Australian National University

ENGN2225 – Systems Engineering Design

Research Portfolio

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Reduce Ongoing Household Electricity Bills

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Prepared to improve the life of a local Canberra resident

Abstract

The overall electricity costs for Australian consumers are expected to increase in 2017/18 and continue to do so into the future (AEMC 2015, pp. 46-82). This portfolio takes a system engineering design approach to advise a local Canberra resident in relation to reducing their ongoing electricity bills. The design approach taken consists of an eight stage design cycle that looks to determine, then communicate the most effective solution.

The eight stages, along with the various analysis techniques used at each stage were:

- Needs and Opportunities – 'problem framing', 'desktop research' and 'field plan & interviews'
- Problem Scoping – 'journey mapping', 'stakeholder analysis' and 'system boundary chart'
- Idea Generation – 'structured brainstorming' and 'concept generation'
- Requirements Analysis – 'pairwise analysis' and 'house of quality'
- Logic & Functional Analysis – 'logical flow diagram' and 'functional flow block diagram'
- System Architecture – 'subsystem interface'
- Testing, Validation & Evaluation – 'unit testing' and 'evaluation matrix'
- Design Communication – 'Delivery and Roadmap'

The three main ideas investigated to reduce the electricity bills were solar generation, battery storage and reduced consumption. Battery storage provided greater flexibility in electricity usage, but the replacement costs proved too out way any benefits. The most effective solution for the resident was found to be installing a 3kW solar PV system with further consideration in relation to do-it-yourself double glazing for the household windows to reduce electricity consumption.

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1. Introduction

Distributed generation (DG) technologies have provided Australian consumers with greater choice to meet their household electricity needs and potentially stem the ever increasing cost of electricity. This along with amendments to Australian National Electricity Rules (NER) and regulations have increased pressure on Distribution Network Service Providers (DNSP) to reduce/minimise electricity network costs to the Australian consumer (AEMC 2015). As a result network costs for State and Territories in the National Electricity Market (NEM) have fallen but, as with the other Australian State and Territories, falling network costs and in turn the overall electricity costs, are not able to be sustained. The overall electricity costs for Australian consumers are expected to increase in 2017/18 and continue to do so into the future (AEMC 2015, pp. 46-82).

This portfolio takes a system engineering design approach to advise a local Canberra resident in relation to reducing their ongoing electricity bills. Initially, the resident requested advice on residential solar and battery systems as they were considering investing to offset their ongoing electricity costs. The design approach taken to advise the resident consists of an eight stage design cycle that looks to determine, then communicate the most effective solution for the identified need and opportunity.

The eight stages, along with the various analysis techniques used at each stage, to identify and assess potential solutions were:

- Needs and Opportunities – 'problem framing', 'desktop research' and 'field plan & interviews'
- Problem Scoping – 'journey mapping', 'stakeholder analysis' and 'system boundary chart'
- Idea Generation – 'structured brainstorming' and 'concept generation'
- Requirements Analysis – 'pairwise analysis' and 'house of quality'
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- Design Communication – 'Delivery and Roadmap'

2. Needs and Opportunities

The first stage of the design cycle was to determine the 'Needs & Opportunities' based on the initial request from a local Canberra resident. To achieve this, problem framing, desktop research, as well as field planning and interview analysis techniques were employed to obtain a greater understanding and clarification of the actual needs and opportunities.

2.1. Problem Framing and Desktop Research

Framing the initial request as an opportunity shifted the attention away from the resident's initial interest in solar and battery systems, focusing on the need that lead them to consider these systems in the first place. This was achieved by turning the problem into a How Might We … statement:

How might the Canberra resident reduce their ongoing household electricity costs?

Problem framing along with desktop research to obtain a greater understanding of the needs and opportunities available, painted a clearer picture before interviewing the Canberra resident to verify the customer requirements.

2.2. Field Plan and Interviewing

Prior to conducting an interview with the resident, to confirm the needs and opportunities a field plan was completed. This ensured the questions posed to the resident were open-ended allowing the actual needs and opportunities to be determined, as well as assisting in verifying the customer requirements.

