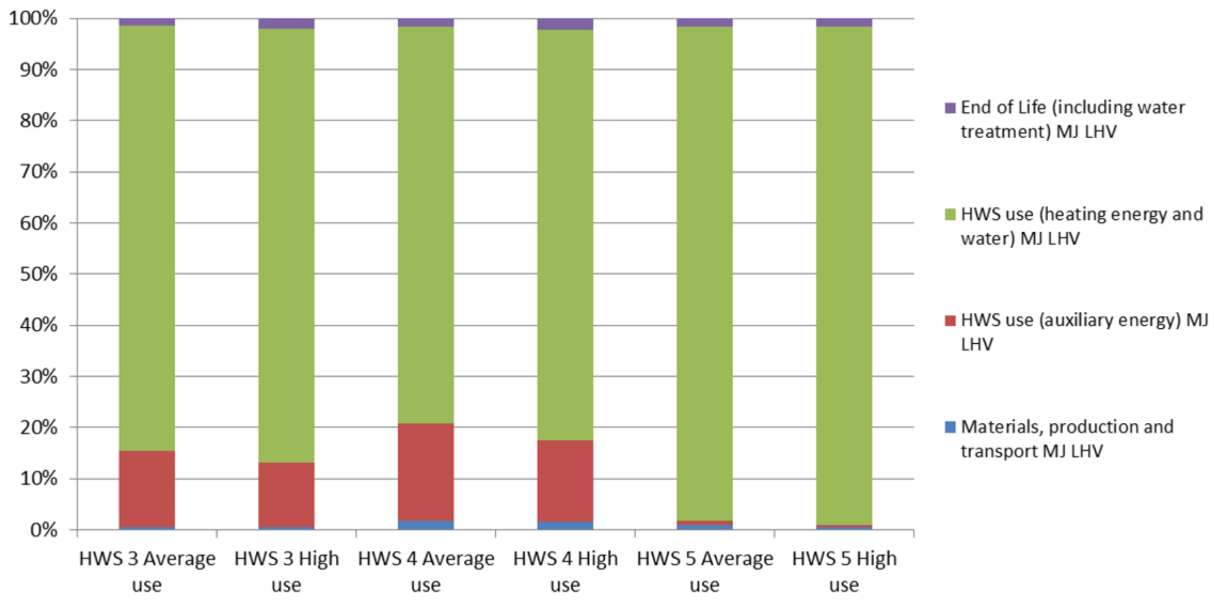

Figure 6-6: Disaggregated % characterisation results for cumulative energy demand for Brahe Place HWSs

Cumulative energy demand generally tracks global warming potential. HWS 3 gas fuelled water heating (83-85%), HWS 4 gas fuelled water heating (79-81%), and HWS 5 coal fire generated electricity based water heating (96-97%) drive global warming potential for all use scenarios. Within HWS 3 the auxiliary electrical energy used is a minor driver at 13-15% across high to average use, with HWS 4 auxiliary electrical energy used a minor driver also at 16-19% across high to average use.

6.1.7 Disaggregated results – Water use at Brahe Place

The water use results have been disaggregated into life cycle stages (Table 6-7 and Figure 6-7)

Table 6-7: Disaggregated results for water use (kL for Brahe Place HWSs per year)

Life cycle stage	Unit	HWS 3 Average use	HWS 3 High use	HWS 4 Average use	HWS 4 High use	HWS 5 Average use	HWS 5 High use
Materials, production and transport	kL	3.86	3.86	4.69	4.69	3.80	3.80
HWS use (auxiliary energy)	kL	2.68	2.68	2.87	3.05	0.14	0.14
HWS use (heating energy and water)	kL	161.04	269.03	160.96	269.48	176.84	295.29
End of Life (including water treatment)	kL	0.17	0.28	0.19	0.28	0.18	0.30
Total	kL	167.75	275.93	169.00	277.24	180.82	299.54

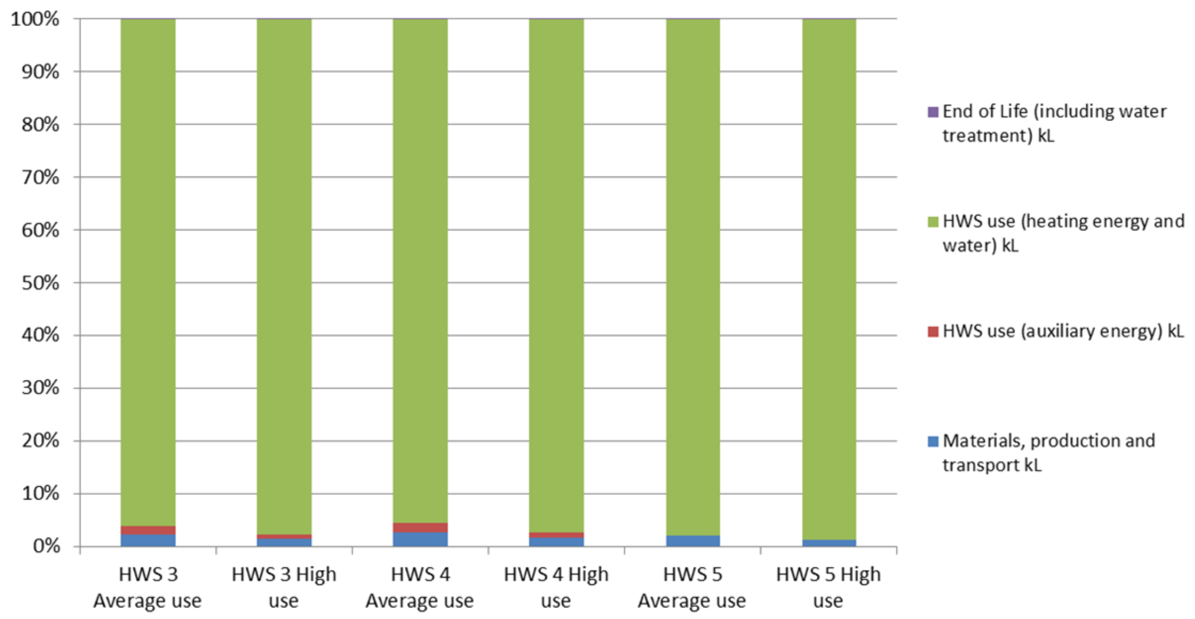

Figure 6-7: Disaggregated % characterisation results for water use for Brahe Place HWSs

Within HWS use (heating energy and water), HWS 3, HWS 4 water draw off (96-98%) and HWS 5 water draw off (89-90%) drive water use for all use scenarios. HWS5 also has a has a minor driver within HWS use in the water used for cooling at coal fire power station generating the electricity used in water heating (9%).

6.1.8 Disaggregated results – Solid waste at Brahe Place

The water use results have been disaggregated into life cycle stages (Table 6-8 and Figure 6-8).

Table 6-8: Disaggregated results for solid waste (kg for Brahe Place HWSs per year)

Life cycle stage	Unit	HWS 3 Average use	HWS 3 High use	HWS 4 Average use	HWS 4 High use	HWS 5 Average use	HWS 5 High use
Materials, production and transport	kg	7.35	7.35	5.48	5.48	1.72	1.72
HWS use (auxiliary energy)	kg	24.29	24.50	26.49	27.15	1.29	1.29
HWS use (heating energy and water)	kg	0.88	1.41	0.75	1.43	145.33	242.24
End of Life (including water treatment)	kg	25.09	27.99	38.10	40.95	8.62	11.58
Total	kg	57.56	61.26	70.82	75.01	156.77	257.39

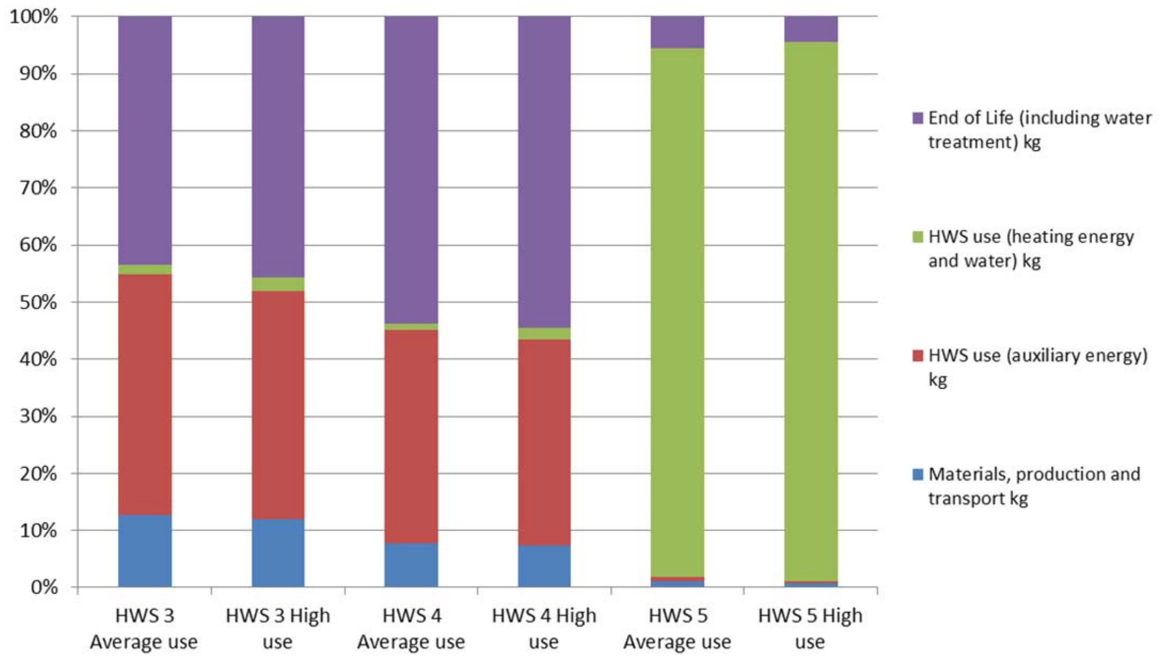

Figure 6-8: Disaggregated % characterisation results for solid waste for Brahe Place HWSs

HWS 3 component landfill and wastewater treatment (44-46%) and waste from coal fired electricity generation for auxiliary electrical energy used (40-42%) drive solid waste for all use scenarios. HWS 4 component landfill and wastewater treatment (53-54%) and waste from coal fired electricity generation for auxiliary electrical energy (36-37%) drive solid waste for all use scenarios. HWS 5 waste from coal fired electricity generation for water heating (93-94%) drives solid waste for all use scenarios.

This is the only impact category in the base case of either building where materials and manufacturing (and transport) are well above the cut off criteria of 2%, both for HWS 3 and HWS 4 (just over or below 10% for both use profiles). This is a flag to see whether recycling these components would affect results. The effect of recycling on solid waste would negate the contribution of the materials and manufacturing (and transport). This would only make the absolute results (as per Table 5-2 and Figure 5-2) better for HWS 3 and HWS 4 compared to HWS 5, so the assumption of 100% landfill stands as it has no directional or major quantitative effect on results.

6.2 Sensitivity analyses

In order to test the robustness of the base case results, a number of sensitivity analyses have been conducted incorporating potential changes to the HWSs, and the subsequent results have been compared. Generally the average use scenario for each building and associated HWSs was used to basis the analyses on.

6.2.1 Region for HWS use

It is important to test if the region in which the buildings in this study are located are modified changes the results in any way.

As per Figure 4-5, Sydney, Perth, Brisbane and Adelaide lay in the same climatic zone, which is a hotter region on average to the base case in Melbourne. For this reason, at the La Banque building the energy results would be the same for HWS1 and HWS 2 in these new regional contexts, using less energy to heat hotter ambient temperature water than Melbourne, as per Table 6-9 for the average use scenario.

Table 6-9: Sensitivity of use phase for HWS use Sydney, Adelaide, Perth and Brisbane (La Banque)

Hot water use profile	Type of hot water systems for LaBanque building	
	HWS1 - Bosch gas plant ring main	HWS2 - MicroHeat CFEWH
	Average	Average
Water use (kL)	6847	6847
Gas use (GJ)	2083.1	0
Electricity use (kWh)	4626	268390
Total Energy use (kWh)	583252	268390

These energy results were then combined with the appropriate energy grids from Table 4-13, and impact assessment run as per Table 6-10 and Figure 6-9 to Figure 6-12.

Table 6-10: Sensitivity of regional results for HWS average use impacts per year (La Banque)

Impact category	Unit	HWS 1	HWS 2
Global warming - Melbourne (base case)	kg CO2	1.40E+05	4.01E+05
Global warming - Adelaide	kg CO2	1.31E+05	1.93E+05
Global warming - Brisbane	kg CO2	1.31E+05	2.55E+05
Global warming - Perth	kg CO2	1.29E+05	2.20E+05
Global warming - Sydney	kg CO2	1.34E+05	2.74E+05
Impact category	Unit	HWS 1	HWS 2
Cumulative energy demand - Melbourne (base case	MJ LHV	2.40E+06	4.47E+06
Cumulative energy demand - Adelaide	MJ LHV	2.25E+06	2.73E+06
Cumulative energy demand - Brisbane	MJ LHV	2.24E+06	2.86E+06
Cumulative energy demand - Perth	MJ LHV	2.24E+06	2.98E+06
Cumulative energy demand - Sydney	MJ LHV	2.27E+06	3.06E+06
Impact category	Unit	HWS 1	HWS 2
Water use - Melbourne (base case)	KL H2O	6901.82	7651.31
Water use - Adelaide	KL H2O	6897.62	7174.50
Water use - Brisbane	KL H2O	6901.11	7583.55
Water use - Perth	KL H2O	6892.93	7312.00
Water use - Sydney	KL H2O	6902.00	7372.38
Impact category	Unit	HWS 1	HWS 2
Solid waste - Melbourne (base case)	kg	549.87	6608.98
Solid waste - Adelaide	kg	512.33	6791.79
Solid waste - Brisbane	kg	667.64	13592.77
Solid waste - Perth	kg	338.81	2787.65
Solid waste - Sydney	kg	833.58	16956.67

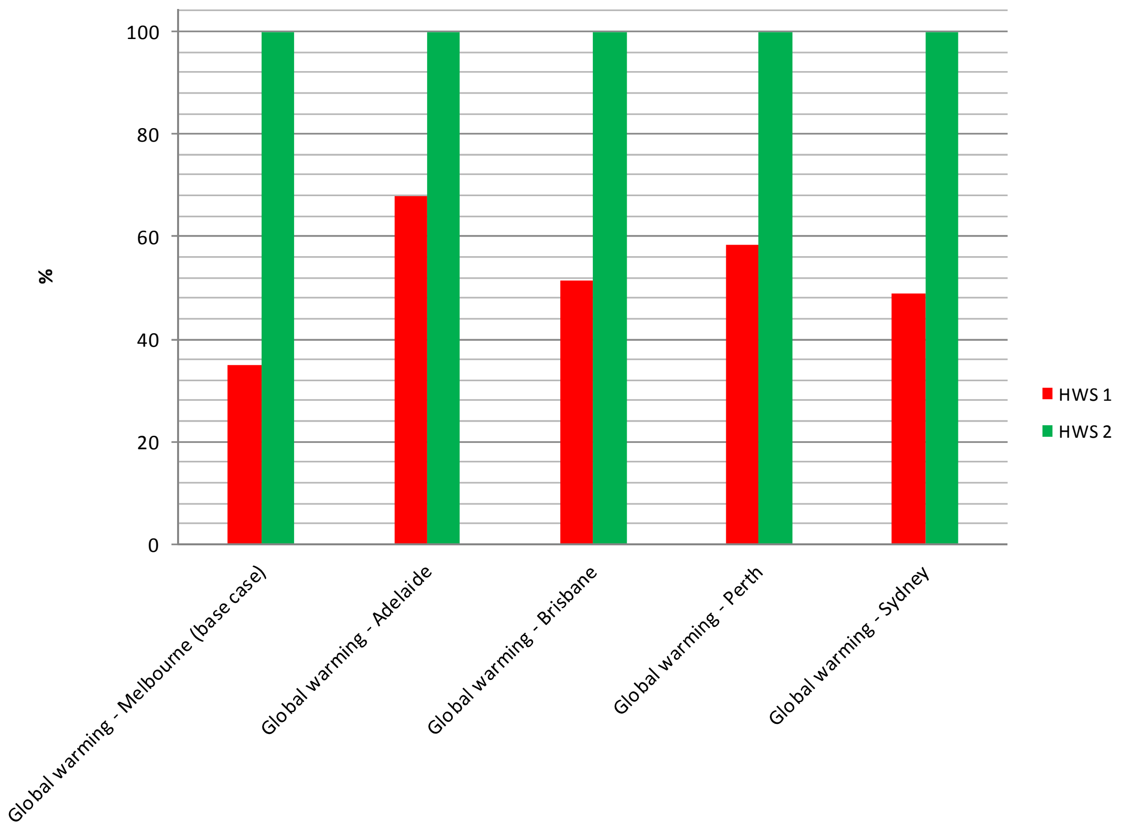

Figure 6-9: Relative summary of sensitivity of regional global warming results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

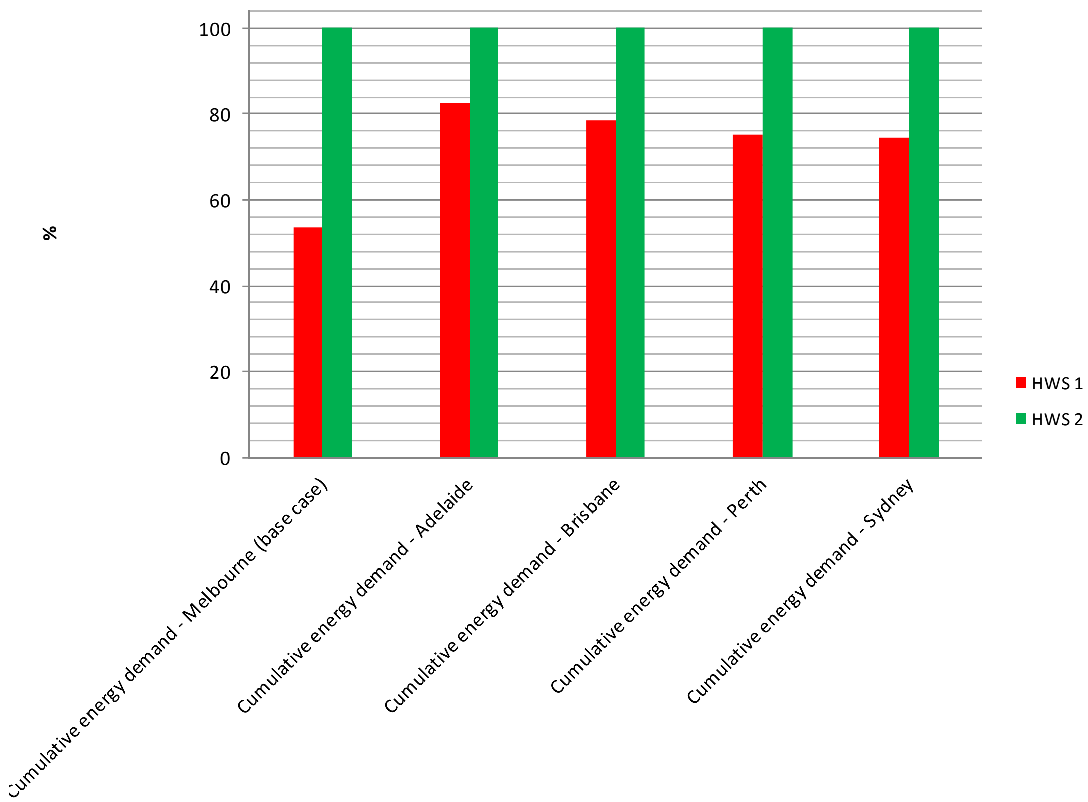

Figure 6-10: Relative summary of sensitivity of regional cumulative energy demand results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

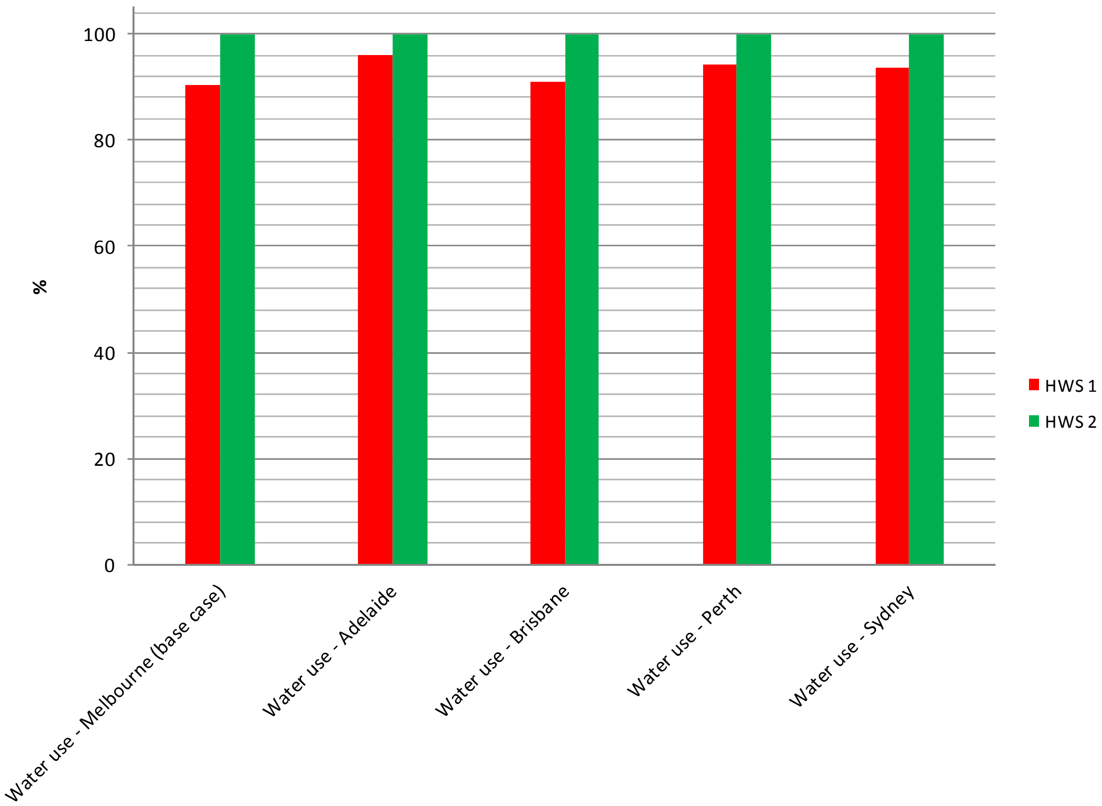

Figure 6-11: Relative summary of sensitivity of regional water use results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

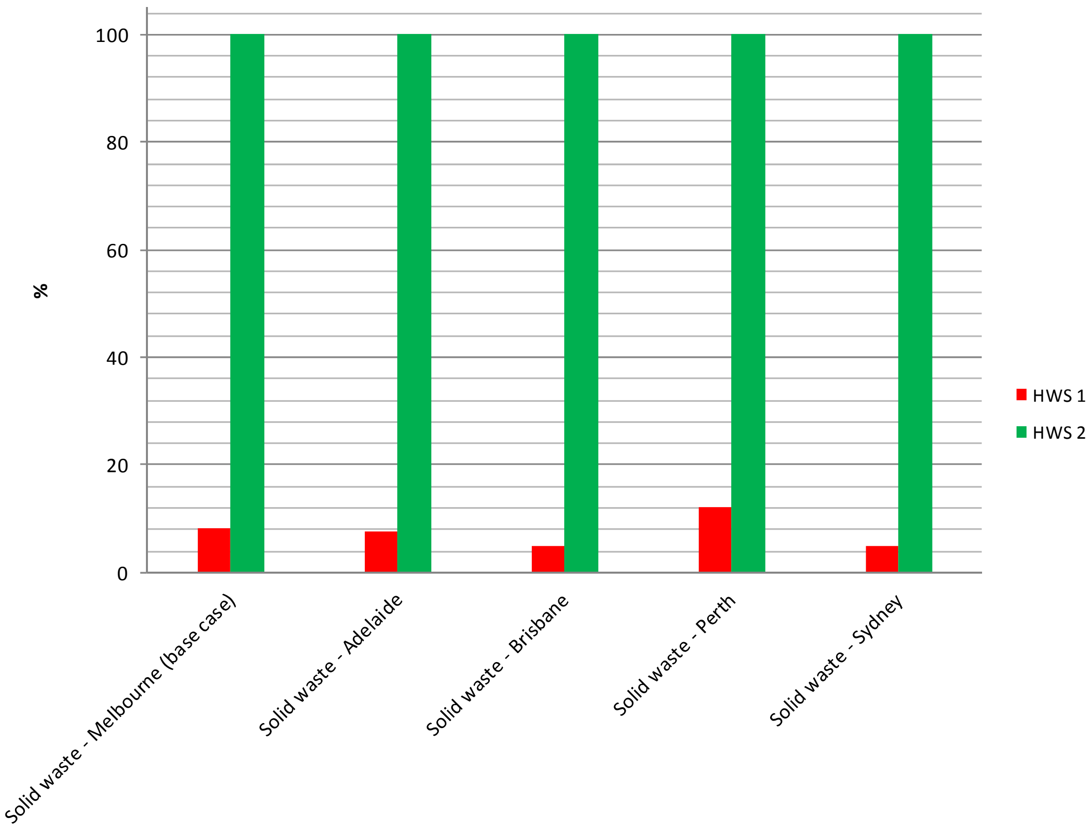

Figure 6-12: Relative summary of sensitivity of regional solid waste results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

As Figure 6-9 to Figure 6-12 demonstrates, there is no change directionally to the results by putting La Banque into different Australian capital cities. It does however affect the quantum of results, Adelaide being the best case for CFEWH (relative to the base case Melbourne and other capitals), where HWS2 is only 32% less than HWS1 in global warming potential, and 17% in cumulative energy demand. Water use and solid waste stay relatively similar.

As per Figure 4-5, Sydney, Perth, Brisbane and Adelaide lay in the same climatic zone, which is a hotter region on average to the base case in Melbourne. For this reason, at the Brahe Place building the energy results would be the same for HWS3 and HWS 5 in these new regional contexts, using less energy to heat hotter ambient temperature water than Melbourne, as per Table 6-11 to Table 6-14 for the average use scenario. HWS 4 however will be different for each average use scenario with different solar gains for each city as per Table 4-15.

Table 6-11: Sensitivity of use phase for HWS use Sydney (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	HWS3 - Rheem gas plant ring main	HWS4 - Rheem gas plant ring main with solar	HWS5 - MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	161	161	161
Gas use (GJ)	90.1	70.3	0
Electricity use (kWh)	1151	1257	6309
Total Energy use (kWh)	26183	20794	6309

Table 6-12: Sensitivity of use phase for HWS use Adelaide (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	HWS3 - Rheem gas plant ring main	HWS4 - Rheem gas plant ring main with solar	HWS5 - MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	161	161	161
Gas use (GJ)	90.1	66.7	0
Electricity use (kWh)	1151	1261	6309
Total Energy use (kWh)	26183	19776	6309

Table 6-13: Sensitivity of use phase for HWS use Brisbane (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	Rheem gas plant ring main	Rheem gas plant ring main with solar	MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	161	161	161
Gas use (GJ)	90.1	68.5	0
Electricity use (kWh)	1151	1260	6309
Total Energy use (kWh)	26183	20287	6309

Table 6-14: Sensitivity of use phase for HWS use Perth (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	HWS3 - Rheem gas plant ring main	HWS4 - Rheem gas plant ring main with solar	HWS5 - MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	161	161	161
Gas use (GJ)	90.1	63.4	0
Electricity use (kWh)	1151	1266	6309
Total Energy use (kWh)	26183	18886	6309

These energy results were then combined with the appropriate energy grids from Table 4-13, and impact assessment run as per Table 6-15 and Figure 6-13 to Figure 6-16

Table 6-15: Sensitivity of regional results for HWS average use impacts per year (Brahe Place)

Impact category	Unit	HWS 3	HWS 4	HWS 5
Global warming - Melbourne (base case)	kg CO2	7.17E+03	6.36E+03	9.46E+03
Global warming - Adelaide	kg CO2	6.58E+03	5.31E+03	4.37E+03
Global warming - Brisbane	kg CO2	6.67E+03	5.55E+03	5.99E+03
Global warming - Perth	kg CO2	6.44E+03	5.04E+03	5.20E+03
Global warming - Sydney	kg CO2	6.89E+03	5.83E+03	6.44E+03
Impact category	Unit	HWS 3	HWS 4	HWS 5
Cumulative energy demand - Melbourne (base case	MJ LHV	1.14E+05	9.87E+04	1.05E+05
Cumulative energy demand - Adelaide	MJ LHV	1.09E+05	8.66E+04	6.22E+04
Cumulative energy demand - Brisbane	MJ LHV	1.08E+05	8.72E+04	6.71E+04
Cumulative energy demand - Perth	MJ LHV	1.08E+05	8.25E+04	6.98E+04
Cumulative energy demand - Sydney	MJ LHV	1.10E+05	9.09E+04	7.17E+04
Impact category	Unit	HWS 3	HWS 4	HWS 5
Water use - Melbourne (base case)	KL H2O	167.75	169.00	180.82
Water use - Adelaide	KL H2O	166.50	167.52	169.26
Water use - Brisbane	KL H2O	167.96	169.14	179.18
Water use - Perth	KL H2O	166.61	167.81	172.82
Water use - Sydney	KL H2O	167.29	168.28	174.20
Impact category	Unit	HWS 3	HWS 4	HWS 5
Solid waste - Melbourne (base case)	kg	57.56	70.82	156.77
Solid waste - Adelaide	kg	73.58	83.87	152.78
Solid waste - Brisbane	kg	95.72	109.29	319.75
Solid waste - Perth	kg	41.03	52.73	67.30
Solid waste - Sydney	kg	115.74	128.66	398.50

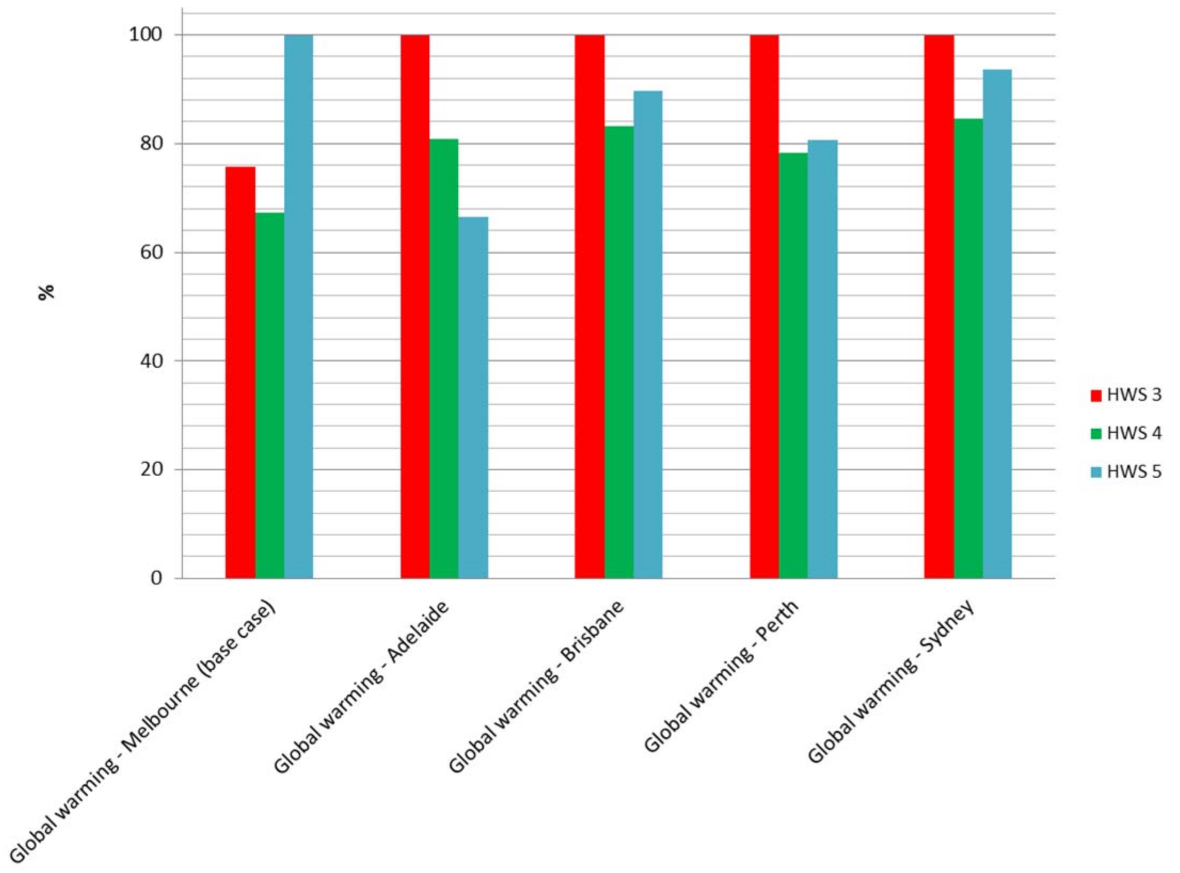

Figure 6-13: Relative summary of sensitivity of regional global warming results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

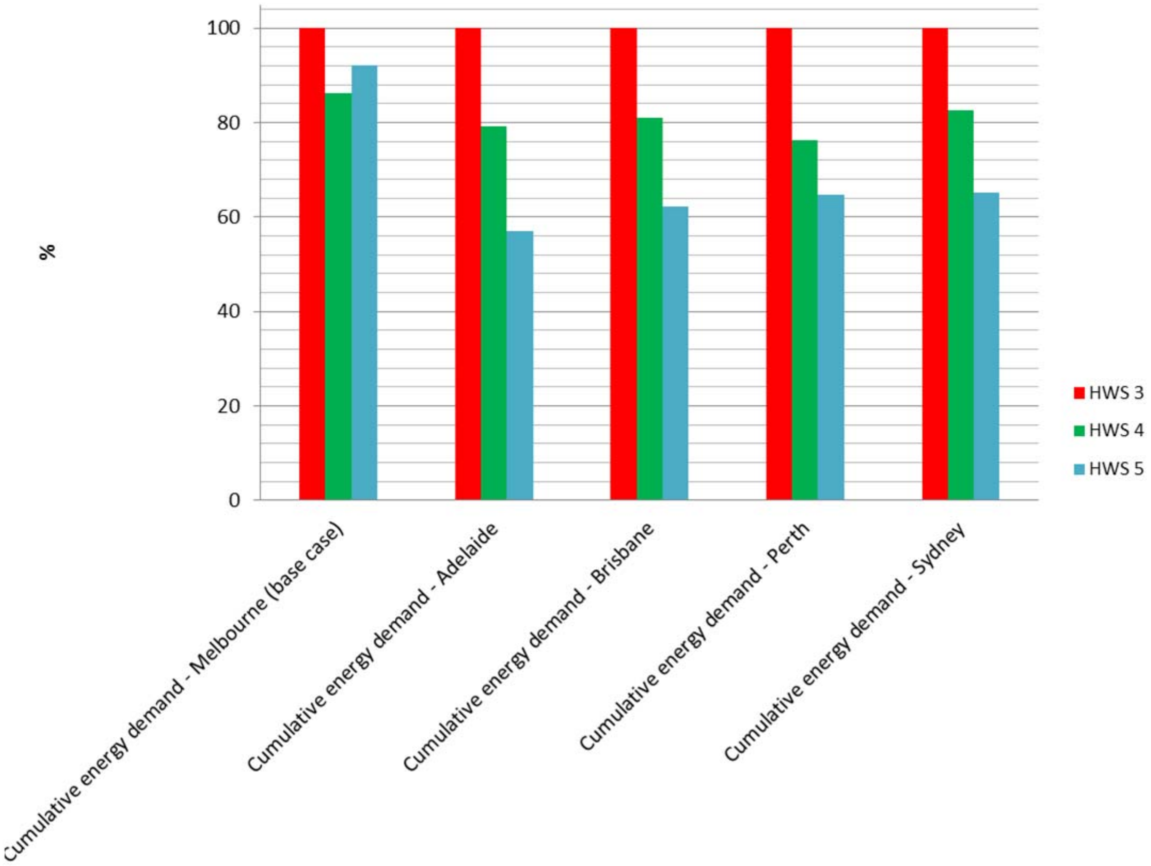

Figure 6-14: Relative summary of sensitivity of regional cumulative energy demand results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

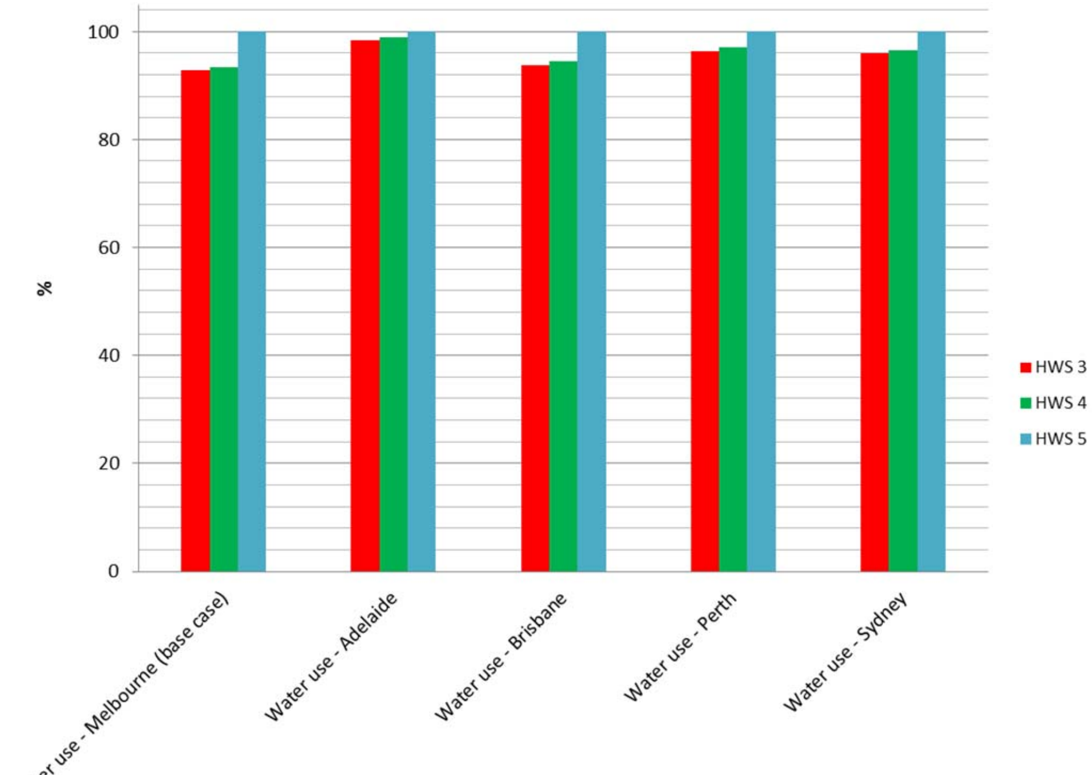

Figure 6-15: Relative summary of sensitivity of regional water use results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

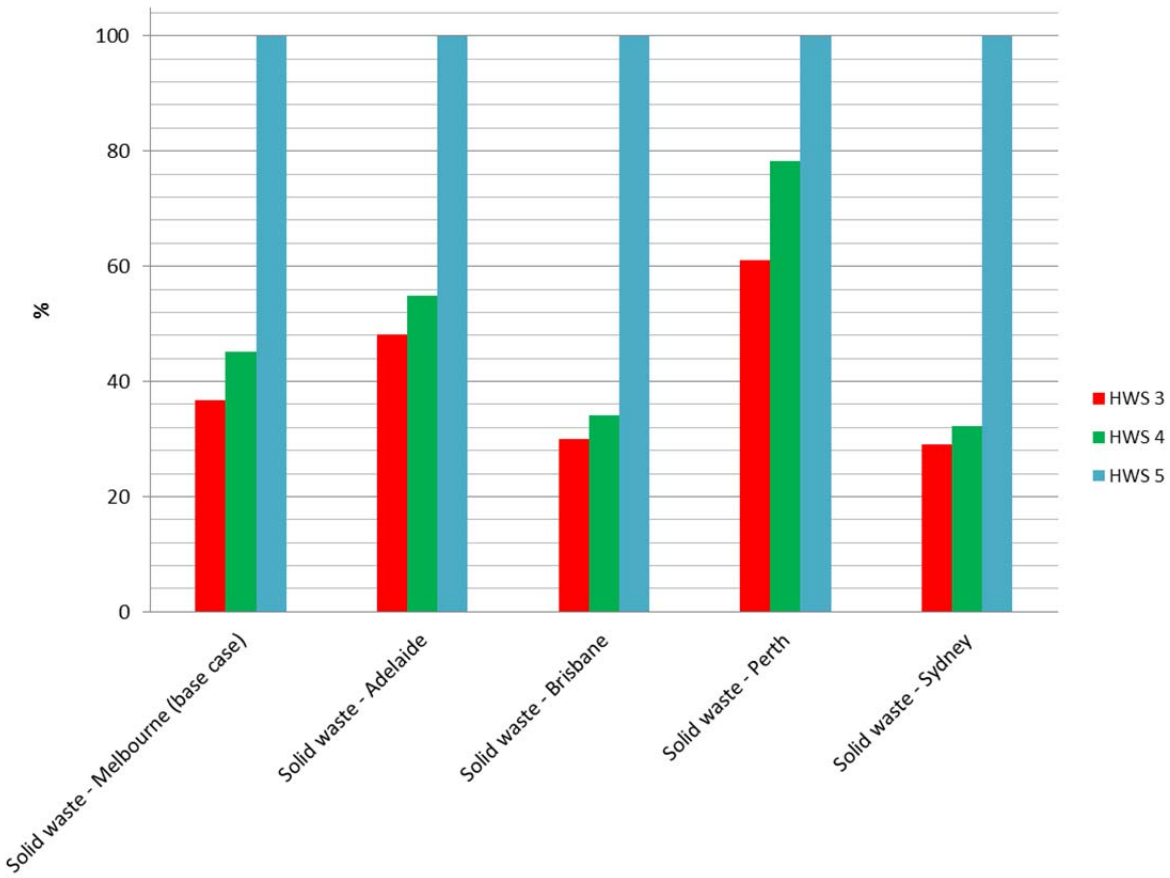

Figure 6-16: Relative summary of sensitivity of regional solid waste results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

As Figure 6-9 to Figure 6-12 demonstrates, there is no change directionally to the results by putting Brahe Place into different Australian capital cities for water use and solid waste.

It does however affect the results for global warming potential and cumulative energy demand. All capital cities other than Melbourne are better on global warming potential for HWS 5 CFEWH compared to HWS 3 centralised gas. Adelaide is the best case for CFEWH (relative to the base case Melbourne and other capitals), where HWS 5 is 31% better than HWS 3 in global warming potential, 10% better than solar boosted HWS 4 in global warming potential, 44% better than HWS 3 in cumulative energy demand, and 11% better than HWS 4 in cumulative energy demand. This shows that buildings like Brahe Place are particularly sensitive to electricity grid that the building uses, and there are opportunities for CFEWH to perform better than gas and solar boosted gas systems in global warning potential and cumulative energy demand today.

6.2.2 Vacancy (and occupancy)

It is important to test if the assumption of 100% occupancy is sensitive to the prediction that city vacancy may increase in the coming decade (Danckert 2012). The average use scenarios for all HWSs within the two buildings were modelled with water use reductions at 95% and 90% occupancy, to test if increased vacancy changes the results in any way.

The La Banque building the energy results change for HWS1 and HWS 2 in these new occupancy contexts, using less energy to heat less water, as per Table 6-16 and Table 6-17 for the average use scenario.

Table 6-16: Sensitivity of use phase for HWS use at 95% occupancy/ 5% vacancy (La Banque)

Hot water use profile	Type of hot water systems for La Banque building	
	Bosch gas plant ring main	MicroHeat CFEWH
	Average	Average
Water use (kL)	6505	6505
Gas use (GJ)	2132.6	0
Electricity use (kWh)	4650	279529
Total Energy use (kWh)	597047	279529

Table 6-17: Sensitivity of use phase for HWS use at 90% occupancy/ 10% vacancy (La Banque)

Hot water use profile	Type of hot water systems for LaBanque building	
	Bosch gas plant ring main	MicroHeat CFEWH
	Average	Average
Water use (kL)	6163	6163
Gas use (GJ)	2067.4	0
Electricity use (kWh)	4606	264920
Total Energy use (kWh)	578896	264920

These energy results were then run with an impact assessment as per Table 6-18 and Figure 6-17.