The customer requirements resulting from the interview were:

- Lower electricity bills;
- Retain existing reliability of supply (electricity);
- Affordable;
- Minimal impact on day-to-day living; and
- Unobtrusive.

These requirements formed the basis for further investigation and analysis of potential design solutions for the portfolio.

3. Problem Scoping

Once the needs and opportunities were determined, the scope of the problem / opportunity was defined, to ensure it is manageable and able to be investigated and analysed within the available timeframe. The problem scoping techniques used to define the scope for the portfolio were journey mapping, stakeholder analysis, as well as a system boundary chart, all completed keeping in mind the information obtained earlier through the resident interview and desktop research. Results from these techniques assisted to firm up the customer requirements initially obtained from the Canberra resident.

3.1. Journey Mapping

Major components of the electricity system within the household were identified using the journey mapping technique (refer to figure 1). This enabled a greater understanding of the household electricity system to be obtained along with how electricity is typically being consumed by residents within the household.

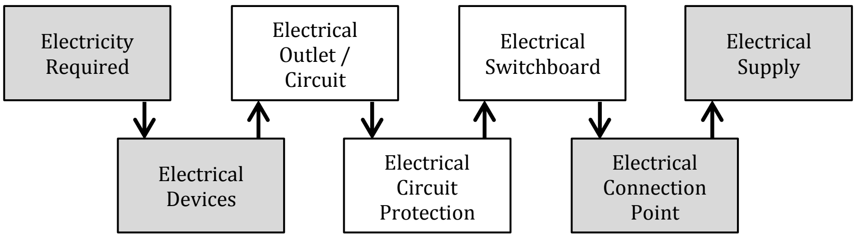


Figure 1: Household Electricity Journey Map

Four main areas were highlighted as potential for reducing the household electricity costs: one being ‘Electricity Required’ and the other three being ‘Electricity Devices’, ‘Electricity Connection Point’ and ‘Electricity Supply. Identifying these areas assisted in refining the system boundaries for the portfolio, ensuring it was manageable and able to be investigated and analysed within the available timeframe.

3.2. Stakeholder Analysis

Stakeholder analysis was conducted to obtain an understanding of the key stakeholders and how they interact with one another and the design opportunity. This was achieved by firstly producing a mud map to identify the stakeholders and their relationships between one another. These stakeholders were arranged to determine which stakeholders had the most influence on reducing the household electricity bills using the influence verses importance map (refer to figure 2).

	Low Importance	High Importance
High Influence	Federal / State Government Solar Panel Manufacturer / Supplier Battery System Manufacturer / Supplier Australian Energy Regulator (AER)	The Canberra Resident Household members Distribution Network Service Provider (DNSP) - ActewAGL
Low Influence	Finance Companies Local Government Builders / Electricians Electrical wholesaler	Household Visitors

Figure 2: Stakeholder Analysis – Influence-Importance Map

As can be seen in figure 2, the main stakeholders that are able to influence the outcome were the manufacturers / suppliers, government, ActewAGL as well as the AER and members of the household. On the other hand the highest importance, were limited to the members of the household and ActewAGL.

3.3. System Boundary Chart

To assist in defining the scope of the portfolio, a system boundary chart was created dividing the components that influence the household electrical system into three categories, internal, external and excluded. This was an essential step that provided a method to establish the boundaries for the investigation and analysis.

The three categories were:

i) 'Internal', included and able to be controlled;

ii) 'External', included but not able to be controlled; and

iii) 'Excluded', relevant but not included in the investigation / analysis.