Table 6-18: Sensitivity of vacancy for HWS average use impacts per year (La Banque)

Impact category	Unit	HWS 1	HWS 2
Global warming - base case 0% vacancy	kg CO2	1.40E+05	4.01E+05
Global warming - 10% vacancy	kg CO2	1.32E+05	3.61E+05
Global warming - 5% vacancy	kg CO2	1.36E+05	3.81E+05
Impact category	Unit	HWS 1	HWS 2
Cumulative energy demand - base case 0% vacancy	MJ LHV	2.40E+06	4.47E+06
Cumulative energy demand - 10% vacancy	MJ LHV	2.26E+06	4.03E+06
Cumulative energy demand - 5% vacancy	MJ LHV	2.33E+06	4.25E+06
Impact category	Unit	HWS 1	HWS 2
Water use - base case 0% vacancy	KL H2O	6.90E+03	7.65E+03
Water use - 10% vacancy	KL H2O	6.22E+03	6.90E+03
Water use - 5% vacancy	KL H2O	6.56E+03	7.28E+03
Impact category	Unit	HWS 1	HWS 2
Solid waste - base case 0% vacancy	kg	5.50E+02	6.61E+03
Solid waste - 10% vacancy	kg	5.26E+02	5.97E+03
Solid waste - 5% vacancy	kg	5.38E+02	6.29E+03

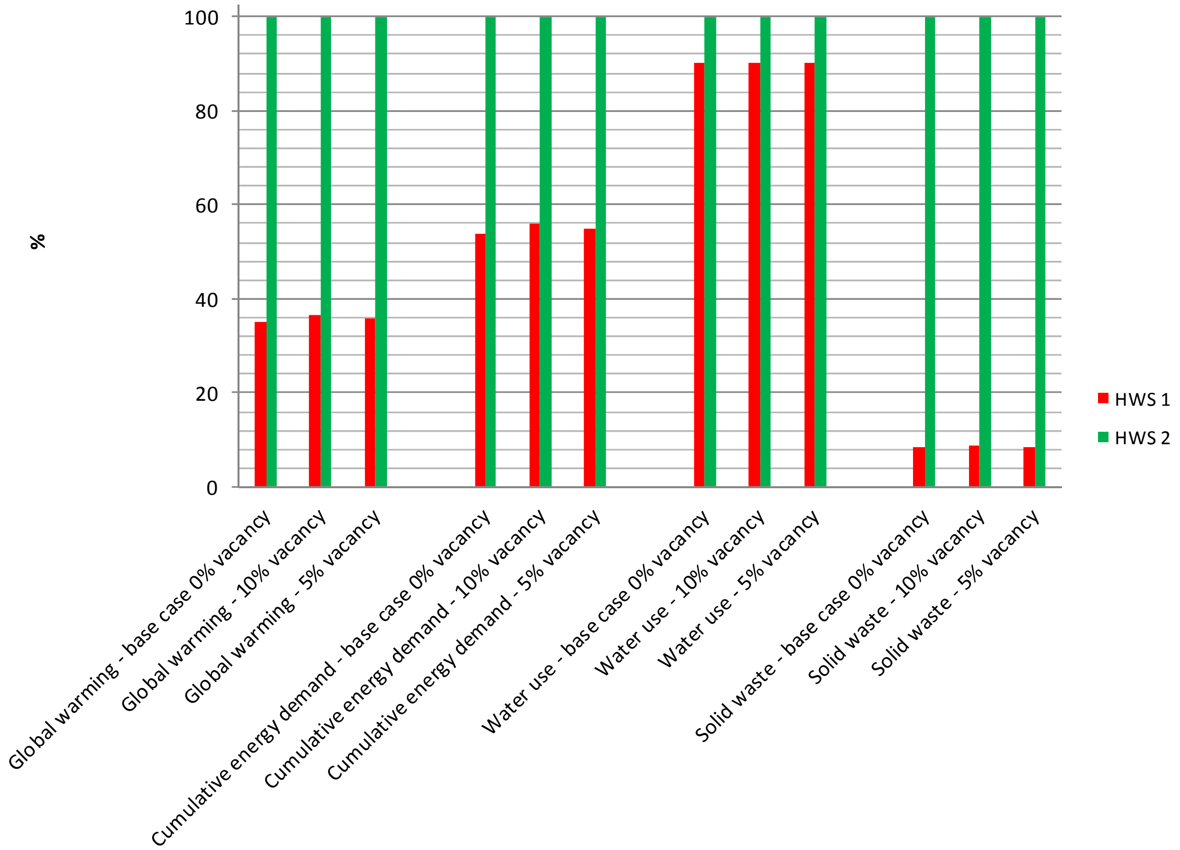

Figure 6-17: Relative summary of sensitivity of vacancy results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

The Brahe Place building the energy results change for HWS 3, HWS 4 and HWS 5 in new occupancy contexts, using less energy to heat less water, as per Table 6-19 and Table 6-20 for the average use scenario.

Table 6-19: Sensitivity of use phase for HWS use at 95% occupancy/ 5% vacancy (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	Rheem gas plant ring main	Rheem gas plant ring main with solar	MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	153	153	153
Gas use (GJ)	91.2	73.2	0
Electricity use (kWh)	1151	1253	6571
Total Energy use (kWh)	26495	21580	6571

Table 6-20: Sensitivity of use phase for HWS use at 90% occupancy/ 10% vacancy (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	Rheem gas plant ring main	Rheem gas plant ring main with solar	MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	145	145	145
Gas use (GJ)	89.7	71.7	0
Electricity use (kWh)	1151	1251	6228
Total Energy use (kWh)	26080	21179	6228

These energy results were then run with an impact assessment as per Table 6-21 and Figure 6-18.

Table 6-21: Sensitivity of vacancy for HWS average use impacts per year (Brahe Place)

Impact category	Unit	HWS 3	HWS 4	HWS 5
Global warming - base case 0% vacancy	kg CO2	7.17E+03	6.36E+03	9.46E+03
Global warming - 10% vacancy	kg CO2	6.98E+03	6.17E+03	8.53E+03
Global warming - 5% vacancy	kg CO2	7.07E+03	6.26E+03	8.99E+03
Impact category	Unit	HWS 3	HWS 4	HWS 5
Cumulative energy demand - base case 0% vacancy	MJ LHV	1.14E+05	9.87E+04	1.05E+05
Cumulative energy demand - 10% vacancy	MJ LHV	1.11E+05	9.54E+04	9.49E+04
Cumulative energy demand - 5% vacancy	MJ LHV	1.13E+05	9.71E+04	1.00E+05
Impact category	Unit	HWS 3	HWS 4	HWS 5
Water use - base case 0% vacancy	KL H2O	167.75	169.00	180.82
Water use - 10% vacancy	KL H2O	151.73	152.97	163.23
Water use - 5% vacancy	KL H2O	159.74	160.98	172.02
Impact category	Unit	HWS 3	HWS 4	HWS 5
Solid waste - base case 0% vacancy	kg	57.56	70.82	156.77
Solid waste - 10% vacancy	kg	57.02	70.20	141.82
Solid waste - 5% vacancy	kg	57.28	70.50	149.31

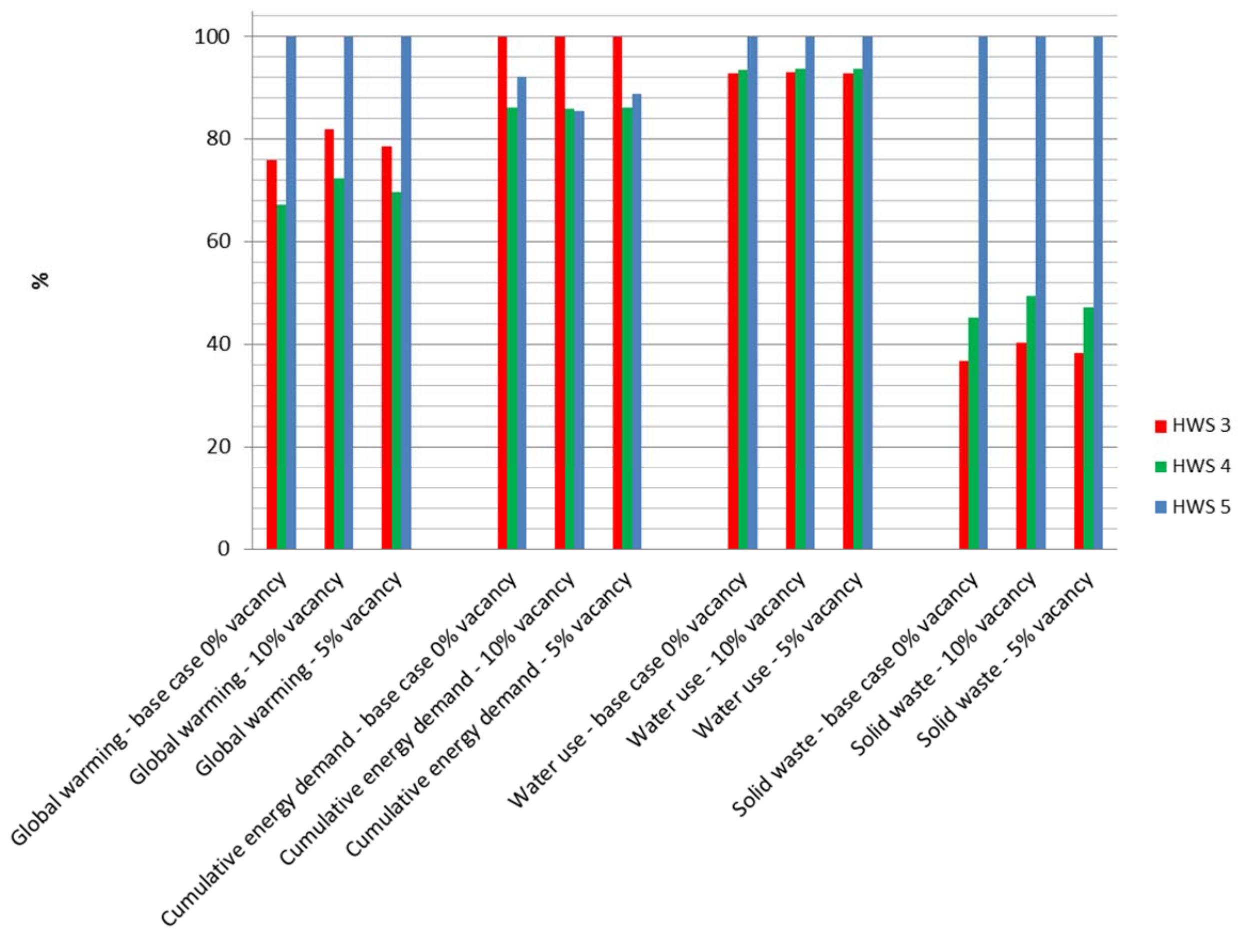

Figure 6-18: Relative summary of sensitivity of vacancy results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

For both buildings, vacancy of up to 10% does not affect the results directionally in all categories, the quantum no more than 10% variation in any given impact category.

6.2.3 Component replacement, component materials, and building life

It is important to test if the assumptions for component replacement in Table 4-12, materials used in components, and a building life of 50 years is acceptable. This can be done in one sensitivity study, by increasing the components for the average use scenarios for all HWSs within the two buildings by 5 and 10 times respectively. This tests if increased component replacements, increased mass of particular materials that have been specified or estimated, or increased amortised component contribution per annum due to a shorter building life for the same amount of components or longer building life with more replacements, change the results in any way.

As an example, the 10 times scenario could simulate all components being replaced double their scheduled replacement, the component materials measuring double the mass, and the building life extending by 2.5 times (i.e. 125 year building life for 2.5 times more replacements on top of the extra replacement schedules), being 2 x 2 x 2.5 increase on materials and manufacturing of components.

The results were run for La Banque with an impact assessment as per Table 6-22 and Figure 6-19.

Table 6-22: Sensitivity of replacement, materials & building life for HWS average use impacts per year (La Banque)

Impact category	Unit	HWS 1	HWS 2
Global warming - Replacement x 10	kg CO2	1.49E+05	4.39E+05
Global warming - Replacement x 5	kg CO2	1.44E+05	4.18E+05
Global warming - Replacement as per base case	kg CO2	1.40E+05	4.01E+05
Impact category	Unit	HWS 1	HWS 2
Cumulative energy demand - Replacement x 10	MJ LHV	2.46E+06	4.74E+06
Cumulative energy demand - Replacement x 5	MJ LHV	2.43E+06	4.59E+06
Cumulative energy demand - Adelaide	MJ LHV	2.40E+06	4.47E+06
Impact category	Unit	HWS 1	HWS 2
Water use - Replacement x 10	KL H2O	7.21E+03	8.73E+03
Water use - Replacement x 5	KL H2O	7.04E+03	8.13E+03
Water use - Replacement as per base case	KL H2O	6.90E+03	7.65E+03
Impact category	Unit	HWS 1	HWS 2
Solid waste - Replacement x 10	kg	2.62E+03	8.32E+03
Solid waste - Replacement x 5	kg	1.47E+03	7.37E+03
Solid waste - Replacement as per base case	kg	5.50E+02	6.61E+03

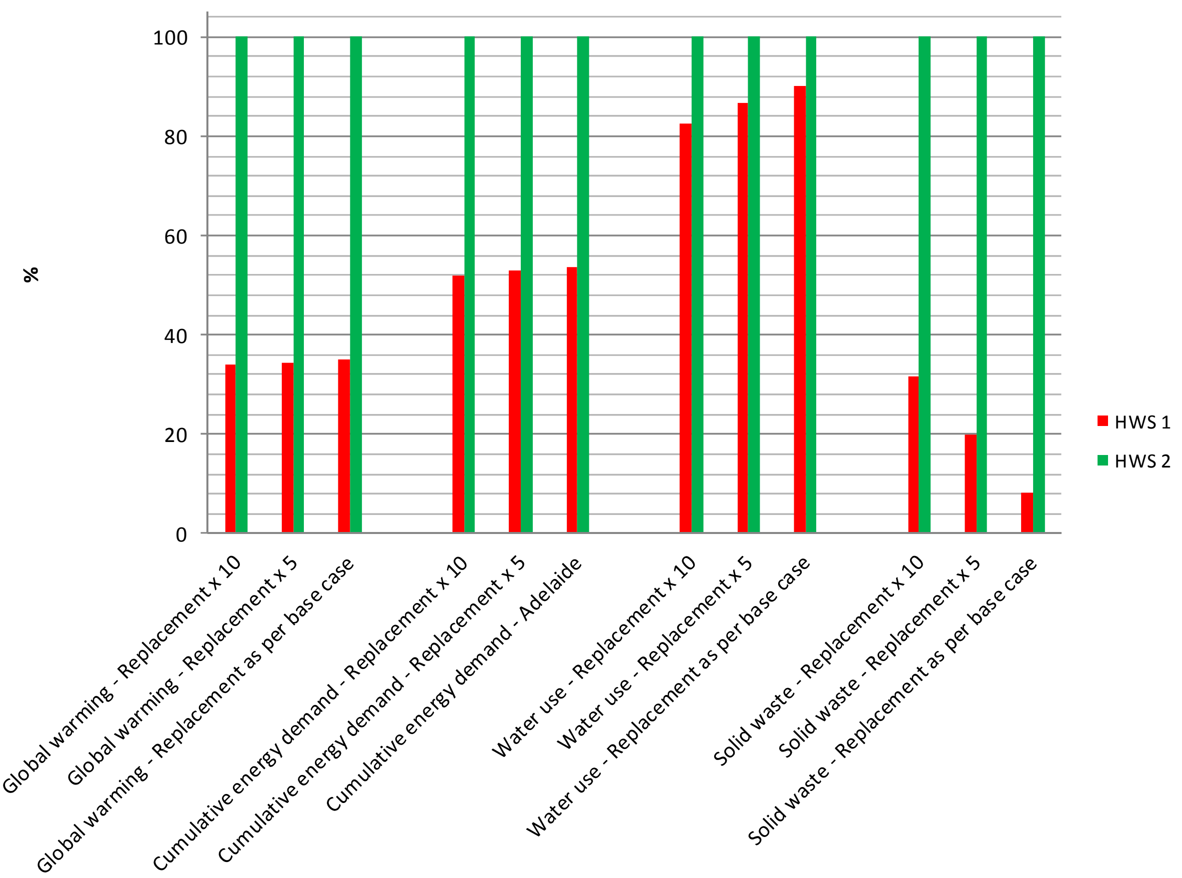

Figure 6-19: Relative summary of sensitivity of replacement, materials & building life results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

The results were run for Brahe Place with an impact assessment as per Table 6-23 and Figure 6-20.

Table 6-23: Sensitivity of replacement, materials & building life for HWS average use impacts per year (Brahe Place)

Impact category	Unit	HWS 3	HWS 4	HWS 5
Global warming - Replacement x 10	kg CO2	8.35E+03	8.39E+03	1.07E+04
Global warming - Replacement x 5	kg CO2	7.69E+03	7.26E+03	9.99E+03
Global warming - Replacement as per base case	kg CO2	7.17E+03	6.36E+03	9.46E+03
Impact category	Unit	HWS 3	HWS 4	HWS 5
Cumulative energy demand - Replacement x 10	MJ LHV	1.20E+05	1.15E+05	1.14E+05
Cumulative energy demand - Replacement x 5	MJ LHV	1.17E+05	1.06E+05	1.09E+05
Cumulative energy demand - Replacement as per base ca	MJ LHV	1.14E+05	9.87E+04	1.05E+05
Impact category	Unit	HWS 3	HWS 4	HWS 5
Water use - Replacement x 10	KL H2O	202.72	211.10	214.49
Water use - Replacement x 5	KL H2O	183.29	187.71	195.78
Water use - Replacement as per base case	KL H2O	167.75	169.00	180.82
Impact category	Unit	HWS 3	HWS 4	HWS 5
Solid waste - Replacement x 10	kg	310.16	423.14	210.03
Solid waste - Replacement x 5	kg	169.82	227.41	180.44
Solid waste - Replacement as per base case	kg	57.56	70.82	156.77

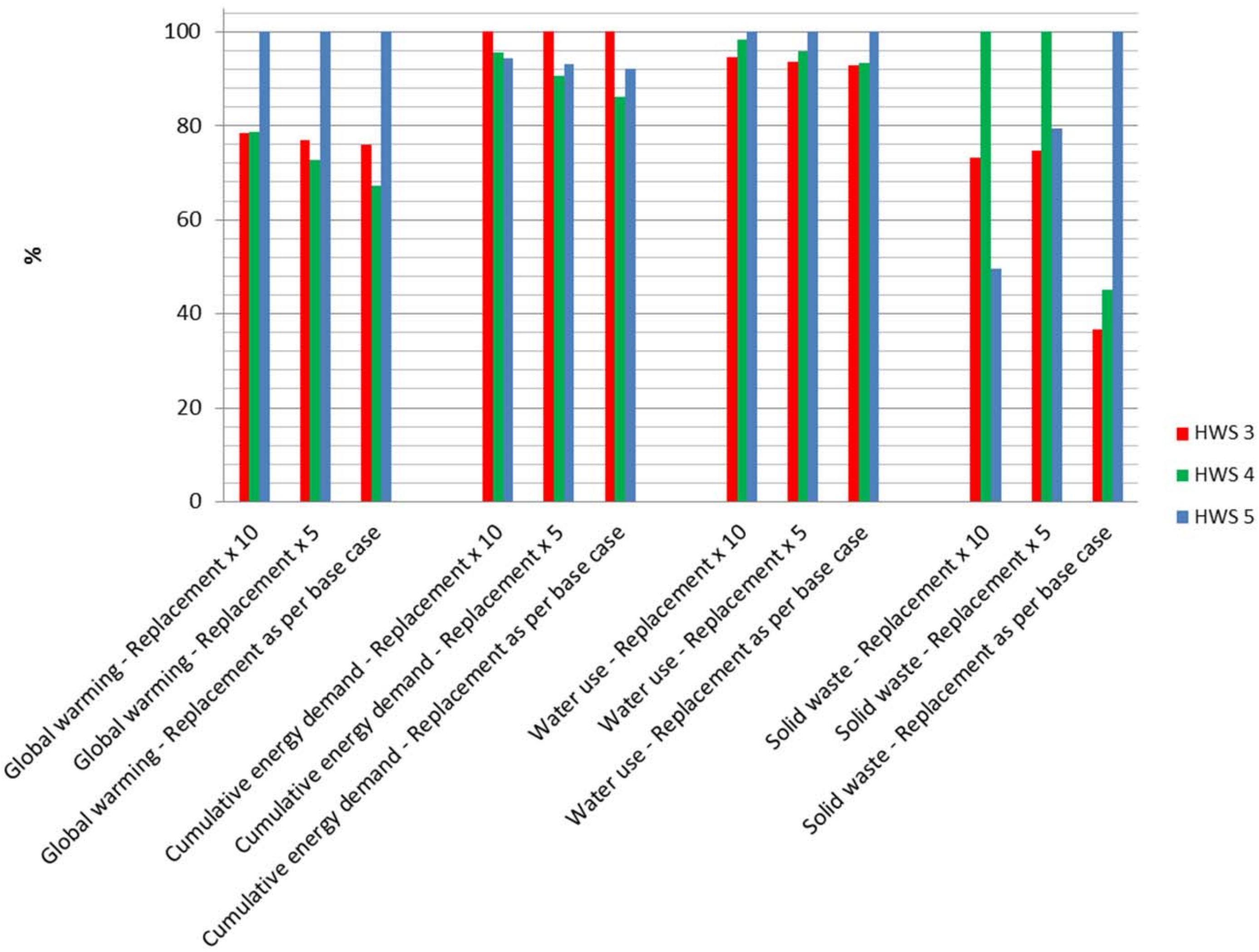

Figure 6-20: Relative summary of sensitivity of replacement, materials & building life results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

For both buildings, increase in components up to 10 times does not affect the results significantly or directionally in all categories apart from solid waste. In La Banque this shifts 23% relatively to the base case for a 10 times change in replacement, and does not change the directional result. In Brahe Place this shifts so HWS 5 is 27-50% lower for a 10 times change in replacement, due to the solid waste from electricity production in HWS 5 being overshadowed by solid waste from increased components in the centralised HWS3 3 and HWS 4 respectively. This is a change in the directional result for solid waste.

6.2.4 CFEWH and solar boosting (substitute electric HWS 4 at Brahe Place)

It is important to test if utilising CFEWH as a solar booster as HWS 4 is in Brahe Place is a good option if specified. This tests if this opportunity for re-specification changes the results for this building in any way.

The Brahe Place energy result changes for HWS 5 in the new context as a solar booster, using less energy, as per Table 6-24 for the average use scenario.

Table 6-24: Sensitivity of use phase for HWS use with CFEWH solar option at Brahe Place

Hot water use profile	Type of hot water systems for Brahe Place building MicroHeat CFEWH with solar Average
Water use (kL)	161
Gas use (GJ)	0
Electricity use (kWh)	4468
Total Energy use (kWh)	4468

The results were run for Brahe Place with an impact assessment as per Table 6-25 and Figure 6-21.

Table 6-25: Sensitivity of HWS average use impacts per year including HWS 5 with solar contribution (Brahe Place)

Impact category	Unit	HWS 3	HWS 4	HWS 5	HWS 5 with solar
Global warming - Average use	kg CO2	7.17E+03	6.36E+03	9.46E+03	6.30E+03
Cumulative energy demand - Average use	MJ LHV	1.14E+05	9.87E+04	1.05E+05	7.02E+04
Water use - Average use	KL H2O	167.75	169.00	180.82	176.01
Solid waste - Average use	kg	57.56	70.82	156.77	116.34

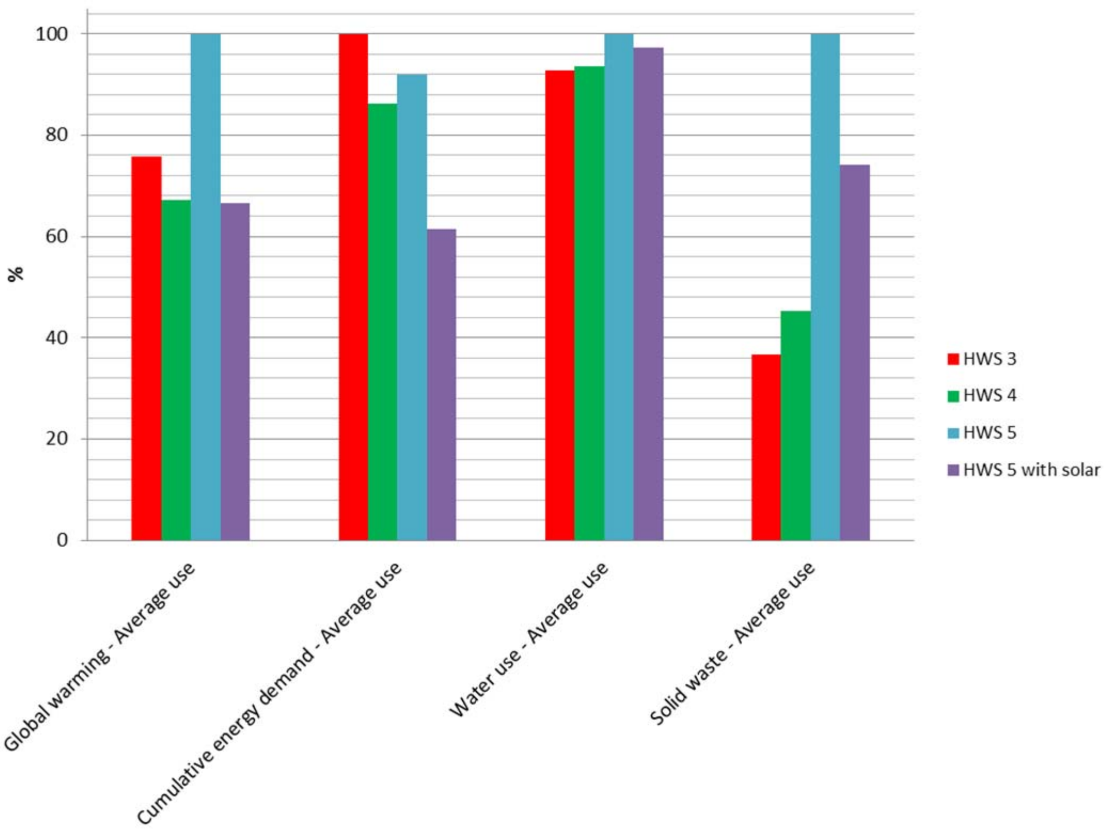

Figure 6-21: Relative summary of Brahe Place average use with HWS 5 solar contribution option (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5, purple bar HWS 5 with solar

As Figure 6-21 demonstrates, there is no change directionally to the results by installing HWS 5 with solar into Brahe Place in both water use and solid waste.

It does however affect the results for global warming potential and cumulative energy demand. HWS 5 with solar performs better on global warming potential compared to HWS 3 centralised gas and marginally better than HWS 4 centralised gas with solar. HWS 5 with solar is better than all options in cumulative energy demand. This shows that buildings like Brahe Place, even in Melbourne with a high greenhouse gas intensity electricity grid, pose opportunities for CFEWH to perform better than gas and solar boosted gas systems in global warning potential and cumulative energy demand today.

6.2.5 Extra centralised system losses in ring main

It is important to test if insulated sections of pipe or componentry carrying hot water in the centralised systems of either building changes the results for this building in any way. This includes tempering valves (observed on site as uninsulated), corner sections, or any other lengths not insulated for whatever reason. This can be done in one sensitivity study, by modelling 30 cm (simulating tempering valves) and 60 cm (simulating uninsulated tempering valve and corner) of uninsulated pipe per apartment respectively.

The La Banque building the energy results change for HWS1 and HWS 2 in these new uninsulated pipe contexts, as per Table 6-26 and Table 6-27 for the average use scenario.

Table 6-26: Sensitivity of use phase for HWS use with 80 m insulated pipes (La Banque)

Hot water use profile	Type of hot water systems for LaBanque building	
	Bosch gas plant ring main	MicroHeat CFEWH
	Average	Average
Water use (kL)	6847	6847
Gas use (GJ)	2425.6	0
Electricity use (kWh)	4862	294138
Total Energy use (kWh)	678637	294138

Table 6-27: Sensitivity of use phase for HWS use with 160 m insulated pipes (La Banque)

Hot water use profile	Type of hot water systems for LaBanque building	
	Bosch gas plant ring main	MicroHeat CFEWH
	Average	Average
Water use (kL)	6847	6847
Gas use (GJ)	2659.8	0
Electricity use (kWh)	5003	294138
Total Energy use (kWh)	743840	294138

The results were run for La Banque with an impact assessment as per Table 6-28 and Figure 6-22.

Table 6-28: Sensitivity of extra centralised system losses for HWS average use impacts per year (La Banque)

Impact category	Unit	HWS 1	HWS 2
Global warming - base case	kg CO2	1.40E+05	4.01E+05
Global warming - 160 m uninsulated pipe	kg CO2	1.67E+05	4.01E+05
Global warming - 80 m uninsulated pipe	kg CO2	1.54E+05	4.01E+05
Impact category	Unit	HWS 1	HWS 2
Cumulative energy demand - base case	MJ LHV	2.40E+06	4.47E+06
Cumulative energy demand - 160 m uninsulated pi	MJ LHV	2.88E+06	4.47E+06
Cumulative energy demand - 80 m uninsulated pip	MJ LHV	2.64E+06	4.47E+06
Impact category	Unit	HWS 1	HWS 2
Water use - base case	KL H2O	6.90E+03	7.65E+03
Water use - 160 m uninsulated pipe	KL H2O	6.90E+03	7.65E+03
Water use - 80 m uninsulated pipe	KL H2O	6.90E+03	7.65E+03
Impact category	Unit	HWS 1	HWS 2
Solid waste - base case	kg	5.50E+02	6.61E+03
Solid waste - 160 m uninsulated pipe	kg	5.57E+02	6.61E+03
Solid waste - 80 m uninsulated pipe	kg	5.54E+02	6.61E+03

Note: HWS 2 (with CFEWH) the same for each impact category

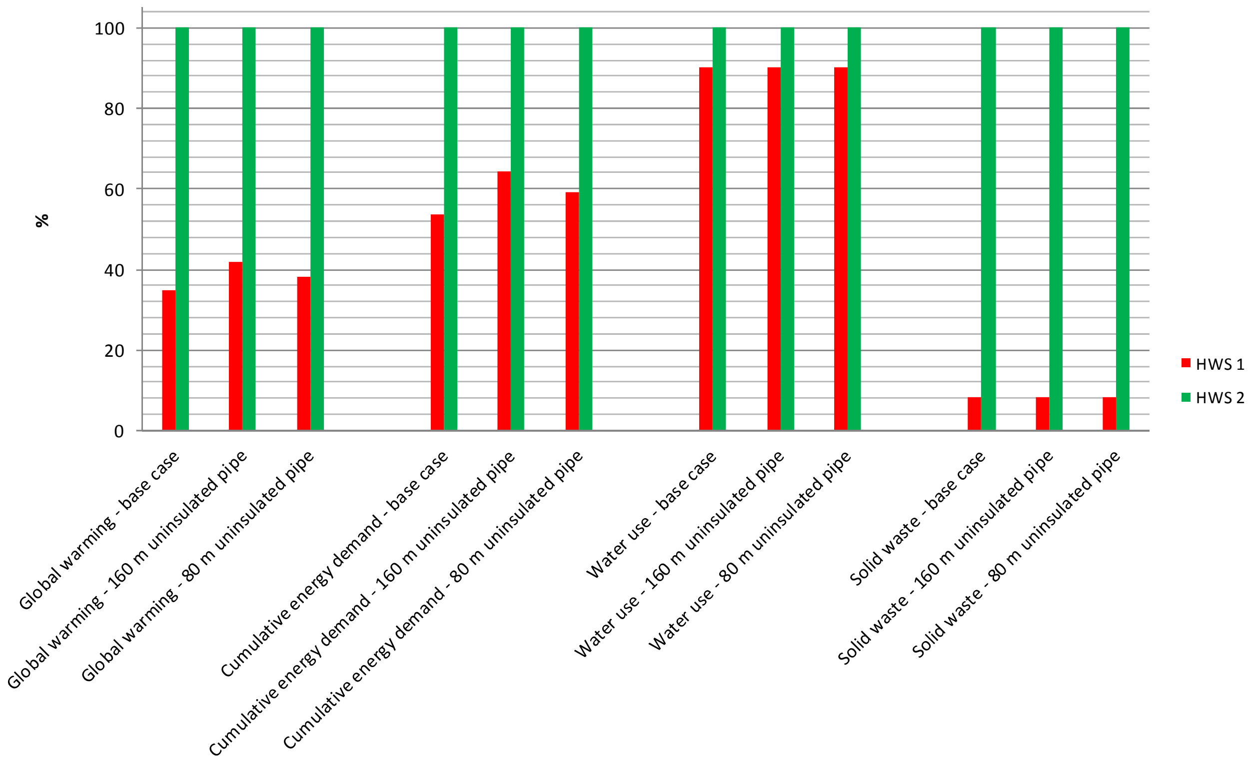

Figure 6-22: Relative summary of sensitivity of extra centralised system loss results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

The Brahe Place building the energy results change for HWS 3, HWS 4 and HWS 5 in new uninsulated pipe scenarios, as per

Table 6-29 and Table 6-30 for the average use scenario.

Table 6-29: Sensitivity of use phase for HWS use with 2.5 m insulated pipes (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	Rheem gas plant ring main	Rheem gas plant ring main with solar	MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	161	161	161
Gas use (GJ)	97.5	79.2	0
Electricity use (kWh)	1154	1262	6913
Total Energy use (kWh)	28230	23269	6913

Table 6-30: Sensitivity of use phase for HWS use with 5 m insulated pipes (Brahe Place)

Hot water use profile	Type of hot water systems for Brahe Place building		
	Rheem gas plant ring main	Rheem gas plant ring main with solar	MicroHeat CFEWH
	Average	Average	Average
Water use (kL)	161	161	161
Gas use (GJ)	102.2	83.9	0
Electricity use (kWh)	1156	1267	6913
Total Energy use (kWh)	29548	24560	6913

The results were run for Brahe Place with an impact assessment as per Table 6-31 and Figure 6-23.

Table 6-31: Sensitivity of extra centralised system losses for HWS average use impacts per year (Brahe Place)

Impact category	Unit	HWS 3	HWS 4	HWS 5
Global warming - base case	kg CO2	7.17E+03	6.36E+03	9.46E+03
Global warming - 5 m uninsulated pipe	kg CO2	7.73E+03	6.91E+03	9.46E+03
Global warming - 2.5 m uninsulated pipe	kg CO2	7.45E+03	6.63E+03	9.46E+03
Impact category	Unit	HWS 3	HWS 4	HWS 5
Cumulative energy demand - base case	MJ LHV	1.14E+05	9.87E+04	1.05E+05
Cumulative energy demand - 5 m uninsulated pipe	MJ LHV	1.24E+05	1.08E+05	1.05E+05
Cumulative energy demand - 2.5 m uninsulated pipe	MJ LHV	1.19E+05	1.03E+05	1.05E+05
Impact category	Unit	HWS 3	HWS 4	HWS 5
Water use - base case	KL H2O	167.75	169.00	180.82
Water use - 5 m uninsulated pipe	KL H2O	167.76	169.03	180.82
Water use - 2.5 m uninsulated pipe	KL H2O	167.76	169.02	180.82
Impact category	Unit	HWS 3	HWS 4	HWS 5
Solid waste - base case	kg	57.56	70.82	156.77
Solid waste - 5 m uninsulated pipe	kg	57.64	71.06	156.77
Solid waste - 2.5 m uninsulated pipe	kg	57.60	70.95	156.77

Note: HWS 2 (with CFEWH) the same for each impact category

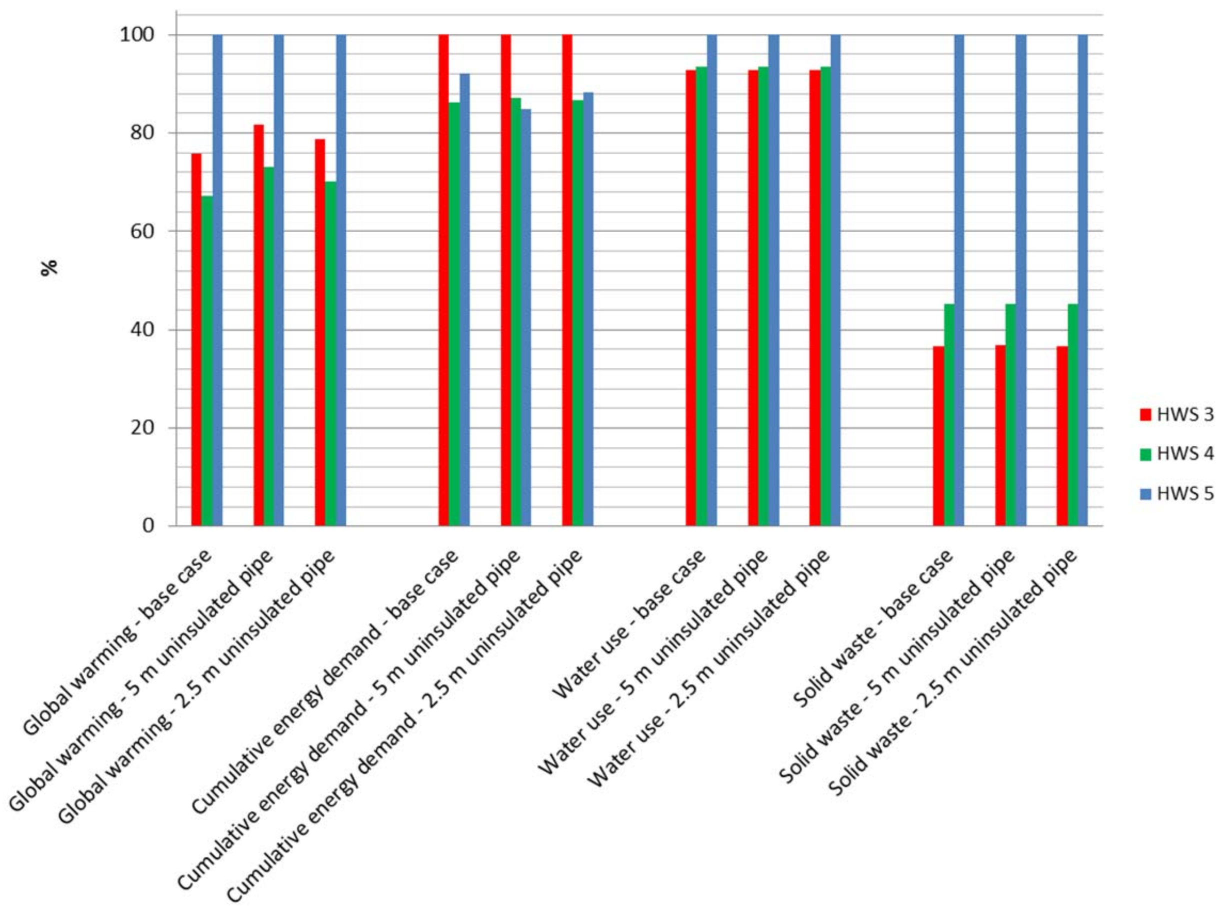

Figure 6-23: Relative summary of sensitivity of extra centralised system loss results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

For both buildings, the uninsulated section modelled do not affect the results directionally in all categories, the quantum no more than 10% variation in any given impact category.

6.2.6 Victorian electricity grid changes (future scenarios)

The current life cycle inventory for electricity production in Victoria in AUPLCI and is an aggregated inventory for the whole of the state. The emission factor for the AUPLCI data is 1.33 kg CO_2 eq/ kWh, as per Table 4-13.

It is important to understand what will happen when this emission factor drops due to technology and fuel source transformations of the Victorian electricity grid in the future. There is currently little literature regarding this, however the following paragraph from a 2012 BREE report by Syed (2012) provides useful insight:

"…Electricity generation in Victoria is largely based on brown coal. The competitiveness of this energy source relative to other technologies is expected to diminish following the introduction of carbon pricing, and importantly due to a fall in the price of renewable electricity generation technologies, specifically solar energy. Unless Victoria invests in the development of its own low emission electricity generation capacity, it is projected to become more dependent on the importation of electricity from other states."

Projecting the emissions intensity of a grid in the period 2013-2050 is highly uncertain due to the design and effectiveness of policy and abatement instruments (e.g. carbon pricing, renewable energy targets). Historically the emission intensity of the Victorian electricity grid has fluctuated with a general downward trend between 1989-2012, as per Figure 24.

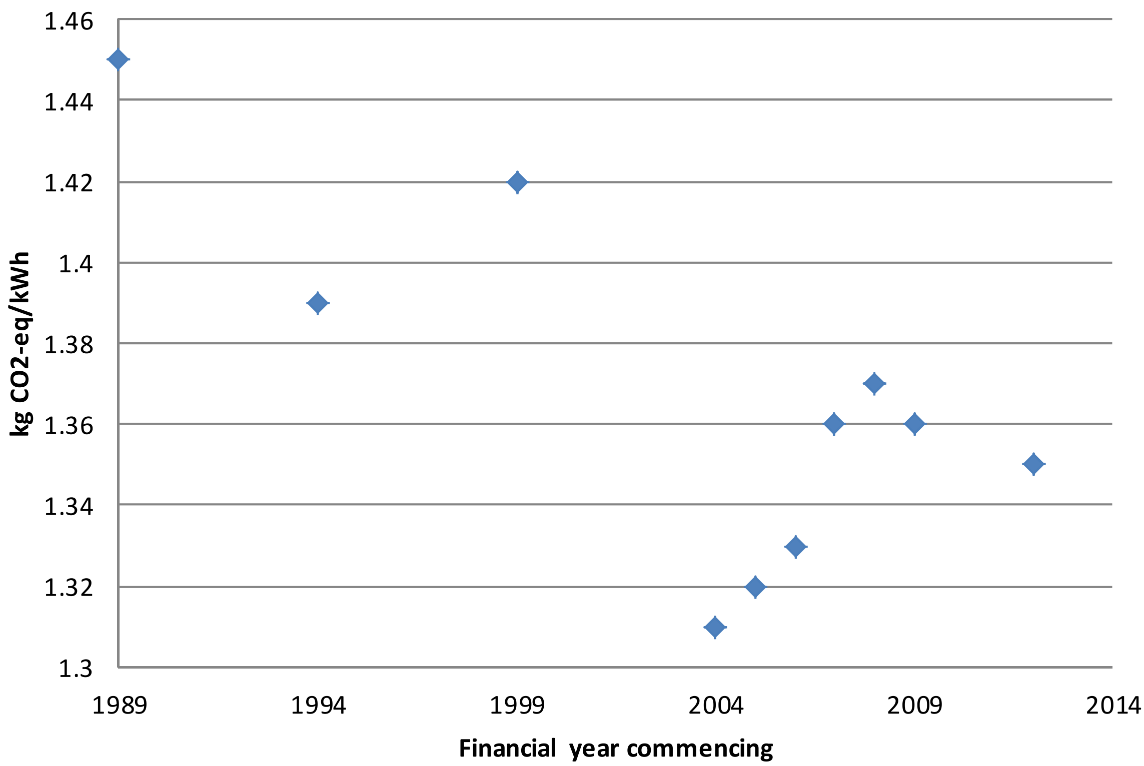

Figure 24: Historical Emission intensity for Victorian grid (DCCEE 2012)

The emission intensity of the Victorian grid is however expected to drop through to 2050 (the temporal scope of this sensitivity analysis), due to a forecast increase in electricity from non-hydro renewable sources, a decrease in the reliance on coal-fired electricity, uptake of carbon capture and storage technologies and a potential decrease in electricity demand (Garnaut 2008).

The Syed (2012) report predicts the energy mix of the national electricity grid to both 2035 and 2050. It was deemed reasonable then to model what Victoria might look like at these points if the national trends from Syed (2012) were applied, seeing as in particular the report predicts that brown coal will reduce to 0% of the grid contribution by 2050, and suggests that Victoria will need to invest in lower emission technologies, or import electricity that is from these sources. Table 6-32 from the report was used for this purpose.

Table 6-32: **Electricity generation, by energy type (TWh) (Syed 2012)**

	Level			Share		
	2012-13	**2034-35**	**2049-50**	**2012-13**	**2049-50**	**Average annual growth 2012-13 to 2049-50**
Energy type				**%**	**%**	**%**
Non-renewables	219	194	183	87	49	-0.5
Coal	153	104	48	60	13	-3.1
black coal	109	100	48	43	13	-2.2
brown coal	44	5	0	17	0	0
Gas	62	85	136	25	36	2.1
Oil	4	4	0	2	0	-8.6
Renewables	34	130	194	13	51	4.8
Hydro	17	17	17	7	5	0.0
Wind	14	64	78	6	21	4.7
Bioenergy	2	7	7	1	2	3.9
Solar	1	25	62	<1	16	12.3
Geothermal	0	17	29	0	8	0
Total	**253**	**324**	**377**	**100**	**100**	**1.1**

The Victoria electricity grid in AUPLCI as per Table 4-13 was modified for both 2035 and 2050 by extrapolating the changes from Table 6-32.

For the 2035 scenario, these figures were adjusted as per the relative absolute levels of coal, renewables and gas at 2034/35, so that coal reduced from 60% to 32% (28% total electricity generation reduction). The same study predicts that Victoria will generate 12% of Australian electricity. The 28% reduction was applied to Victorian coal, which was shifted to 87.5% black coal as the study also states that brown coal with reduce to 1.5% of total Australian generation (or 12.5% of total Victorian generation). It is assumed that all of this brown coal will be used in Victoria at this stage, as it is the primary fuel of the Victorian electricity grid. The reduction in coal generated electricity was replaced by 96% wind and 4% gas, as per the relative changes in Table 6-32 for renewable energy and gas generated electricity (i.e. 27% renewables and 1% gas increases of total electricity generation).

For 2012-2050 the study predicts that coal will reduce from 60% grid share to 13% (47% total electricity generation reduction). This was applied to the brown coal in the Victorian electricity grid, which was shifted to black coal as the study also states that brown coal with reduce to 0%. The reduction in coal generated electricity was replaced by 78% wind and 22% gas, as per the relative changes in Table 6-32 for renewable energy and gas generated electricity (i.e. 38% renewables and 11% gas increases of total electricity generation).

Overall this gave the emission factor for the Victorian electricity grid of 0.89 kg CO_2 eq/ kWh for 2035 (closest to NSW from Table 4-13), and 0.58 kg CO_2 eq/ kWh for 2050 (closest to SA from Table 4-13). These grids were then incorporated into models and compared against the baseline average use scenario for all HWSs, the results shown in for La Banque in Table 6-33 and Figure 6-25, and for Brahe Place Table 6-34 and Figure 6-26.