Table 1: System Boundary Mapping Chart

Internal	External	Excluded
▪ Residential distributed generation ▪ Household electricity connection ▪ Household electricity switchboard ▪ Household typical electricity usage ▪ Household energy efficiency (windows, doors, walls, etc)	▪ Cost of distributed generation ▪ Distribution electricity network ▪ Electricity network costs ▪ Electricity retail price ▪ Household members ▪ ACT government solar schemes ▪ Australian government solar schemes	▪ Climate ▪ Weather effect on generation ▪ Electricity wholesale price ▪ Household main building structure ▪ Household electricity wiring ▪ Household electrical devices ▪ Household maintenance ▪ Government regulations ▪ External finance ▪ Extra electricity usage (e.g. visitors) ▪ Third party funded distributed generation ▪ Local Council development approvals

Internal components identified as directly influencing the household electrical system were related to the areas highlighted in the journey mapping analysis, with the exception of electrical devices. All of these components provide significate opportunities to reduce the overall household electricity costs through modifying the household electricity demands and/or providing residential distributed generation.

Similarly, the external components were also related to the areas highlighted in the journey mapping analysis. Some examples being the ‘distribution electricity network’, which provides the existing electricity supply to the household, ‘electricity network costs’ charged by the local Distribution Network Service Provider (DNSP) and set by the Australian regulator, and ‘household members’, which were assumed to be creatures of habit. All of the ‘external’ components detailed in table 1 influence the household electrical system, therefore need to be considered throughout the design process, but as stated earlier they were not able to be controlled.

Excluded components identified, either did not provided a significate opportunity to reduce the overall household electricity costs and/or were deemed to be outside the boundaries of the portfolio. One example is ‘household electrical devices”, such as fridges, electric hotwater systems, etc., which would impact the electricity costs (Resource & Energy 2014), but were identified as energy efficient devices during the initial interview with the Canberra resident. As a result, ‘household electrical devices’ were excluded – no significate opportunity to reduce the overall household electricity costs. Excluding components based on the resident interview, desktop research, as well as other constraints imposed by the portfolio, was necessary to ensure that a viable solution was able to be determined within the available timeframe.

4. Idea Generation

As stated earlier, a number of ideas had already been mentioned by the resident, but they were by no means the only possibilities (McGee 2013). There are a wide variety of solutions known to reduce electricity costs, but again, limiting the focus of the portfolio to commonly known solutions removes the opportunity for other creative and innovative ideas, which may in fact be the most effective at addressing the customer requirements. Therefore, to ensure that the most effective solutions were not overlooked, structured brainstorming techniques were paired with concept generation to generate and classify ideas that would potentially address the design opportunity.

4.1. Structured Brainstorming

Structured brainstorming enabled a broad range of ideas to be generated for the design opportunity by answering a simple question. How might we reduce ongoing household electricity costs? To ensure a diverse range of ideas were generated, hypothetical constraints were considered, such as limited/unlimited funds, change/‘no change’ to the building structure and limited/unlimited technology. Generating ideas by adding/removing constraints allowed the opportunity to be considered from a number of directions, generating ideas based on the desktop research, whilst not excluding other creative and innovative solutions. Structured brainstorming highlighted three main themes: reduce consumption; electricity generation and energy storage.

4.2. Concept Generation

Structured brainstorming identified more ideas than were able to be evaluated, therefore it became necessary to classify them, to single out the most promising concepts. This was achieved by creating a concept generation tree, grouping similar ideas together, and then mapping them out to form the various branches. Less promising concepts / ideas were then removed based on the customer requirements and previous desktop research resulting the concept tree detailed in figure 3.

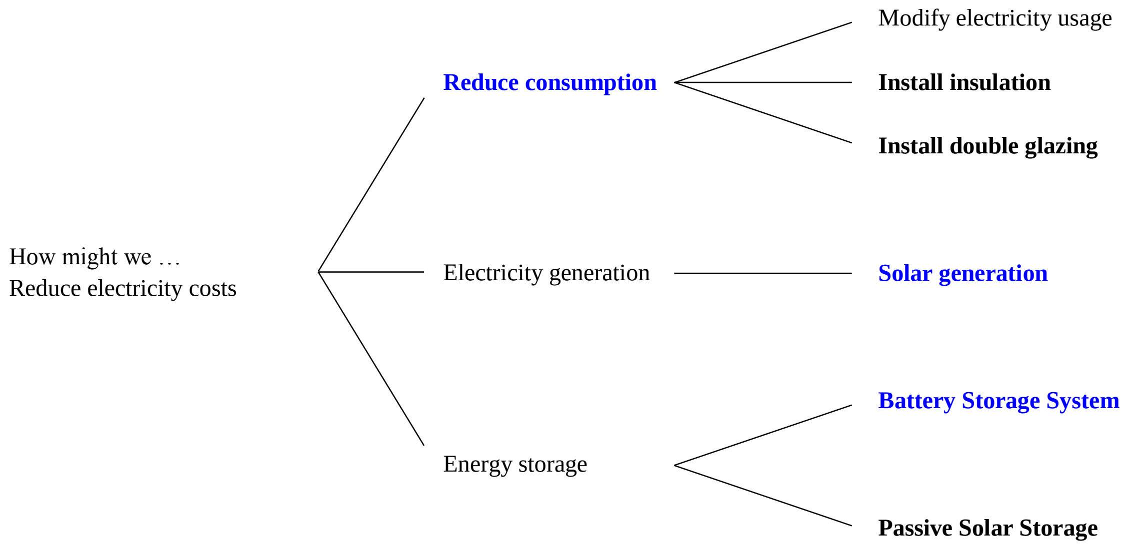


Figure 3: Concept classification tree

Three concepts / ideas were identified as more promising than the others in addressing the design opportunity for the Canberra resident. These three were: solar generation, battery storage system and reduced consumption, consisting of multiple ideas including installing insulation, replacing window panels with double glazing and passive solar storage.

Solar Generation

For the purpose of this portfolio, solar generation refers to a residential grid connected solar PV system. Based on the most recent ActewAGL annual planning report, there are already 15,717 households connected to the ActewAGL network taking advantage of solar generation. The average size PV system connected to the network is 3kW, with a combined installed capacity of 46.8MW (ActewAGL 2015, pp. 63).

The proposed PV panels to be analysed for the local Canberra resident would be north facing with a tilt angle of approximately 20 degrees and a maximum surface area of around 40m^2 (i.e. available north facing roof space is approximately 11m wide by 4.4m). These details are based on installing the PV system on the resident's existing tiled roof with minimal to no alterations. Any unused electricity produced by the proposed PV system is assumed to be purchased by ActewAGL based on their present feed-in tariff.

Battery Storage

The potential battery storage solution is to be considered in isolation as well as combined with grid connected solar generation solution to meet the household electricity demands. Although there are a number of batteries systems available, the portfolio focused on the recently released Tesla Powerwall 6.4kWh system retailing for approximately $12,000 (Doyle & Barnes 2016). This system is assumed to have a maximum expected lifespan of 15 years.

Reduced Consumption

The reduced household electricity consumption concept combines multiple ideas to reduce the overall electricity consumption, which in turn, reduces the household overall cost of electricity. The ideas considered as part of the portfolio were: installing wall insulation, replacing window panels with double glazing and identifying opportunities for passive solar storage. All of these ideas attempt to reduce the energy required for heating & cooling, which, with the exception of hot water, are the major contributors to household energy use (McGee 2013; Resource & Energy 2014). Other ideas, such as draught proofing doors & windows and replacing the hot water system and/or household electrical appliances, were excluded from the portfolio as the resident had previously addressed these areas.

5. Requirement Analysis

To enable potential ideas to be compared against one another, as well as confirming whether they meet the identified needs and opportunities, a number of requirements analysis techniques were applied. Firstly, design priorities were identified using pairwise analysis, ranking the five customer requirements. Then, technical performance measures were established by determining relevant design requirements along with associated metrics, to enable further analysis to be conducted later in the design cycle. Finally, house of quality, a form of requirements mapping, was utilised to analyse, organise and compare the design requirements that were determined.