Table 6-33: Sensitivity of electricity grid projections for HWS average use impacts per year (La Banque)

Impact category	Unit	HWS 1	HWS 2
Global warming - base case	kg CO2	1.40E+05	4.01E+05
Global warming - 2035	kg CO2	1.38E+05	2.88E+05
Global warming - 2050	kg CO2	1.37E+05	1.89E+05
Impact category	Unit	HWS 1	HWS 2
Cumulative energy demand - base case	MJ LHV	2.40E+06	4.47E+06
Cumulative energy demand - 2035	MJ LHV	2.39E+06	3.53E+06
Cumulative energy demand - 2050	MJ LHV	2.38E+06	2.67E+06
Impact category	Unit	HWS 1	HWS 2
Water use - base case	KL H2O	6.90E+03	7.65E+03
Water use - 2035	KL H2O	6.90E+03	7.44E+03
Water use - 2050	KL H2O	6.89E+03	7.21E+03
Impact category	Unit	HWS 1	HWS 2
Solid waste - base case	kg	5.50E+02	6.61E+03
Solid waste - 2035	kg	5.38E+02	5.85E+03
Solid waste - 2050	kg	5.95E+02	9.47E+03

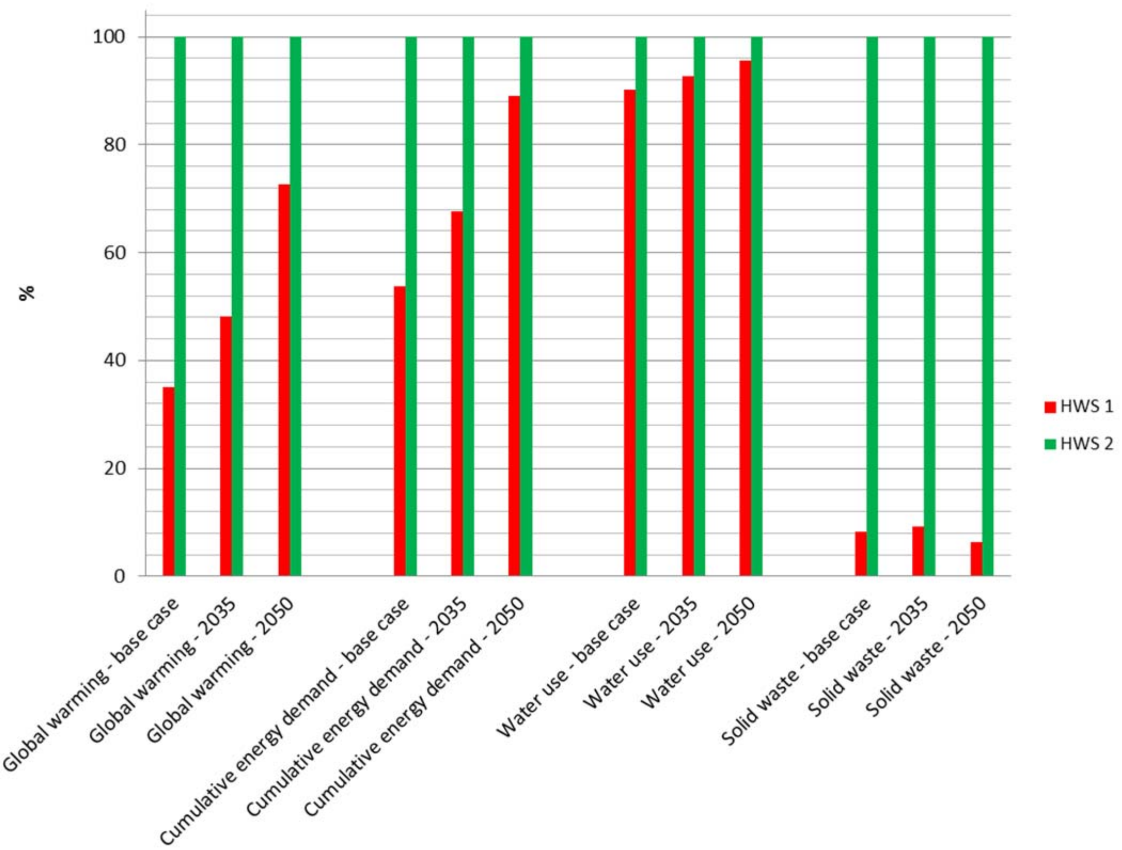

Figure 6-25: Relative summary of sensitivity of electricity grid projections results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

Table 6-34: Sensitivity of electricity grid projections for HWS average use impacts per year (Brahe Place)

Impact category	Unit	HWS 3	HWS 4	HWS 5
Global warming - base case	kg CO2	7.17E+03	6.36E+03	9.46E+03
Global warming - 2035	kg CO2	6.73E+03	5.87E+03	6.79E+03
Global warming - 2050	kg CO2	6.34E+03	5.45E+03	4.47E+03
Impact category	Unit	HWS 3	HWS 4	HWS 5
Cumulative energy demand - base case	MJ LHV	1.14E+05	9.87E+04	1.05E+05
Cumulative energy demand - 2035	MJ LHV	1.11E+05	9.47E+04	8.33E+04
Cumulative energy demand - 2050	MJ LHV	1.07E+05	9.10E+04	6.29E+04
Impact category	Unit	HWS 3	HWS 4	HWS 5
Water use - base case	KL H2O	167.75	169.00	180.82
Water use - 2035	KL H2O	166.93	168.11	175.90
Water use - 2050	KL H2O	166.03	167.13	170.50
Impact category	Unit	HWS 3	HWS 4	HWS 5
Solid waste - base case	kg	57.56	70.82	156.77
Solid waste - 2035	kg	54.59	67.58	138.95
Solid waste - 2050	kg	68.76	83.04	223.99

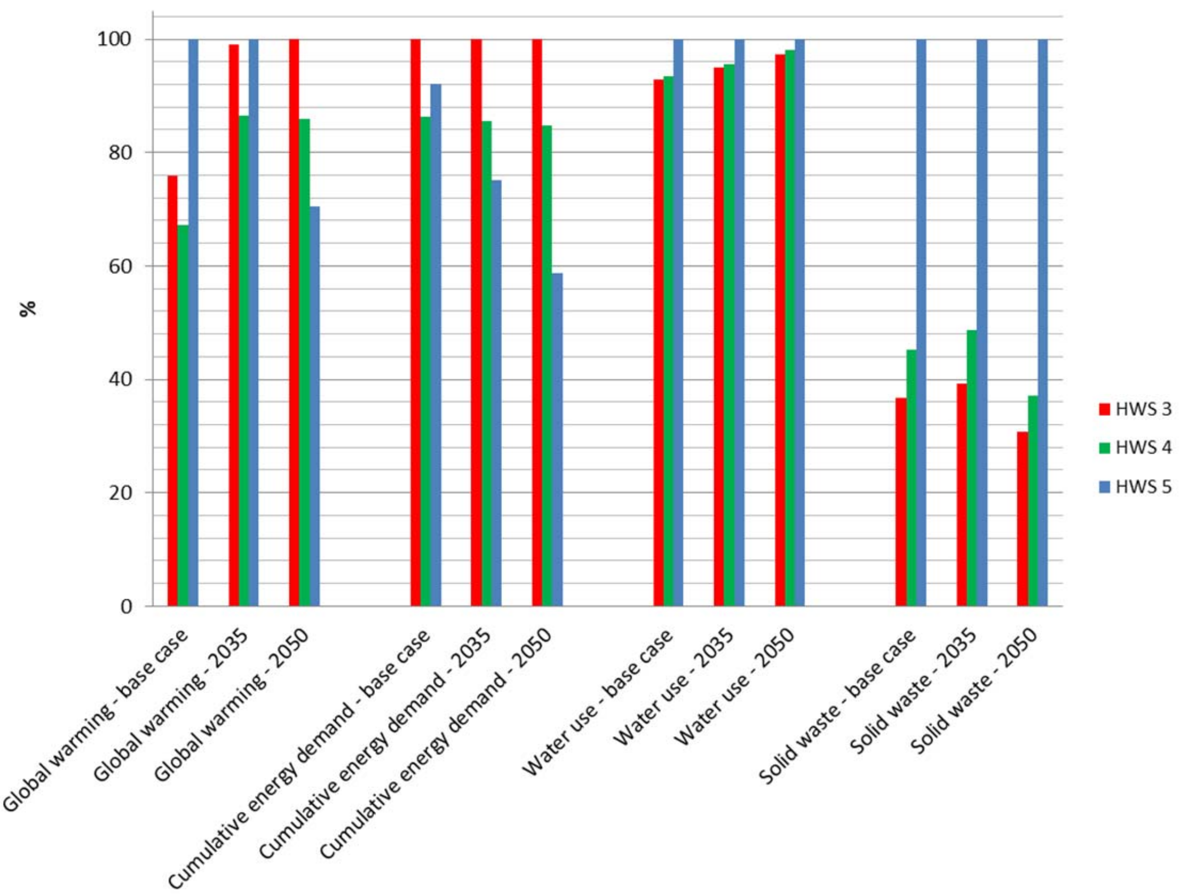

Figure 6-26: Relative summary of electricity grid projections results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

As Figure 6-25 demonstrates, there is no change directionally to the results by putting in the selected Victorian electricity grid projections in all impact categories. The gap however between HWS 2 and HWS 1 is drastically reduced by 2050, HWS 2 only 27% worse in global warming potential and 11% worse in cumulative energy demand, as the Victorian grid use more renewables, gas and imported black coal fired electricity generation.

Figure 6-26 demonstrates that there is a dramatic effect to the results for global warming potential and cumulative energy demand for Brahe Place in the selected Victorian electricity grid projections. By 2050 HWS 5 performs better on global warming potential compared to HWS 3 centralised gas and HWS 4 centralised gas with solar by 30% and 14% respectively. HWS 5 is better by 2035 and 2050 than all other HWS options in cumulative energy demand at Brahe Place. Solid waste and water use stays much the same for HWS 5 over the same period. This shows that buildings like Brahe Place as Melbourne's electricity greenhouse gas intensity drops, opportunities will exist for CFEWH to perform better than gas and solar boosted gas systems in global warning potential and cumulative energy demand today, a future proofing example.

6.2.7 Purchasing green electricity

It is important to test if purchasing green power for the CFEWH HWSs changes the results for both buildings in any way. This was done by modelling 25% renewable electricity (wind power) and 50% renewable electricity (wind power) for the average use scenario for all HWSs, the results shown in for La Banque in Table 6-35 and Figure 6-27, and for Brahe Place Table 6-36 and Figure 6-28.

Table 6-35: Sensitivity of green power for HWS average use impacts per year (La Banque)

Impact category	Unit	HWS 1	HWS 2
Global warming - base case 0% wind power	kg CO2	1.40E+05	4.01E+05
Global warming - 25% wind power	kg CO2	1.39E+05	3.03E+05
Global warming - 50% wind power	kg CO2	1.37E+05	2.05E+05
Impact category	Unit	HWS 1	HWS 2
Cumulative energy demand - base case 0% wind pow	MJ LHV	2.40E+06	4.47E+06
Cumulative energy demand - 25% wind power	MJ LHV	2.39E+06	3.65E+06
Cumulative energy demand - 50% wind power	MJ LHV	2.38E+06	2.82E+06
Impact category	Unit	HWS 1	HWS 2
Water use - base case 0% wind power	KL H2O	6.90E+03	7.65E+03
Water use - 25% wind power	KL H2O	6.90E+03	7.48E+03
Water use - 50% wind power	KL H2O	6.90E+03	7.31E+03
Impact category	Unit	HWS 1	HWS 2
Solid waste - base case 0% wind power	kg	5.50E+02	6.61E+03
Solid waste - 25% wind power	kg	5.25E+02	5.06E+03
Solid waste - 50% wind power	kg	5.01E+02	3.51E+03

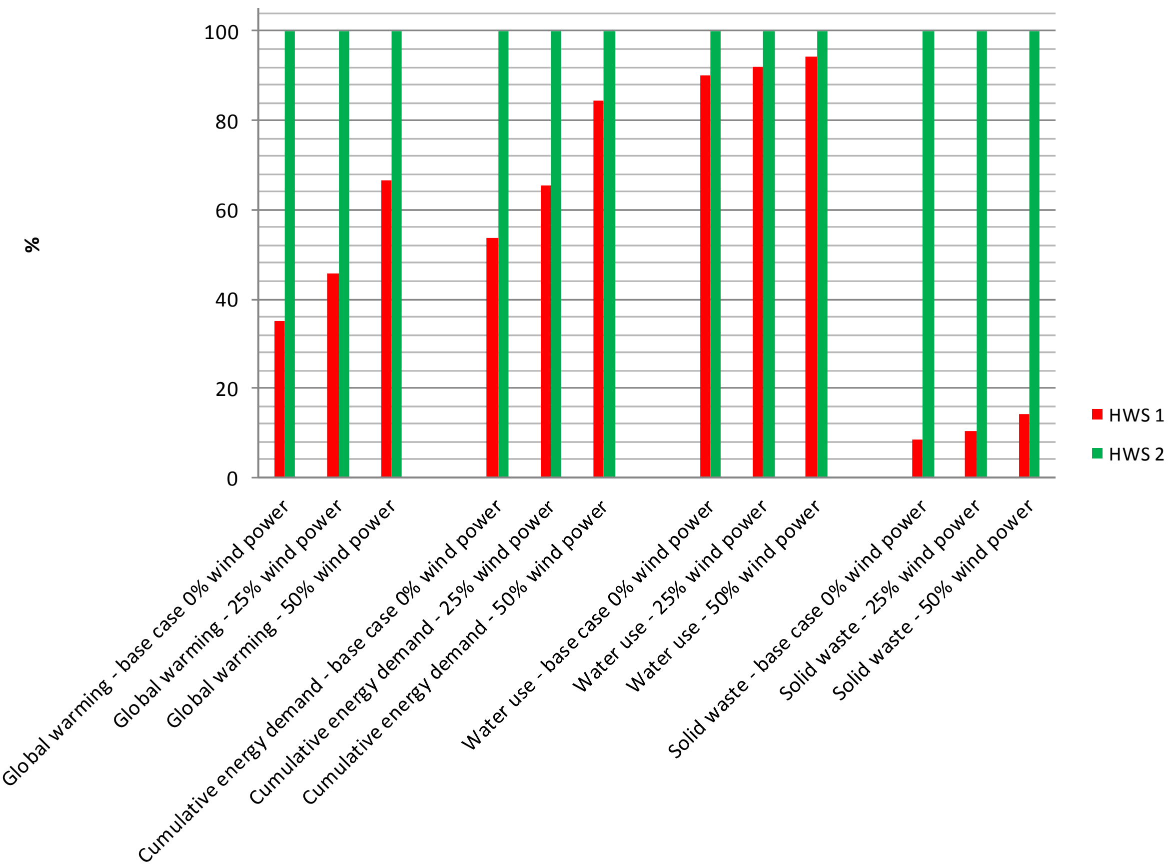

Figure 6-27: Relative summary of green power results for La Banque (scaled from highest impact) red bar HWS1, green bar HWS2

Table 6-36: Sensitivity of green power for HWS average use impacts per year (Brahe Place)

Impact category	Unit	HWS 3	HWS 4	HWS 5
Global warming - base case 0% wind power	kg CO2	7.17E+03	6.36E+03	9.46E+03
Global warming - 25% wind power	kg CO2	6.79E+03	5.94E+03	7.16E+03
Global warming - 50% wind power	kg CO2	6.40E+03	5.52E+03	4.86E+03
Impact category	Unit	HWS 3	HWS 4	HWS 5
Cumulative energy demand - base case 0% wind powe	MJ LHV	1.14E+05	9.87E+04	1.05E+05
Cumulative energy demand - 25% wind power	MJ LHV	1.11E+05	9.51E+04	7.99E+04
Cumulative energy demand - 50% wind power	MJ LHV	1.08E+05	9.16E+04	6.65E+04
Impact category	Unit	HWS 3	HWS 4	HWS 5
Water use - base case 0% wind power	KL H2O	167.75	169.00	180.82
Water use - 25% wind power	KL H2O	167.09	168.28	176.86
Water use - 50% wind power	KL H2O	166.43	167.56	172.89
Impact category	Unit	HWS 3	HWS 4	HWS 5
Solid waste - base case 0% wind power	kg	57.56	70.82	156.77
Solid waste - 25% wind power	kg	51.49	64.21	120.36
Solid waste - 50% wind power	kg	45.42	57.59	83.94

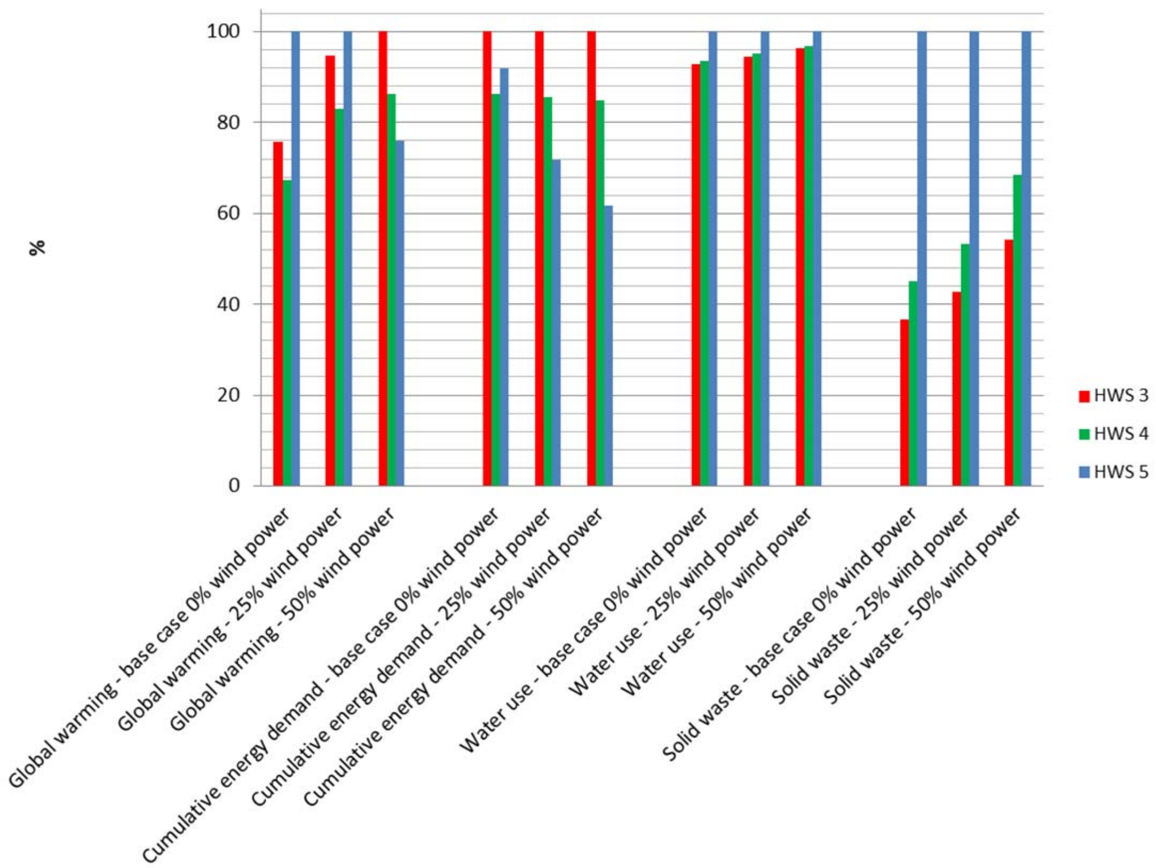

Figure 6-28: Relative summary of sensitivity of green power results for Brahe Place (scaled from highest impact) red bar HWS3, green bar HWS4, blue bar HWS 5

As Figure 6-27 demonstrates, there is no change directionally to the results by purchasing up to 50% renewable electricity for all impact categories in La Banque. The gap however between HWS 2 and HWS 1 is drastically reduced by 2050, HWS 2 only 33% worse in global warming potential and 16% worse in cumulative energy demand, as the Victorian grid use more renewables, gas and imported black coal fired electricity generation.

Figure 6-28 demonstrates that there is a dramatic effect to the results for global warming potential and cumulative energy demand for Brahe Place if renewable electricity is purchased in Victoria. If 50% renewable electricity is purchased, HWS 5 performs better on global warming potential compared to HWS 3 centralised gas and HWS 4 centralised gas with solar by 24% and 10% respectively. HWS 5 is better at 25% and 50% renewable electricity than all other HWS options in cumulative energy demand at Brahe Place. Solid waste and water use stay much the same. This shows that for buildings like Brahe Place opportunities exist today for CFEWH to perform better than gas and solar boosted gas systems in global warning potential and cumulative energy demand, if renewable electricity is purchased at different proportions of total electricity load.

6.3 Other studies

A search for relevant LCA studies to compare this work proved difficult, particularly in the context of whole of life cycle with a focus on medium and high density building

HWSs that take a whole of system approach (which is a limitation). Elements considered critical to relevant to this study included region, technology, assessment approach, size of buildings, similar impact categories, etc.

The closet published study identified was that of an energy analysis of solar and conventional domestic hot water systems in Melbourne, Australia (Crawford and Treloar 2004). This was at least regionally specific, had some technology alignment, and looked at energy use annually. The system boundary of this study only included energy in use and energy in manufacture and materials of the components of each HWS. The model is also for a four person house, rather than multi dwelling buildings. The use phase energy modelling was compiled from manufacturer top level specifications, rather than the more sophisticated TRNSYS modelling completed in this study. It must also be noted that the LCA methodology of this study was fundamentally different, in that it was constructed using hybrid input out/ process LCA, rather than solely process based LCA. The results were taken from the study, and embodied energy of each system amortised to a building life of 50 years (in line with the assumption of this study) to give an annual energy figure for the HWSs, as detailed in Table 6-37.

Table 6-37: Annual embodied energy and operational energy of hot water systems for Melbourne (GJ) adapted from (Crawford and Treloar 2004)

	Electric storage	Gas storage	Gas instantaneous	Solar electric	Solar gas
Annual embodied energy (GJ)*	0.29	0.25	0.14	0.69	0.87
Annual operational energy (GJ)	22.94	22.70	20.85	18.43	10.43
Total annual energy (GJ)	23.23	22.95	20.99	19.12	11.30

* extrapolated by using total embodied energy divided by 50 year building life as per this study.

The main consistency of the past study related this study is that materials and manufacturing of components play a small part of the total energy load of the HWSs. Energy use is driven by the use phase as per this study. The results regarding solar versus centralised systems (storage in this case) is directionally consistent to this study in that energy use drops due to the solar contribution. Apart from this no other consistencies can really be drawn, due to the lack of elemental alignment and methodological differences.

6.4 Conclusions

This report has documented the methods, assumptions, data used, inventory, impact assessment results, sensitivity analysis and the limitations of a Life Cycle Assessment (LCA) study of HWSs within two buildings. The two buildings used as case studies for the HWSs were;

1. An existing high-density apartment complex, La Banque building, located in the Melbourne CBD at 380 Little Lonsdale Street, consisting of 257 apartments on 35 levels.

2. A proposed medium-density apartment complex, the Brahe Place building, located in East Melbourne at 18 Brahe Place, consisting of eight apartments on three levels.

Environmental comparisons were based upon the following functional unit.

"Hot water produced and delivered to the typical apartment residents in a building over the course of 1 year at 50°C."

The system boundary of the LCA included material extraction and production, manufacturing, transport, HWS use and post-consumer waste management. Infrastructure processes (including capital equipment), and overheads were not included. The regions considered included Europe, Asia, USA and Australia for the production of materials and manufacturing of HWSs, and Australia for the distribution, use (Melbourne) and disposal of the HWSs.

For both buildings the centralised gas (except for cumulative energy demand in average hot water use in Brahe Place) and centralised gas solar boosted systems have the lower impacts than CFEWH systems in global warming potential, cumulative energy demand, water use and solid waste. The magnitude of the impacts, relative to the CFEWH systems vary depending upon the impact of interest, hot water use profiles and building examined.

For the La Banque building, the centralised gas HWS 1 relative to the CFEWH HWS 2 exhibited impact reductions in the base case of:

- 61-70% for global warming potential (low to high use)
- 40-54% for cumulative energy demand (low to high use)
- 12% for non-turbine water use (low to high use)
- 91-93% for solid waste (low to high use)

For the Brahe Place building, the centralised gas HWS 3 relative to the CFEWH HWS 5 exhibited impact reductions in the base case of:

- 24-46% for global warming potential (low to high use)
- 22% for cumulative energy demand (high use, it was 8% worse than HWS 5 for average use)
- 8% for non-turbine water use (low to high use)
- 64-76% for solid waste (low to high use)

For the Brahe Place building, the centralised gas solar boosted HWS 4 relative to the CFEWH HWS 5 exhibited impact reductions in the base case of:

- 33-55% for global warming potential (low to high use)
- 6-32% for cumulative energy demand (low to high use)
- 7% for non-turbine water use (low to high use)
- 55-71% for solid waste (low to high use)

In the case of the global warming potential, the HWSs are dominated by greenhouse gas emissions from the use phase, either natural gas consumption or grid electricity. The HWSs show much the same trend for cumulative energy demand as for global warming potential, driven by use phase energy consumption across the board. Hot water consumption drives water use in all scenarios, whilst for the centralised HWSs end of life and materials drive solid waste, whilst for the CFEWH HWSs waste in electricity production drives solid waste.

The sensitivity analyses of the base case average use scenario results for both buildings included altering the:

- Region for HWS use
- Occupancy and vacancy
- Component replacement, component materials, and building life
- CFEWH and solar boosting (substitute electric HWS 4)
- Extra centralised system losses in ring main
- Victorian electricity grid changes
- Green power purchasing

The results of the sensitivity analyses confirmed that the base case study has taken a more conservative approach when comparing HWSs within the La Banque building, with all alterations resulting in the same directional results, albeit at a different quantum.

It must be noted however that the results for the smaller building Brahe Place shifted directionally for a number of altered assumptions, including:

- The alteration of region for HWS use resulting in favourable cumulative energy demand results for CFEWH HWS 5 over HWS 3 and HWS 4 in every capital city studied, global warming potential and for CFEWH HWS 5 over HWS 3 in every capital city studied, and global warming potential for CFEWH HWS 5 over HWS 4 in Adelaide.
- CFEWH with solar boosting performing better in global warming potential and cumulative energy demand results than HWS 3 and HWS 4 (only marginally in global warming potential).
- The projected Victorian electricity grid changes selected resulting in favourable cumulative energy demand results for CFEWH HWS 5 over HWS 3 and HWS 4 by the 2035 scenario, and favourable global warming potential for CFEWH HWS 5 over HWS 3 and HWS 4 by the 2050 scenario.
- Renewable electricity purchasing for all HWSs results in favourable cumulative energy demand results for CFEWH HWS 5 over HWS 3 and HWS 4 in the 25% and 50 % renewable electricity contribution scenarios, and favourable global warming potential for CFEWH HWS 5 over HWS 3 and HWS 4 in the 50 % renewable electricity contribution scenario.

The results of the sensitivity analyses for Brahe Place show that for this type of building, where standby energy in a centralised system of a is higher as a proportion of total energy demand than the bigger building (making it less efficient overall as a system as the larger building) significant opportunities exist today (with renewable electricity, CFEWH solar boosting, and in state capitals where lower grid emissions and lower heating requirements where higher ambient water temperatures exist) and in the future (with Victorian grid emission reductions) for CFEWH to perform better than gas and solar boosted gas systems in global warning potential and cumulative energy demand.

This demonstrates that context is the key to selection of the environmentally better HWSs, and that policy makers should consider a systems approach in regulating HWSs rather than product specific rules of thumb. It also highlights that although not environmentally preferable in the base case, CFEWHs are in some circumstances a choice of resilience and future-proofing, where efficiency and electricity grid emission reductions can combine to produce a more desirable environmental outcome.

6.5 Limitations

The data used in this study was limited by the quality of primary data collected from industry, and the quality of secondary data sets utilised in existing Life Cycle Inventories. The following limitation topics are listed in order of importance.

6.5.1 Water use and scarcity

Water use was selected as the measure for water consumption in this study, which was simply the addition of non-turbine fresh water use throughout the product systems. Water-foot printing is well recognised as a significant area of research in LCA. Water-foot printing methodologies are varied and there is still no consensus in LCA methodology on the overall applicability of these methods. There is even debate on the definitions of water sources which underpin these methods.

The Centre for Design recognises that the regional impacts of water are important; the environmental consequences of water use are regionally specific. However, the current commercially available LCA modelling tools are a significant obstacle in achieving water use indicators that reflect regional importance. The Centre for Design does not consider applying simple factors to one country, due to the complexity of regional water stress indexes (WSI, as per Figure 6-28 (notice the Australian eastern seaboard variance where most of the systems derive), which are also temporal.

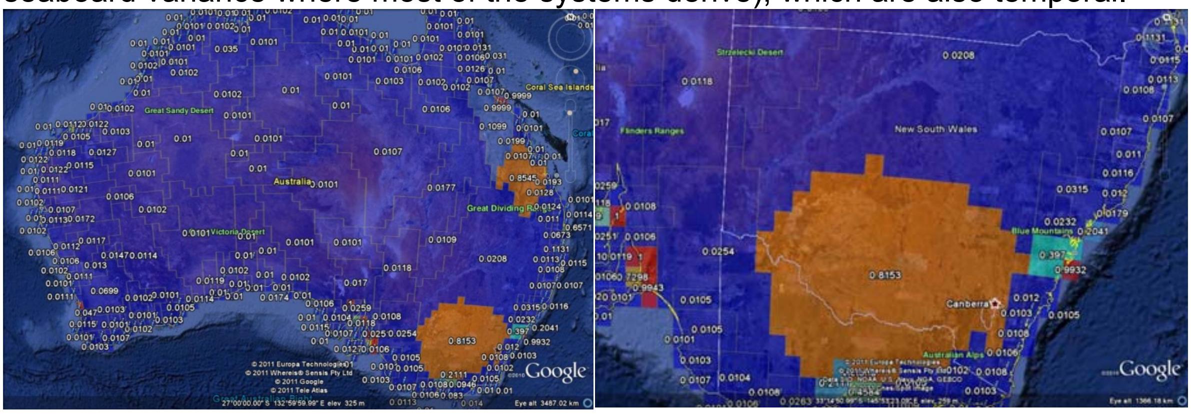

Figure 6-29: 2011 Australian water stress indexes (derived from Google Earth images with the Water Stress Index layer from Pfister et al in 2011)

According to Ridoutt and Pfister (2009), the "location of water consumption at each point in the product life cycle" must be defined and coupled with water stress indicator values across the supply chain. In addition, where possible, "specific coordinates" across the supply chain must be identified.

Based on the current SimaPro modelling and background inventories, regionalisation of water flows is not currently possible without significant alterations to the overall database structures and modifications of the life cycle inventories. As an example, regionalisation of water impacts for the production of electricity from a European grid will involve modifying approximately 50 life cycle inventories as well as regionalising the elementary flows. In addition, the location of specific power stations would need to be sourced in order to apply relevant WSIs. The location of these power stations is currently not well documented in the life cycle inventories. As such with the current LCA tool and generic LCI framework regionalisation is not possible, and would take significant extra data collection and modelling to sufficiently track water stress impacts.

6.5.2 Context

Currently the HWS components are produced in Australia, Asia, USA and Europe and used in Australia. In assessing potential environmental impacts, the study does not differentiate between local and global impacts. For certain environmental indicators, such as water use, this can be important because water may be scarce locally, but not scarce at foreign locations (although there is a growing body of evidence suggesting water is becoming a global issue). Other environmental impacts, such as global warming potential, can be considered of equal importance both locally and at foreign locations. As such, the results are limited to the regions considered in this study and may be different for other regions.

The life cycle impact assessment (LCIA) results are relative expressions and do not predict impacts on category end points, the exceeding of thresholds or safety margins. Comparison of the results of this study to other LCA studies should be treated with caution, given that there can be differences in LCA methodology, including but not limited to:

- Functional unit
- System boundaries, including the exclusion of life-cycle stages, e.g. use and end-of-life (cradle-to-gate).
- The application of different characterisation factors in the impact assessment (e.g. for global warming potential, the use of IPCC 1996 vs. IPCC 2007 factors).
- The application of CO_2 eq credits for the use of fossil-fuel derived electricity by the purchase of Renewable Energy Certificates (RECs).

6.5.3 Victorian electricity grid projections

Projecting the emissions intensity of a grid in the period 2013-2050 is highly uncertain due to the design and effectiveness of policy and abatement instruments (e.g. carbon pricing, renewable energy targets). Historically the emission intensity of the Victorian electricity grid has fluctuated with a general downward trend in-between 1989-2012. The emission intensity of the Victorian grid is however expected to drop through to 2050 (the temporal scope of this sensitivity analysis), due to a forecast increase in electricity from non-hydro renewable sources, a decrease in the reliance on coal-fired electricity, uptake of carbon capture and storage technologies and a potential decrease in electricity demand (Garnaut 2008).

The Syed (2012) report predicts the energy mix of the national electricity grid to both 2035 and 2050. It was deemed reasonable then to model what Victoria might look like at these points if the national trends from Syed (2012) were applied, seeing as in particular the report predicts that brown coal will reduce to 0% of the grid contribution by 2050, and suggests that Victoria will need to invest in lower emission technologies, or import electricity.

6.5.4 Other

Inventory items for which MicroHeat and suppliers provided primary data included manufacturing processes (with associated energy consumption), materials, part masses, shipping and transport locations, and some energy consumption data not contained in existing data sets currently.

Some inventory items required secondary data that derived from a region other than the origin of the specific inventory item. No materials or processes contributed to more than 5% of a particular impact category (apart from the inventory measure of solid waste for HWS 3 and HWS 4 in Brahe Place), so the electricity grids were not modified for materials sourced by MicroHeat or manufacturers from countries other than those in the data source to reflect the electricity grid profiles of those regions.

7 References

7.1 SimaPro® background databases utilised

Database name	Description
Australasian Unit Process Life Cycle Inventory (AUPLCI)	Australian LCA database developed from 1998 up to 2008 by Centre for Design from data originally developed with the CRC for Waste Management and Pollution Control, as part of an Australian Inventory data project. The data from this project has been progressively updated, particularly the data for metals production, energy, transport and paper and board production.
CFD Internal data	LCA models created by the Centre for Design at RMIT University.
Ecoinvent 2.2 May 2010	Life Cycle Inventories compiled by the Swiss centre for Life Cycle Inventories. The ecoinvent database consists of approximately 4100 datasets covering a suite of industries in Switzerland and Western Europe.

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Appendix A Characterisation Factors

Not available for Web.

Appendix B Peer reviewer comments and actions

Attached after report in this pdf.

Appendix C Non assessed substances

Not available for Web.

Appendix D Summary of inventory

Not available for Web.

Appendix E SAMME report on CFEWH performance

See pdf file *MicroHeat_summary_of_peformance_final.pdf*

Appendix F SAMME report on TRNSYS modelling

See pdf file MicroHeat_summary_of_TRNSYS_final.pdf

Appendix G Life Cycle Use Phase of Hot Water Delivery report

Not available for Web.

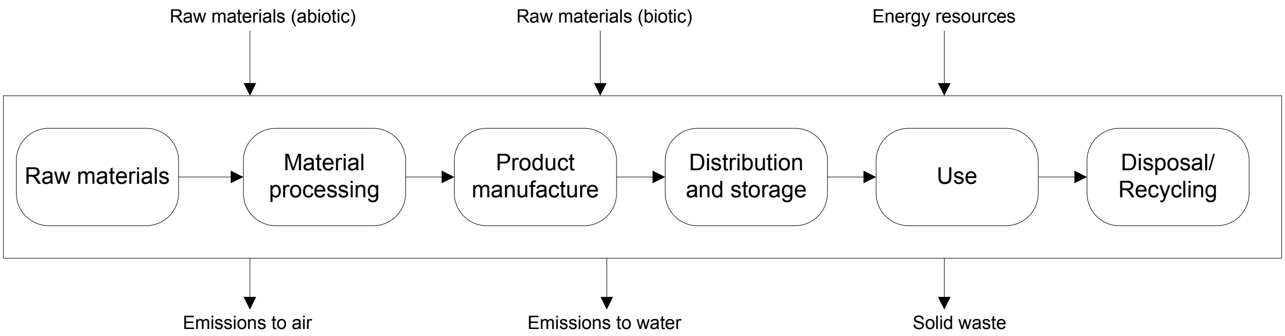
Appendix H Methodology

The following sections provide a brief description of the LCA methodology. The most important terminology is explained, as well as how to interpret outcomes of the assessment.

Life Cycle Assessment

LCA is the process of evaluating the potential effects that a product, process or service has on the environment over the entire period of its life cycle. Figure 7-1 illustrates the life cycle system concept of natural resources and energy entering the system with products, waste and emissions leaving the system.

Figure 7-1: Life cycle system concept

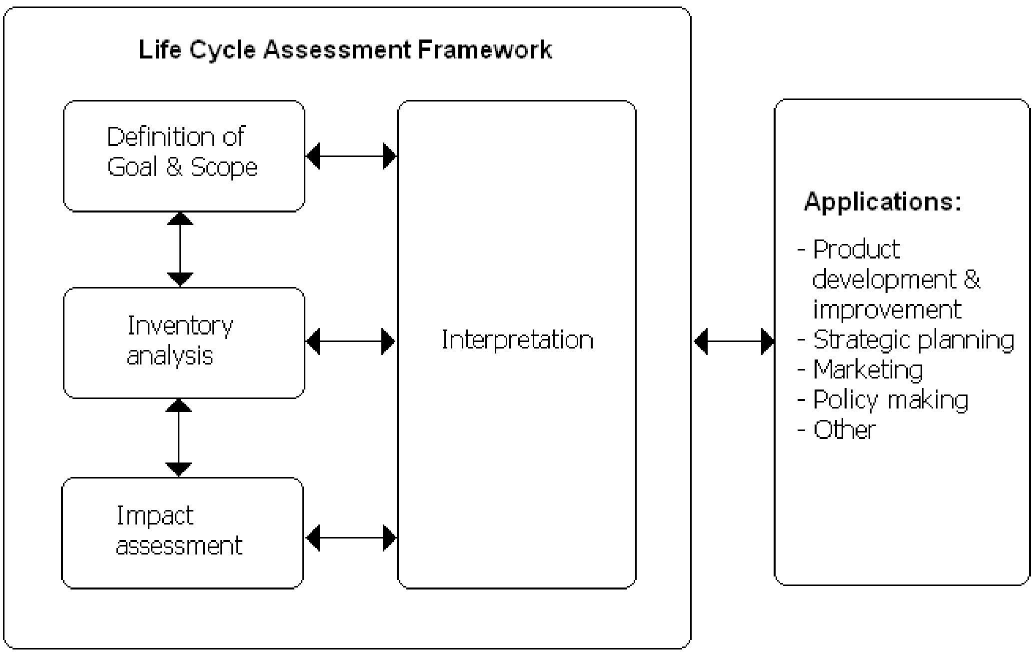


The International Standards Organisation (ISO) has defined LCA as:

"[A] Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle" ((International Organization for Standardization 2006a)pp.2).

The technical framework for LCA consists of four components, each having a very important role in the assessment. They are interrelated throughout the entire assessment and in accordance with the current terminology of the International Standards Organisation (ISO). The components are goal and scope definition, inventory analysis, impact assessment and interpretation as illustrated in Figure 7-2.

Figure 7-2: The Framework for LCA from the International Standard ((International Organization for Standardization 2006a)pp. 8)



Goal and scope definition

At the commencement of an LCA, the goal and scope of the study needs to be clearly defined. The goal should state unambiguously the intended application/purpose of the study, the audience for which the results are intended, the product or function that is to be studied, and the scope of the study. When defining the scope, consideration of the reference unit, system boundaries and data quality requirements are some of the issues to be covered.

Inventory analysis

Inventory analysis is concerned with the collection, analysis and validation of data that quantifies the appropriate inputs and outputs of a product system. The results include a process flow chart and a list of all emissions and raw material & energy inputs (inventory table) that are associated with the product under study.

Impact assessment

The primary aim of an impact assessment is to identify and establish a link between the product's life cycle and the potential environmental impacts associated with it. The impact assessment stage consists of three phases that are intended to evaluate the significance of the potential environmental effects associated with the product system:

- The first phase is the characterisation of the results, assigning the elemental flows to impact categories, and calculating their contribution to that impact.

- The second phase is the comparison of the impact results to total national impact levels and is called normalisation.

- The third phase is the weighting of these normalised results together to enable the calculation of a single indictor result. In this study, only the first two phases are undertaken.

Interpretation

Interpretation is a systematic evaluation of the outcomes of the life cycle inventory analysis and/or impact assessment, in relation to the goal and scope. This interpretation result into conclusions of the environmental profile of the product or system under investigation, and recommendations on how to improve the environmental profile.

SimaPro®

The LCA comparison was undertaken using the SimaPro® software package to model the life cycle of each product (or system), which could then be analysed to determine relevant potential environmental impacts.

SimaPro® is the most widely used Life Cycle Assessment software in the world. Introduced in 1990 in response to industry needs, the SimaPro® product family facilitates the application of LCA, using transparent and comprehensive analysis tools (process trees, graphs and inventory tables).

Appendix I Charts for pumps used in HWS use phases

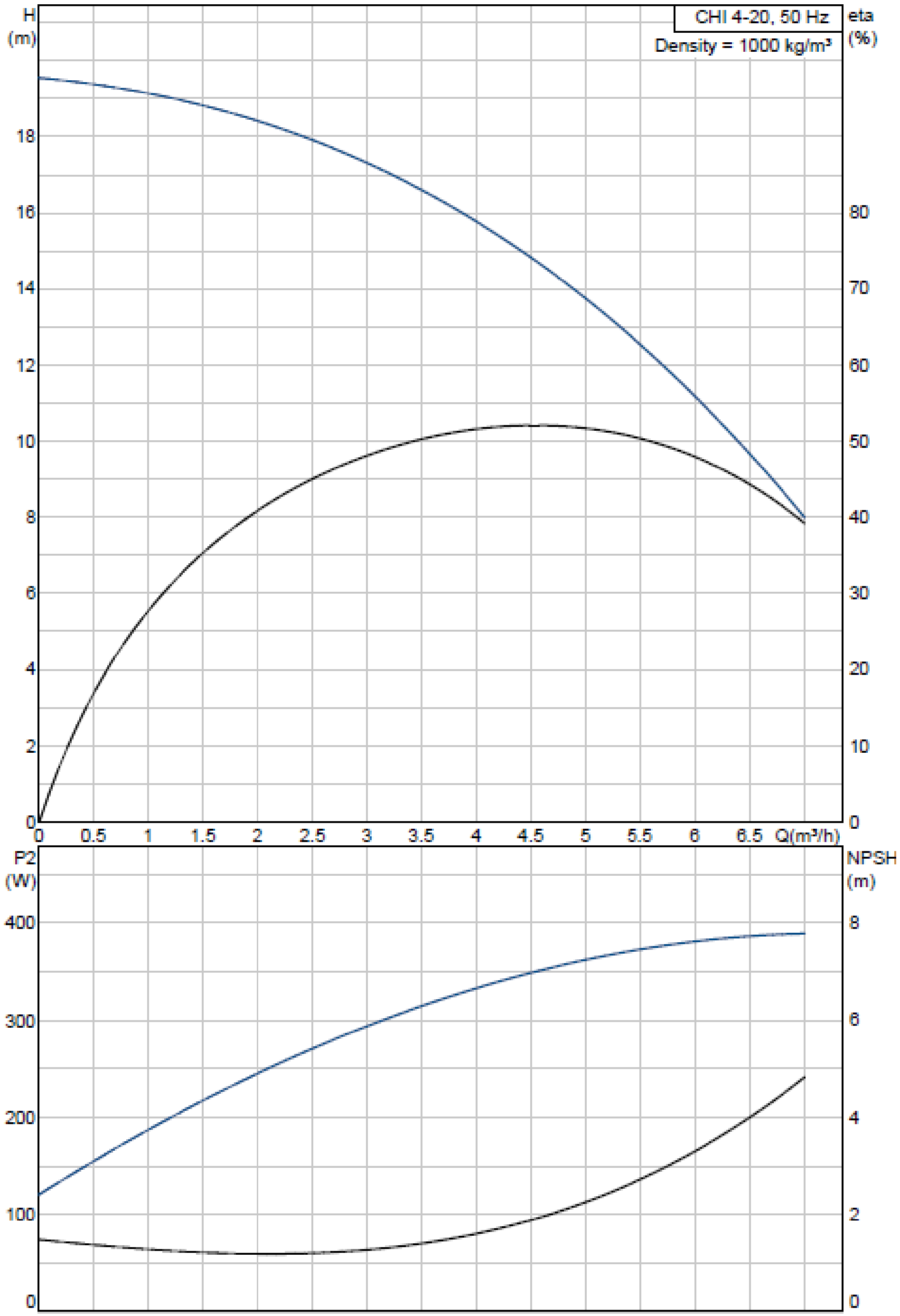


Figure 7-3: Grundfos CHI 4-20 performance curves (Grundfos 2012)

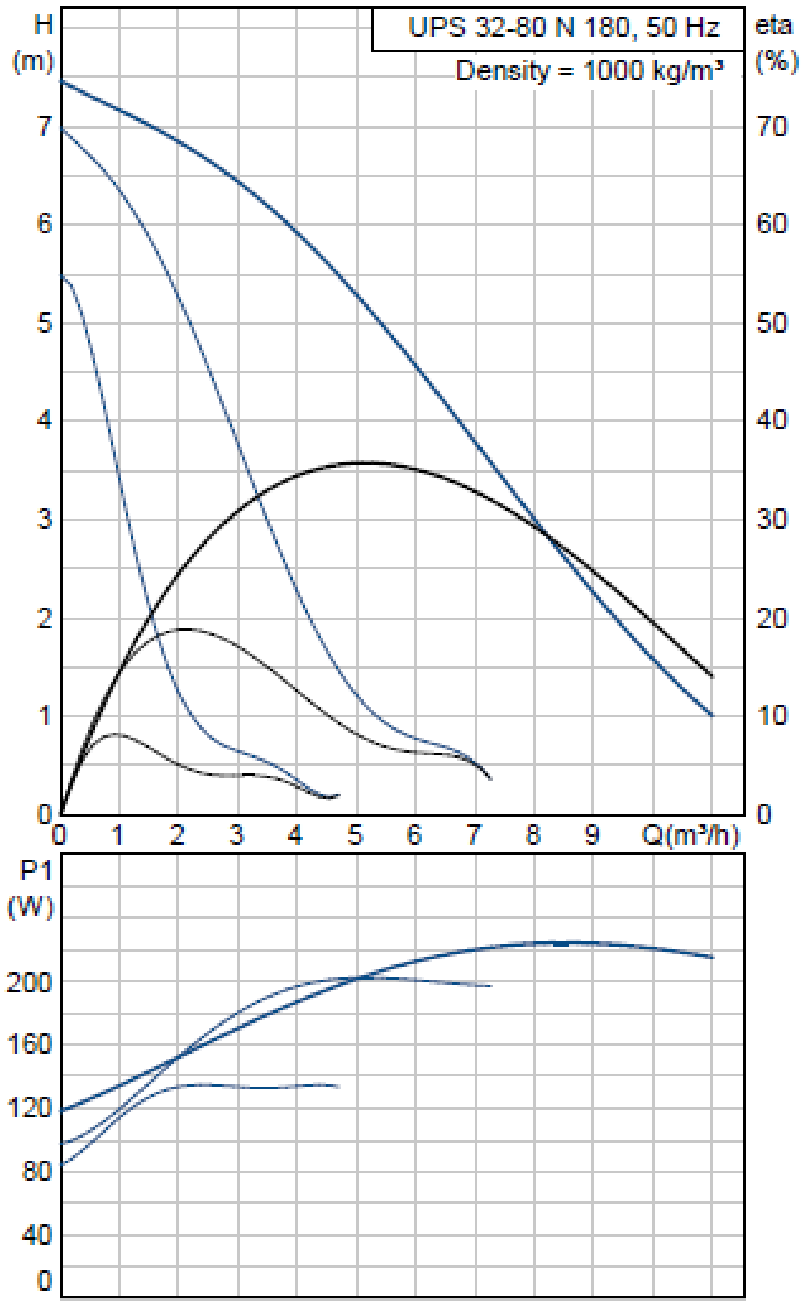


Figure 7-4: Grundfos UPS 32-80 N 180 performance curves (Grundfos 2007a)

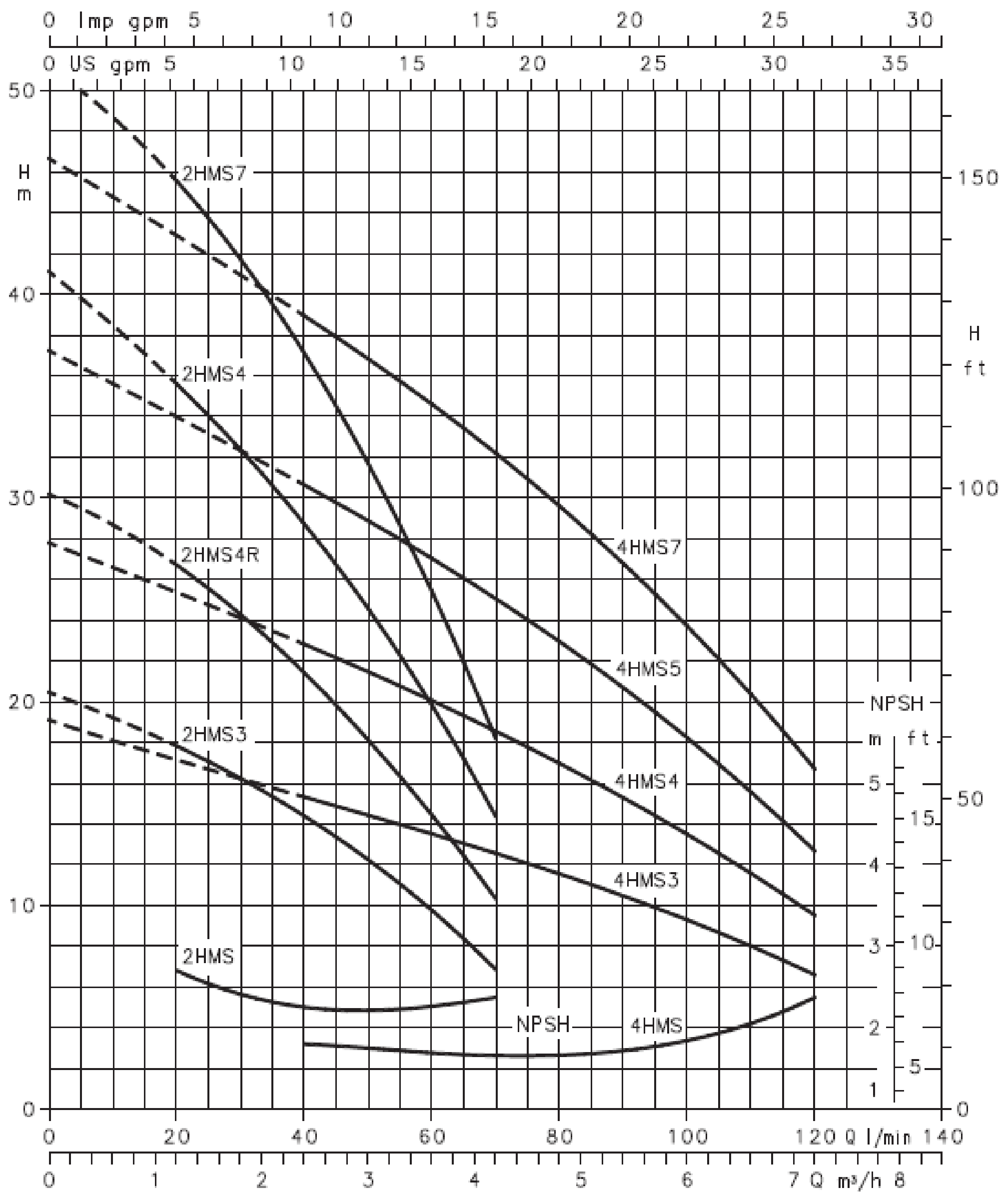


Figure 7-5: Lowara 4HMS3 performance curves (Lowara 2009)

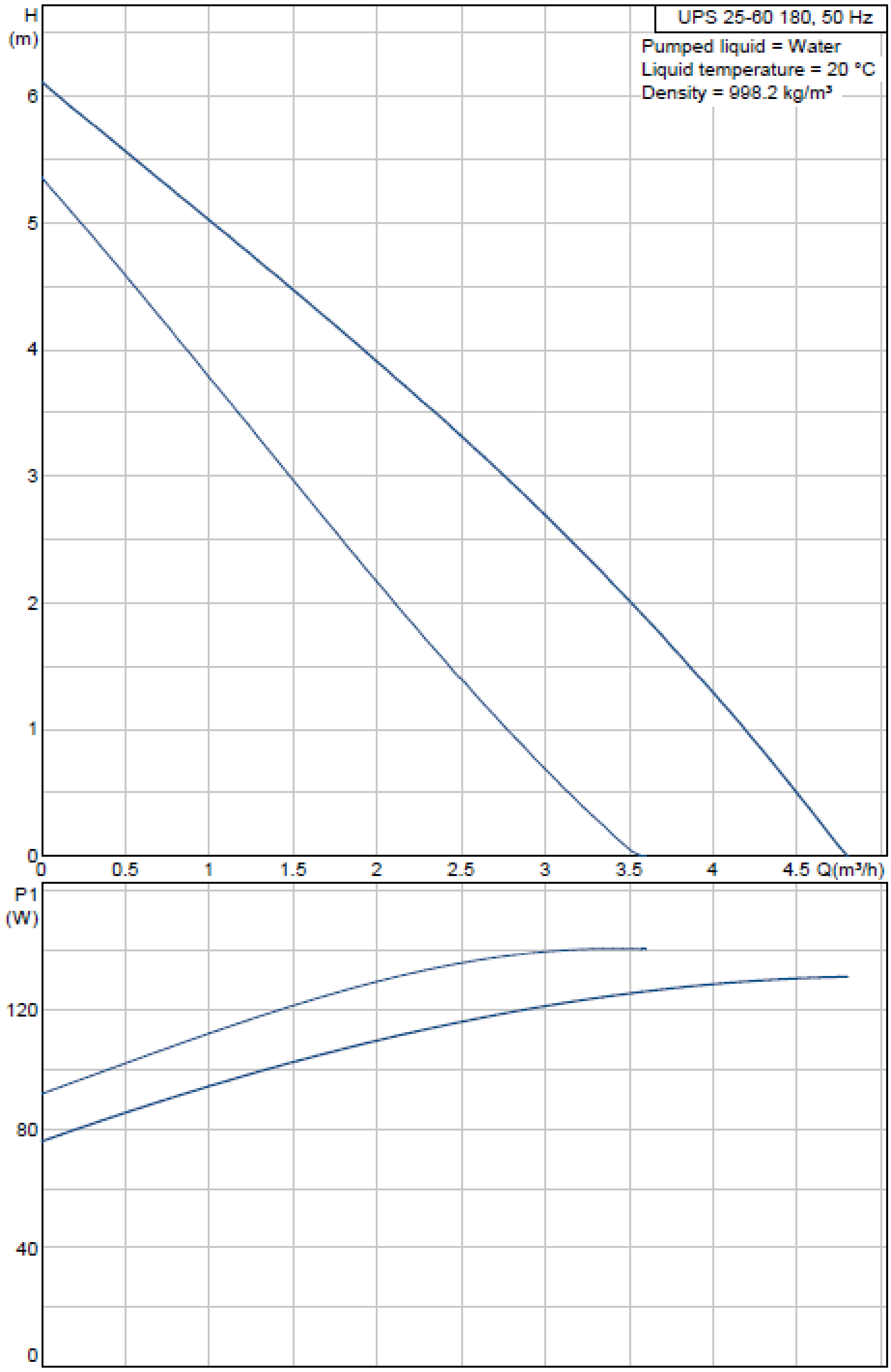


Figure 7-6: Grundfos UPS 25-60 180 performance curves (Grundfos 2007b)

Appendix J Reference flows

Tables 7.1 to 7.5 detail the top five inventory reference flows contributing to impacts in the different HWSs in the base case relative to the functional unit.

Table 7-1: Top 5 reference flows for HWS contributing to impacts in relation to functional unit

Impact category	Unit	Use scenario	HWS 1 Central gas plant
Energy from natural gas for heating	MJ	Low	1.88E+06
		Average	2.20E+06
		High	2.93E+06
Auxiliary electricity in use	MJ	Low	1.61E+04
		Average	1.68E+04
		High	1.91E+04
Reticulated water supply	kL	Low	5.17E+03
		Average	6.86E+03
		High	1.07E+04
Landfill waste	kg	Low	216.5
		Average	216.5
		High	216.5
HWS components	kg	Low	216.5
		Average	216.5
		High	216.5

Table 7-2: Top 5 reference flows for HWS 2 contributing to impacts in relation to functional unit

Impact category	Unit	Use scenario	HWS 2 CFEWH point of use
Electricity in use for heating	MJ	Low	7.92E+05
		Average	1.05E+06
		High	1.64E+06
Auxiliary electricity in use	MJ	Low	7.02E+03
		Average	7.02E+03
		High	7.02E+03
Reticulated water supply	kL	Low	5.67E+03
		Average	7.52E+03
		High	1.17E+04
Landfill waste	kg	Low	136
		Average	136
		High	136
HWS components	kg	Low	136
		Average	136
		High	136

Table 7-3: Top 5 reference flows for HWS 3 contributing to impacts in relation to functional unit

Impact category	Unit	Use scenario	HWS 4 Central gas plant & solar
Energy from natural gas for heating	MJ	Average	9.27E+04
		High	1.13E+05
Auxiliary electricity in use	MJ	Average	4.15E+03
		High	4.18E+03

Impact category	Unit	Use scenario	HWS 4 Central gas plant & solar
Reticulated water supply	kL	Average	164
		High	272
Landfill waste	kg	Average	26.8
		High	26.8
HWS components	kg	Average	26.8
		High	26.8

Table 7-4: Top 5 reference flows for HWS 4 contributing to impacts in relation to functional unit

Impact category	Unit	Use scenario	HWS 4 Central gas plant & solar
Energy from natural gas for heating	MJ	Average	7.46E+04
		High	9.39E+05
Auxiliary electricity in use	MJ	Average	4.52E+03
		High	4.64E+03
Reticulated water supply	kL	Average	164
		High	272
Landfill waste	kg	Average	32.9
		High	32.9
HWS components	kg	Average	32.9
		High	32.9

Table 7-5: Top 5 reference flows for HWS 5 contributing to impacts in relation to functional unit

Impact category	Unit	Use scenario	HWS 4 Central gas plant & solar
Electricity in use for heating	MJ	Average	2.47E+04
		High	4.13E+05
Auxiliary electricity in use	MJ	Average	220
		High	220
Reticulated water supply	kL	Average	177
		High	295
Landfill waste	kg	Average	4.23
		High	4.23
HWS components	kg	Average	4.23
		High	4.23

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Responses to peer review of Life Cycle Assessment Hot Water Delivery

WEB VERSION

Prepared for:
Wahidul Biswas and Michele Rosano
Curtin University.

Prepared by:
Simon Lockrey
RMIT University, Centre for Design

Melbourne, 28th May 2013
VERSION N° 2.0

The following details the responses (in *italics*) and any actions taken by Simon Lockrey of the Centre for Design (CfD) at RMIT, in response to the specific comments from the ISO14040/44 compliance peer review by Wahidul Biswas and Michele Rosano of Curtin University.

<u>Final response 28/05/13</u>

Following the initial responses on 17/05/13 to the peer review, Wahidul Biswas signed off the ISO compliance of the report, however highlighted some comments he still wanted further clarification on. The responses are as follows:

3.2 Functional unit

It also may have been useful to have a functional unit that determines the impacts of the production and delivery of a cubic metre (m3) of hot water supplied. This would then help other researchers to use this data as generic data for calculating the carbon footprint of hot water systems use in high and low density buildings and to assist government policy support for renewable energy systems.

Further from a discussion on the phone, CfD is reticent to include a functional unit that determines the impacts of the production and delivery of a cubic metre (m3) of hot water supplied. This is because the LCA is comparative, and some of the common inventory items across the HWSs have been left out (i.e. booster pumps, installation, etc.). For this treason the results should now=t be used as absolutes, but as comparisons, and providing a cubic metre (m3) of hot water supplied figure may result in findings being used as absolutes rather than comparisons.

3.4 Timeframe and geography

The lifetime of the HWS has been determined by a thorough literature review of both local and international studies. The hot water system has been developed to suit local conditions in Melbourne. The local ambient temperature has been considered to determine temperature the difference and heat losses for estimating the energy requirements of hot water demand in Melbourne. However, the average Australian hourly water load curve was used to calculate the total demand for hot water in Victoria. A Victorian water consumption curve could be used to estimate this demand more accurately. This point needs to be mentioned as a limitation in the analysis.

Further from a discussion on the phone, this was noted at the end of Section 4.14 in the initial response as a limitation, although it remains consistent with Australian Standard methodology.

3.8 Mass and energy balance

It would have been useful to show five inventory flow charts for 5 HWS options with each flow chart showing the quantitative values of energy, chemicals and metals for four stages of the life cycle of the production and delivery of hot water at 50C to an apartment. It is not suggested to have a detailed breakdown of the components (i.e. metals) for this type of inventory flow chart, but at least display the main components in the flow chart. It helps the reader to relate how energy and materials associated with hot water delivery are causing different impacts.

In the initial response this was noted as explained in detail in the disaggregated results in Sections 6.1.1 to 6.1.8, particularly the explanation of drivers of the life cycle stages of influence for each impact category for the various HWS. The top five inventory reference flows contributing to impacts in Tables 7.1 to 7.5 in Appendix J.

Moreover the reason the mass and energy flows are detailed in the inventory, and as flow charts are not an ISO requirement, it has been decided not to include them as the combination of information detailed above is deemed adequate.

3.9 Results of life cycle impact assessment

The presentation of the process flow networks for five HWS's would have been generated by the Simapro software and these flow charts would have been useful to show in Scope 1, Scope 2 and Scope 3 of this LCA analysis.

We initially assumed you are talking about Scope 1, Scope 2 and Scope 3 greenhouse gas emissions; however you were referring to including network diagrams. In the base case this would mean including another 48 diagrams (12 HWS/ water use profile combinations, for 4 impact categories). This was the reason that the disaggregated results section (tables and graphs) was included, which showed what stages of the life cycle was driving impacts in each HWS for each impact category, including a further explanation as to the major influences of impacts within these life cycle stages (as observed on network diagrams on Simapro). This was chosen over network diagrams to simplify communication without compromising on detail relevant to the target audience.

Some results in the table have numbers and some are scientific. The report needs to standardise the decimal places used in the tables.

As previously stated, results are to 2 decimal places. Further clarification is noted that results over 1.00E+03 are represented in scientific notation, to keep the tables manageable, yet are still standardised to 2 decimal places

It appears that the HWS with solar water heater emits the lowest GHG emissions followed by gas and electric water heaters. The electricity mix in Victoria is brown coal dominated and therefore, it is logical to have this technological sequence in terms of GHG emissions. The large difference in GHG emissions between the central gas plant and CFEWH in the case of La Banque is reasonable as the emission factor for gas heating is expected to be half that of the Victorian electricity mix. However, there is a small difference in GHG emissions between the two HWSs in Brahe Place compared to La Banque , which requires further explanation.

This was noted as explained, both in the report completed by SAMME on TRNSYS modelling as per the pdf file MicroHeat_summary_of_TRNSYS_final.pdf, and a comment in Section 4.16.6 and the Conclusion in Section 6.4. The smaller building runs a larger load of standby energy (to keep the water hot at all times) in proportion *to the direct HWS energy used for any water draw off, thus making it less efficient overall as a system as the larger building.*

Further explanation is now included in Section 4.16.6. This draws attention to Brahe Place having less residents for average and high scenarios being smaller apartments (leading to lower water draw offs, making standby heating a higher proportion of these scenarios than La Banque), and the fact that Brahe Place has almost double the hot water pipe (12.5 m) to deliver hot water per apartment than La Banque (6.5 m) in the centralised HWSs, with the majority of these pipes of similar heat loss (10.4 - 14.1 W/m), resulting in more heat is lost in Brahe Place standby compared to La Banque (apart from 9% of pipes at 75 mm in La Banque losing 21.2 W/m).

Also, the incorporation of the solar collector in the central gas plant does not seem to save a reasonable amount of GHG emissions, which could also be investigated/ commented on.

This is due to the way the system operates, as explained in the report completed by SAMME on TRNSYS modelling as per the pdf file MicroHeat_summary_of_TRNSYS_final.pdf. The peak time of water use in not the peak time of solar gain for the system, and as such the solar contribution is not optimal. We have added this comment to Section 4.16.4.

Further explanation is now included in Section 4.16.4. Based on Melbourne solar gain potential, the solar contribution represents a small proportion of the energy required heat and maintain direct draw off hot water and standby around the Brahe Place centralised HWS4.

<u>Initial response – 17/05/13</u>

If Wahidul Biswas could review these responses and once satisfied with the ISO compliance of the report, please sign the front page of the final report (file *Life cycle assessment HWS peer review response.pdf*) and send it back via email to Simon Lockrey at simon.lockrey@rmit.edu.au as well as a letter or email confirming the ISO 14040/44 compliance has been achieved.

RMIT Centre for Design thanks Curtin University for such a thorough peer review that has added to the robustness and quality of this LCA.

3. Specific Comments

3.1 Goal

It appears from the review that the goal of this study is to assess the concomitant global warming impact, embodied energy, water use and solid waste production associated with the delivery of hot water for bathrooms by three different hot water systems for low and high density buildings. However, the noted goal of the research should be made clearer to understand and it is recommended the author revise the goal definition accordingly.

The goal has now been made more specific, and reads in Section 2.2:

The primary goal of this LCA study was to quantify and compare the potential environmental impacts of 5 HWSs within two chosen buildings, one medium density, the other high density, over the full life cycle.

In addition, whilst Simapro LCA software provides both higher and lower heating values, it needs to be explained further as to why the higher heating value has been excluded in this LCA analysis.

This has now been explained in Section 3.9 as follows:

Lower heating value (LHV) is used for cumulative energy demand in the Australian Impact Assessment Method, as well as many European Assessment Methods. LHV is appropriate as much of the systems assessed are not condensing the vapour from fuel combustion to reclaim the latent heat. This is appropriate for Australasian Unit Process LCI (AUPLCI), where the majority of the LCI is derived from.

3.2 Functional unit

The functional unit contradicts the system boundary as the functional unit did not mention the disposal stage whilst this stage has been included in the system boundary. It would be appropriate to state the production, delivery and disposal of the HWS associated with the production of hot water. It also may have been useful to have a functional unit that determines the impacts of the production and delivery of a cubic metre (m3) of hot water supplied. This would then help other researchers to use this data as generic data for calculating the carbon footprint of hot water systems use in high and low density buildings and to assist government policy support for renewable energy systems.

The functional unit in the executive summary and Section 3.2 has now been changed to the following to align with the system boundary:

"Hot water produced, delivered, used and disposed of by the typical apartment residents in a building over the course of 1 year at 50°C."

3.3 System boundary

The system boundary is well defined and appears to include all the relevant components, including pumps, pipes, heater and storage tank. The author also needs to discuss why the option with the solar collector has been excluded from the high density building.

This was excluded from the large building, as the base cases were defined by the engineering specification provided by Wood and Grieve (which included feasibility of HWS options within each building). Solar hot water was not included by Wood and Grieve as an option in the La Banque building. As solar hot water was provided as an option with gas heating in the Brahe Place building, a sensitivity analysis was conducted analysing the CFEWH with solar hot water.

3.4 Timeframe and geography

The lifetime of the HWS has been determined by a thorough literature review of both local and international studies. The hot water system has been developed to suit local conditions in Melbourne. The local ambient temperature has been considered to determine temperature the difference and heat losses for estimating the energy requirements of hot water demand in Melbourne. However, the average Australian hourly water load curve was used to calculate the total demand for hot water in Victoria. A Victorian water consumption curve could be used to estimate this demand more accurately. This point needs to be mentioned as a limitation in the analysis.

This is now noted at the end of Section 4.14.

3. 5 Indicators

The ISO standards require a comprehensive group of indicators for the product system under investigation. Electricity generation and any natural gas combustion will have significant impacts on GHG emissions and resource scarcity, which therefore makes global warming impact and embodied energy important indicators. The purpose of the HWS is only to convert cold water to hot water, and therefore, water use can only be considered as an additional indicator. It will be difficult to determine the 'hotspots' of HWS production unless regional and process specific data are available. The solid waste indicators work well when remanufacturing, reuse and recycled strategies are sufficiently incorporated into the LCA analysis.

We will treat this as a comment.

3. 6 Allocation

It needs to be made clearer as to what the goals of the project are. Is the amount of hot water estimated in this project only for bathroom hot water usage? Or has this hot water been estimated for the entire apartments use- in which case the impacts need to be allocated to specifically to hot water use in each utility area - laundry, kitchen and bathroom.

The primary goal of this LCA study was to quantify and compare the potential environmental impacts of 5 HWSs within two chosen buildings, one medium density, the other high density, over the full life cycle. The hot water has been allocated on an apartment and building level. Allocating to different utility areas of the apartments is outside the scope of the study, and contrary to the functional unit.

3. 7 Life cycle inventory

This section of the report covered material production, manufacturing, use and disposal stages quite sufficiently. Some suggestions are as follows:

The goal of this LCA was to quantify the environmental impacts of HWS's in certain scenarios and the functional unit was to determine the environmental impacts associated with the production and delivery of hot water at 50C to a typical apartment resident over 12 months. A booster pump was excluded from the LCA analysis on the grounds that the goal of the study was to compare HWS's and it was assumed all the HWS's use the same booster pump.

We will treat this as a comment.

This study considered hot water delivery to a bathroom but not the kitchens or laundry and yet the functional unit of this research was to determine the environmental impacts associated with the production and delivery of hot water of 50C to a typical apartment resident over the course of one year. This issue should be clarified further the goal and functional unit definitions.

It is, the delivery of water is to the apartments in the building, and not at a utility area level.

Also it needs to be explained more clearly why the kitchen (and also the washing machine) have been excluded as hot water is usually directly supplied to all end-uses in an apartment. The type of end-use appliances (e.g. shower head) that are used in the apartments need to be mentioned and also their efficiency as this may affect the calculation of the hot water supply. Although water consumption for the apartment has been generated from ABS and SQM data, it would have been useful to consider the variability of water usages associated with technological changes (e.g. smart shower head) using a related technology factor.
The delivery of water is to the apartments in the building, and not at a utility area or appliance level. It is therefore outside the scope to consider the suggestion here, although by modelling different use profiles for each building the variability of technology and appliance efficiency would be adequately covered. As a side note, most modern washing machines use cold water, and heat within the appliance, rather than be supplied directly with hot water.

The schematic diagram of the HWS needs referencing and a brief explanation is needed as to how this is relates to your inventory analysis. Perhaps a diagrammatic scheme of the HWS could be put in the appendix.

We want to keep these up front in the body of the report.

Some inputs such as the manufacturing process of materials have been excluded on the grounds that they contribute a very small percentage (e.g. 3%) of a particular impact. The aforementioned exclusion has to be acknowledged and or noted in the section on limitations. An explanation is needed on how the weight of different components has been measured?

We have not excluded any manufacturing/ materials. We stated in Section 4.7 is the following:

For any data derived from ecoinvent 2.2 where the materials are manufactured in a different region to Europe, it is assumed that production is similar globally so relative changes to the environmental impacts would be negligible. In addition to this, ***the combined materials and manufacturing processes (including replacement schedules over the building life) contributed no more than 3% of a particular impact category for both buildings in reference to the functional unit,*** *so it was* *deemed unnecessary to modify materials used by manufacturers from countries other than the sourced LCI data to reflect the electricity grid profiles of those regions.*

This was not referring to leaving out manufacturing/ materials, but not modifying the energy mix regionally for manufacturing/ materials that contributed less than 3% of a particular impact category.

The mass balance should show that the total weight of the HWS is equal to the mass of all components. The picture of an individual component with their weight and material type would be useful.

A mass balance is now in included in Tables 4.7 and 4.8 where the total mass of components in each HWS is added at the end of each inventory. Tables 4.7 and 4.8 detail every component, mass and all the materials specified or proxies for the LCI. A picture is not deemed necessary.

The CFEWH system excluded the use of a solar water heater. Reasons should be given to the reason why it has been excluded It also requires clarification as to whether the Brahe Place has sufficient roof and sun -light exposure area to generate heat from solar collectors?

This was excluded, as the base cases were defined by the engineering specification provided by Wood and Grieve (which included feasibility of HWS options within each building). Solar hot water was not included by Wood and Grieve as an option in the La Banque building. As solar hot water was provided as an feasible option with gas heating in the Brahe Place building, a sensitivity analysis was conducted analysing the CFEWH with solar hot water. Feasible solar gain modelling was completed by SAMME in the report on TRNSYS modelling as per the pdf file MicroHeat_summary_of_TRNSYS_final.pdf

It also would have been useful to discuss as to where there is any potential for designing a building structure to install a number of solar water heaters and whether water can be preheated before being heated by electric heaters?

We will treat this as a comment. Design suggestions are outside the scope of this study.

Emission data bases were used from AUPLCI. Is this the Australian Unit Process LCI? This point requires checking as to whether this should be referred to as the AusLCI (previously RMIT) databases, as these databases provide the emission factors of locally produced metals. Otherwise, if they were taken from CSIRO (Terry A Norgate's paper), then please reference accordingly.

It is the AUPLCI, as stated many times in the report.

In manufacturing LCA assessment double counting needs to be avoided. For example, cast iron has been included in the BoM (bill of materials), but is mentioned again in the manufacturing stage section. Please check this further.

There is no double counting, the reference to cast iron in Tables 4.7, 4.8, 4.9 and 4.10 clearly states that this unit process includes both the material and manufacturing, and as such is included in both tables but only once in the model.

In the case of manufacturing process, it will be useful to show the total weight of each system and, then to show how this mass has been broken down in terms of the individual components. It needs to be made clear how the breakdown of different processes has been done. It can be done a number of ways:

• By disassembling the system and then measuring the weight of the components
• By knowing the percentage of the total weight of each component using a literature review
• By interviewing manufacturers

This needs to be made clear in the report.

The method of data disaggregation is clearly defined in the first paragraph of both Section 4.7 and 4.8, as manufacturing data sources, direct manufacturer correspondence or estimated from the best component supplier literature source available. A mass balance is now in included in Tables 4.7 and 4.8 where the total mass of components in each HWS is added at the end of each inventory. Tables 4.7 4.8, 4.9 and 4.10 cover every component detail of mass and the materials or manufacturing specified or proxies for the LCI.

The assembling and testing stages are final processes in manufacturing but do not appear to be discussed in the report. Although these processes don't usually contribute significant impacts during the product life cycle, the exclusion of these processes should be noted as a limitation in the report.

This is now mentioned as an exclusion in Section 3.4.1 and Table 3-2.

The use stage mainly involves hot water supply but is not articulated clearly in the report. The main purpose of this section is to calculate the energy required to pump, heat and then to circulate water throughout the building. A few improvements to improve the clarity of the report:

I. Provide a separate formula for pumping and heating for each HWS option
2. Provide a complete calculation for each HWS showing how the energy for heating and pumping has been calculated.
3. Briefly discuss the following parameters using a sub-heading for each.
    a. Water demand (flow rate)
    b. Temperature difference
    c. Heat losses
        i. Pipe
        ii. Water tank

It needs to be shown clearly how these water losses have been incorporated into the formula.

All points (1, 2, 3a, 3b and 3c) are covered in the report completed by SAMME on TRNSYS modelling as per pdf file MicroHeat_summary_of_TRNSYS_final.pdf. 3b and 3c - i are covered in Section 4.16, and 3c – ii is covered in Sections 4.16.1 and 4.16.3.

It is strongly advised that the charts for the pump characteristics and heat loss Tables (4-7, 4-8,4-9,4-11,4-12,4-16, 4-17) are removed from the report and included in the appendix instead, as these figures are making the section unnecessarily unwieldy.

The charts have been moved. The tables remain as is as all of these are direct LCI data sets or relevant to the LCI data.

It would also be useful to have a separate table showing various heat losses (piping and water tank) and pumping energy demand for the five HWS options.

This is all detailed in the report completed by SAMME on TRNSYS modelling as per the pdf file MicroHeat_summary_of_TRNSYS_final.pdf.

Tables 4-44 and 4-45 are the only tables considered essential for this LCI section.

We will treat this as a comment.

The replacement of parts is another activity during the use stage which has been discussed in the report. It would have useful to have a table showing what amount (kg) and what type of materials (e.g. copper) have been considered to have been replaced.

Tables 4.7 4.8, 4.9 and 4.10 cover every component detail of mass and the materials or manufacturing specified or proxies for the LCI. Table 4.12 identifies what the replacement schedules are for each of the components, which can be related back to materials if required by the reader. Section 6.2.3 also explores a sensitivity study that tests if these replacement schedules have any major influence on the results if they are increased. They don't, apart from solid waste in the smaller building.

A decrease in the heating load due to climatic change could also have been taken into account in order to determine the future energy consumption of the water heating. A similar sort of study has been presented in a study by Guan (2009). Implication of global warming on air-conditioned office buildings in Australia. It may be beyond the scope of this research to consider this issue, but perhaps it could be included in the use section of the LCI.

We will treat this as a comment, but agree this is outside the scope of this study.

3.8 Mass and energy balance

It would have been useful to show five inventory flow charts for 5 HWS options with each flow chart showing the quantitative values of energy, chemicals and metals for four stages of the life cycle of the production and delivery of hot water at 50C to an apartment. It is not suggested to have a detailed breakdown of the components (i.e. metals) for this type of inventory flow chart, but at least display the main components in the flow chart. It helps the reader to relate how energy and materials associated with hot water delivery are causing different impacts.

This is explained in detail in the disaggregated results in Sections 6.1.1 to 6.1.8, particularly the explanation of drivers of the life cycle stages of influence for each impact category for the various HWS. We have however now included the top five inventory reference flows contributing to impacts in Tables 7.1 to 7.5 in Appendix J

3.9 Results of life cycle impact assessment

The presentation of the process flow networks for five HWS's would have been generated by the Simapro software and these flow charts would have been useful to show in Scope 1, Scope 2 and Scope 3 of this LCA analysis.

We assume you are talking about Scope 1, Scope 2 and Scope 3 greenhouse gas emissions. This is implicit in the Australian Impact Assessment Method, which includes the full fuel cycle with scope 1 and 3 and scope 2 and 3 emissions. We do not disaggregate these emission types because it is not relevant for the intended audience of the report.

Some results in the table have numbers and some are scientific. The report needs to standardise the decimal places used in the tables.
Results or calculation are to decimals are to 2 decimal places unless less precise in which they have less decimals. Some third party data is to more or less decimals than this, but provided in the form as per the reference.

Global warming impact is typically represented as kg or tonne C02 equivalent or kg C02 -e. In this report, it is written that the global impact potential is kg C02, which needs to be corrected.

This has been corrected to kg C02 equivalent or kg C02 –e.

The disaggregated results for each of the four impacts were useful as they highlighted which stage is causing the most impact. The LCA has produced expected results in that the use stage accounts for a significant proportion of the total emissions. The same type of results has been obtained for other products (e.g. machinery, infrastructure) unless renewable energy has been used during the use stage.

We will treat this as a comment.

It appears that the HWS with solar water heater emits the lowest GHG emissions followed by gas and electric water heaters. The electricity mix in Victoria is brown coal dominated and therefore, it is logical to have this technological sequence in terms of GHG emissions. The large difference in GHG emissions between the central gas plant and CFEWH in the case of La Banque is reasonable as the emission factor for gas heating is expected to be half that of the Victorian electricity mix. However, there is a small difference in GHG emissions between the two HWSs in Brahe Place compared to La Banque , which requires further explanation.

This is explained, both in the report completed by SAMME on TRNSYS modelling as per the pdf file MicroHeat_summary_of_TRNSYS_final.pdf, and a comment in Section 4.16.6 and the Conclusion in Section 6.4. The smaller building runs a larger load of standby energy (to keep the water hot at all times) in proportion to the direct HWS energy used for any water draw off, thus making it less efficient overall as a system as the larger building.

Also, the incorporation of the solar collector in the central gas plant does not seem to save a reasonable amount of GHG emissions, which could also be investigated/ commented on.

This is due to the way the system operates, as explained in the report completed by SAMME on TRNSYS modelling as per the pdf file MicroHeat_summary_of_TRNSYS_final.pdf. The peak time of water use in not the peak time of solar gain for the system, and as such the solar contribution is not optimal. We have added this comment to Section 4.16.4.

It is interesting to see that some stages produce more impacts under average use conditions than under high use conditions. For example, the cumulative energy demand (936.98 MJ) of material productions for HWS-5 under average use conditions was higher than (926 MJ) under high use conditions. These results require further explanation.
This was an error and has been resolved. Some minor flows were incorrectly apportioned to the materials, production and transport, and the auxiliary heating energy for the CFEWHs, and now these impacts are unified for each HWS in each impact category. All disaggregated tables and graphs were updated. In this process it was also noted that the manufacturing and materials for the solar pant had been omitted from the impact assessment for HWS4, and as such, all of the results tables and graphs for Brahe place were adjusted, but no directional results changed (as it had such a small contribution overall).

In the case of sensitivity analysis, the global warming impacts have varied across states due to differences in the emission factors. It would have been interesting if the comparison had been made with the HWS's in Tasmania, because around 70% of the electricity in this state is generated from hydropower. It is interesting to see that the cumulative energy demand for the South Australian case was the lowest compared to other states and perhaps the reasons for this could be noted.

We will treat this as a comment.

This LCA shows that the reduction in the number of replacements of HWS components does not seem to change the GHG emissions and embodied energy consumption significantly, which is largely because the material production and manufacturing stages accounted for a very small share (around 5%) of these impacts. Other than a replacement reduction strategy, a remanufacturing option could also be considered as a potential option which would significantly reduce the solid waste impact.

We will treat this as a comment.

In summary, the results obtained in this LCA work are interesting but would be of more value with further methodological review as noted in this report.

We will treat this as a comment.

It may also be worth noting that at least a few results from other global warming and embodied energy LCA assessments to context these results may also add further salience to the analysis.

As noted in the report, there are almost no published LCA studies with direct relevance where the whole hydraulic system of hot water delivery are modelled for medium and higher density residential buildings. The one noted in Section 6.3 (Crawford and Treloar 2004) had similarities but still marked differences in context. This is stated as a limitation.

3.10 Data quality assessment

There is no formal data quality assessment provided in the report. This assessment may be made quantitative by using uncertainty assessment, such as *Monte Carlo* simulation, which is available in the Simapro software.

This is included in Section 4.19 and Table 4-50 quantitatively as required by the ISO standard. There is no Monte Carlo analysis, but adequate sensitivity analyses to test the validity and quality of data along with this qualitative data quality assessment.

3.11 Conclusions

The conclusions are supported by the data in the LCA, and sensitivity analysis gives a very good overview of some of the important parameters in the study.

We will treat this as a comment.

4. References

References need to be thoroughly checked as some important references are missing such as AUPLCI, Norgate, ecoinvent etc.

Although we have included direct literature references in the LCI of data provenance within LCI databases AUPLCI and Ecoinvent, we deem it adequate to refer to the top level databases in the references as per Section 7.1.

Bibliography

Crawford, R. H. and G. J. Treloar (2004). "Net energy analysis of solar and conventional domestic hot water systems in Melbourne, Australia." Solar Energy **76**: 159–163.

Curtin University

Peer review of

Life Cycle Assessment Hot Water Delivery

LCA practitioner: Simon Lockrey, Centre for Design, RMIT

Peer review by: Wahidul Biswas and Michele Rosano

10th May 2013

1. The brief

The Sustainable Energy Group, Curtin University was asked to undertake a peer review of a life cycle assessment of Hot Water Delivery which was completed by the Centre for Design, RMIT.

The LCA was assessed against the international LCA standards ISO 14040 Principles and Framework (International Organization for Standardization 2006) and Requirements and Guidelines (International Organization for Standardization 2006).

2. General comments

The report provides a very useful analysis of the LCA results of three different hot water systems for five scenarios, two of them for low density apartments and three of them for high density apartments with reasonable quality data on the project. The methodology has used the five steps of ISO 14040-44 guidelines. A number of recommendaitons are made to the report to improve its readability and the salience of the analysis . Some sections of the report require clarification and other areas further explanation together with a grammatical edit before the final submission.

3. Specific Comments

3.1 Goal

It appears from the review that the goal of this study is to assess the concomitant global warming impact, embodied energy, water use and solid waste production associated with the delivery of hot water for bathrooms by three different hot water systems for low and high density buildings. However, the noted goal of the research should be made clearer to understand and it is recommended the author revise the goal definition accordingly.

In addition, whilst Simapro LCA software provides both higher and lower heating values, it needs to be explained further as to why the higher heating value has been excluded in this LCA analysis.

3.2 Functional unit

The functional unit contradicts the system boundary as the functional unit did not mention the disposal stage whilst this stage has been included in the system boundary. It would be appropriate to state the production, delivery and disposal of the HWS associated with the production of hot water. It also may have been useful to have a functional unit that determines the impacts of the production and delivery of a cubic metre (m^3) of hot water supplied. This would then help other researchers to use this data as generic data for calculating the carbon footprint of hot water systems use in high and low density buildings and to assist government policy support for renewable energy systems.

3.3 System boundary

The system boundary is well defined and appears to include all the relevant components, including pumps, pipes, heater and storage tank. The author also needs to discuss why the option with the solar collector has been excluded from the high density building.

3.4 Timeframe and geography

The lifetime of the HWS has been determined by a thorough literature review of both local and international studies. The hot water system has been developed to suit local conditions in Melbourne. The local ambient temperature has been considered to determine temperature the difference and heat losses for estimating the energy requirements of hot water demand in Melbourne. However, the average Australian hourly water load curve was used to calculate the total demand for hot water in Victoria. A Victorian water consumption curve could be used to estimate this demand more accurately . This point needs to be mentioned as a limitation in the analysis.

3.5 Indicators

The ISO standards require a comprehensive group of indicators for the product system under investigation. Electricity generation and any natural gas combustion will have significant impacts on GHG emissions and resource scarcity, which therefore makes global warming impact and embodied energy important indicators. The purpose of the HWS is only to convert cold water to hot water, and therefore, water use can only be considered as an additional indicator. It will be difficult to determine the 'hotspots' of HWS production unless regional and process specific data are available. The solid waste indicators work well when remanufacturing, reuse and recycled strategies are sufficiently incorporated into the LCA analysis.

3.6 Allocation

It needs to be made clearer as to what the goals of the project are. Is the amount of hot water estimated in this project only for bathroom hot water usage? Or has this hot water been estimated for the entire apartments use- in which case the impacts need to be allocated to specifically to hot water use in each utility area - laundry, kitchen and bathroom.

3.7 Life cycle inventory

This section of the report covered material production, manufacturing, use and disposal stages quite sufficiently. Some suggestions are as follows:

The goal of this LCA was to quantify the environmental impacts of HWS's in certain scenarios and the functional unit was to determine the environmental impacts associated with the production and delivery of hot water at 50°C to a typical apartment resident over 12 months. A booster pump was excluded from the LCA analysis on the grounds that the goal of the study was to compare HWS's and it was assumed all the HWS's use the same booster pump.

This study considered hot water delivery to a bathroombut not the kitchens or laundry and yet the the functional unit of this research was to determine the environmental impacts associated with the production and delivery of hot water of 50°C to a typical apartment resident over the course of one year. This issue should be clarified further the goal and functional unit definitions. Also it needs to be explained more clearly why the kitchen (and also the washing machine) have been excluded as hot water is usually directly supplied to all end-uses in an apartment. The type of end-use appliances (e.g. shower head) that are used in the apartments need to be mentioned and also their efficiency as this may affect the calculation of the hot water supply. Although water consumption for the apartment has been generated from ABS and SQM data, it would have been useful to consider the variability of water usages associated with technological changes (e.g. smart shower head) using a related technology factor.

The schematic diagram of the HWS needs referencing and a brief explanation is needed as to how this is relates to your inventory analysis. Perhaps a diagrammatic scheme of the HWS could be put in the appendix.

Some inputs such as the manufacturing process of materials have been excluded on the grounds that they contribute a very small percentage (e.g. 3%) of a particular impact.The aforementioned exclusion has to be acknowledged and or noted in the section on limitations. An explanation is needed on how the weight of different components has been measured? The mass balance should show that the total weight of the HWS is equal to the mass of all components. The picture of an individual component with their weight and material type would be useful.

The CFEWH system excluded the use of a solar water heater. Reasons should be given to the reason why it has been excluded It also requires clarification as to whether the Brahe Place has sufficient roof and sun –light exposure area to generate heat from solar collectors?. It also would have been useful to discuss as to where there is any potential for designing a building structure to install a number of solar water heaters and whether water can be preheated before being heated by electric heaters?.

Emission data bases were used from AUPLCI. Is this the Australian Unit Process LCI? This point requires checking as to whether this should be referred to as the AusLCI (previously RMIT) databases, as these databases provide the emission factors of locally produced metals. Otherwise, if they were taken from CSIRO (Terry A Norgate's paper), then please reference accordingly.

In manufacturing LCA assessment double counting needs to be avoided. For example, cast iron has been included in the BoM (bill of materials), but is mentioned again in the manufacturing stage section.Please check this further.

In the case of manufacturing process, it will be useful to show the total weight of each system and , then to show how this mass has been broken down in terms of the individual components. It needs to be made clear how the breakdown of different processes has been done. It can be done a number of ways:

- By disassembling the system and then measuring the weight of the components
- By knowing the percentage of the total weight of each component using a literature review
- By interviewing manufacturers

This needs to be made clear in the report.

The assembling and testing stages are final processes in manufacturing but do not appear to be discussed in the report. Although these processes don't usually contribute significant impacts during the product life cycle, the exclusion of these processes should be noted as a limitation in the report.

The use stage mainly involves hot water supply but is not articulated clearly in the report. The main purpose of this section is to calculate the energy required to pump, heat and then to circulate water throughout the building. A few improvements to improve the clarity of the report:

1. Provide a separate formula for pumping and heating for each HWS option
2. Provide a complete calculation for each HWS showing how the energy for heating and pumping has been calculated.
3. Briefly discuss the following parameters using a sub-heading for each.
    a. Water demand (flow rate)
    b. Temperature difference
    c. Heat losses
        i. Pipe
        ii. Water tank

It needs to be shown clearly how these water losses have been incorporated into the formula.

It is strongly advised that the charts for the pump characteristics, heat loss and heat loss Tables (4-7, 4-8, 4-9, 4-11, 4-12, 4-16, 4-17) are removed from the report and included in the appendix instead, as these figures are making the section unnecessarily unwieldy.

It would also be useful to have a separate table showing various heat losses (piping and water tank) and pumping energy demand for the five HWS options.

Tables 4-44 and 4-45 are the only tables considered essential for this LCI section.

The replacement of parts is another activity during the use stage which has been discussed in the report. It would have useful to have a table showing what amount (kg) and what type of of materials (e.g. copper) have been considered to have been replaced.

A decrease in the heating load due to climatic change could also have been taken into account in order to determine the future energy consumption of the water heating. A similar sort of study has been presented in a study by Guan (2009).Implication of global warming on air-conditioned office buildings in Australia.It may be beyond the scope of this research to consider this issue, but perhaps it could be included in the use section of the LCI.

3.8 Mass and energy balance

It would have been useful to show five inventory flow charts for 5 HWS options with each flow chart showing the quantitative values of energy, chemicals and metals for four stages of the life cycle of the production and delivery of hot water at 50 ℃ to an apartment. It is not suggested to have a detailed breakdown of the components (i.e. metals) for this type of inventory flow chart, but at least display the main components in the flow chart . It helps the reader to relate how energy and materials associated with hot water delivery are causing different impacts.

3.9 Results of life cycle impact assessment

The presentation of the process flow networks for five HWS's would have been generated by the Simapro software and these flow charts would have been useful to show in Scope 1, Scope 2 and Scope 3 of this LCA analysis.

Some results in the table have numbers and some are scientific. The report needs to standardise the decimal places used in the tables.

Global warming impact is typically represented as kg or tonne CO_2 equivalent or kg CO_2 – e. In this report, it is written that the global impact potential is kg CO_2 , which needs to be corrected.

The disaggregated results for each of the four impacts were useful as they highlighted which stage is causing the most impact. The LCA has produced expected results in that the use stage accounts for a significant proportion of the total emissions. The same type of results has been obtained for other products (e.g. machinery, infrastructure) unless renewable energy has been used during the use stage.

It appears that the HWS with solar water heater emits the lowest GHG emissions followed by gas and electric water heaters. The electricity mix in Victoria is brown coal dominated and therefore, it is logical to have this technological sequence in terms of GHG emissions. The large difference in GHG emissions between the central gas plant and CFEWH in the case of La Banque is reasonable as the emission factor for gas heating is expected to be half that of the Victorian electricity mix. However, there is a small difference in GHG emissions between the two HWSs in Brahe Place compared to La Banque , which requires further explanation. Also, the incorporation of the solar collector in the central gas plant does not seem to save a reasonable amount of GHG emissions, which could also be investigated/commented on.

It is interesting to see that some stages produce more impacts under average use conditions than under high use conditions. For example, the cumulative energy demand (936.98 MJ) of material productions for HWS-5 under average use conditions was higher than (926 MJ) under high use conditions. . These results require further explanation.

In the case of sensitivity analysis, the global warming impacts have varied across states due to differences in the emission factors. It would have been interesting if the comparison had been made with the HWS's in Tasmania, because around 70% of the electricity in this state is generated from hydropower. It is interesting to see that the cumulative energy demand for the South Australian case was the lowest compared to other states and perhaps the reasons for this could be noted.

This LCA shows that the reduction in the number of replacements of HWS components does not seem to change the GHG emissions and embodied energy consumption significantly, which is largely because the material production and manufacturing stages accounted for a very small share (around 5%) of these impacts. Other than a replacement reduction strategy, a remanufacturing option could also be considered as a potential option which would significantly reduce the solid waste impact.

In summary, the results obtained in this LCA work are interesting but would be of more value with further methodological review as noted in this report. It may also be worth noting that at least a few results from other global warming and embodied energy LCA assessments to context these results may also add further salience to the analysis.

3.10 Data quality assessment

There is no formal data quality assessment provided in the report. This assessment may be made quantitative by using uncertainty assessment, such as *monte carlo* simulation, which is available in the Simapro software.

3.11 Conclusions

The conclusions are supported by the data in the LCA, and sensitivity analysis give a very good overview of some of the important parameters in the study.

4. References

References need to be thoroughly checked as some important references are missing such as AUPLCI, Norgate, ecoinvent etc.

Regards

Wahidul Biswas

Date....10/05/2013

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24th of May 2013

Dear Simon,

Thanks for sending the revised version of the report entitled, "Life Cycle Assessment Hot Water Delivery" that we have received after the peer reviewing process.

We recognize this work as a comprehensive LCA analysis in the area of utilities and thermal engineering. This work will undoubtedly contribute to the Australian LCA literature.

We have signed this report and trust that the author will incorporate following comments in the peer review report as they were not addressed in the revised report.

3.2 Functional unit – comment 2
3.4 Timeframe and geography
3.8 Mass and energy balance
3.9 Results of life cycle impact assessment – comments 1, 2, 5, 6

We have numbered the comments in the attached review report for author's convenience.

Please feel free to contact us for any clarifications.

Kind regards

Wahidul Biswas
On behalf of the reviewing team