5.1. Pairwise Analysis

The five customer requirements were ranked using the pairwise technique to remove any ambiguity between the importance of each requirement. This enabled a weighted average to be assigned to each requirement, providing greater ability to assess potential ideas later on in the design cycle. Another, valuable outcome of the comparison was identifying that lower electricity bills was not the most important requirement, only ranking third in the order of importance. The most important requirement, was found to be retaining the existing reliability of supply presently maintained by ActewAGL, the resident's DNSP.

Table 2: Pairwise analysis of customer requirements

	(LB)	(ER)	(A)	(MI)	(U)	Sum	Rank
1. Lower electricity bills (LB)		0	0	1	1	2	3
2. Retain existing reliability of supply (ER)	1		1	1	1	4	1
3. Affordable (A)	1	0		1	1	3	2
4. Minimal impact on day-to-day living (IL)	0	0	0		1	1	4
5. Unobtrusive (U)	0	0	0	0		0	5

5.2. Technical Performance Measures

Each of the five customer requirements determined from discussions Canberra resident and desktop research, were translated into measureable design requirements (refer to table 2). This was performed to develop technical performance measures to enable further analysis to be conducted later in the design cycle. Determining measurable design requirement and relevant metrics, play a key role in comparing ideas against one another, as well as confirming whether they meet the requirements or not.

One example being, the customer requirement to 'retain existing reliability of supply (electricity)'. This was translated into three measurable requirements with the metrics based on the requirements maintained by the resident's existing local DNSP, ActewAGL (ActewAGL 2015, pp. 28 & 40). These are essential criteria, which if not met, would not address the customer requirements.

The remaining four customer requirements were translated into a another eight measurable design requirements, which collectively enable the ideas generated to be tested, validated and evaluated against one another, as well as the requirements themselves.

Table 3: Customer and Design Requirements

Customer Requirements	Design Requirements	Metric	Direction	Target
1. Lower electricity bills	1.1. Distribution network electricity usage	kWh/year	Down	-
2. Retain existing reliability of supply (electricity)	2.1. Steady State Voltage	Volts	Steady	216.2 - 253 [(1)]
	2.2. Time without electricity	mins/year	Down	91 [(1)]
	2.3. Frequency of electricity outages	No.	Down	1.2 [(1)]
3. Affordable	3.1. Capital investment	$	Down	≤ 5000 [(2)]
	3.2. Ongoing maintenance cost	$/year	Down	≤ 50 [(2)]
	3.3. Replacement cost	$/year	Down	≤ 200 [(2)]
4. Minimal impact on day-to-day living	4.1. Initial disruption	days	Down	≤ 10 [(2)]
	4.2. Ongoing maintenance	days/year	Down	≤ 2 [(2)]
5. Unobtrusive	5.1. Visibility	Score out of 5	Up	≥ 3 [(2)]
	5.2. Aesthetics	Score out of 5	Up	≥ 3 [(2)]

5.3. Requirement Mapping (House of Quality)

House of quality analysis technique, a form of requirement mapping, was utilised to organise and compare requirements as well as establishing the relationships between them (refer to figure 4). This was achieved via an iterative process, revising as required throughout the stages of the design cycle allowing the important requirements / relationships to be identified.

For example, on the first pass it clearly highlighted that although affordability was ranked second in the customer requirements order of importance, it played an important role in determining whether a potential solution was successful in addressing the needs of the Canberra resident. That is, life cycle cost of any solution was found to be nearly as important as reliability of supply.

[1] Technical performance measure to match existing levels targeted by ActewAGL (ActewAGL 2015, pp. 28, 40)
[2] Technical performance measure set by the Canberra resident

Legend
1 weak relationship
3 medium relationship
9 strong relationship
+/- positive / negative

Customer Reqs.	Relative Importance (*5 high important; 1 low importance*)	1.1. Distribution network electricity usage	2.1. Steady State Voltage	2.2. Time without electricity	2.3. Frequency of electricity outages	3.1. Capital investment	3.2. Ongoing maintenance cost	3.3. Replacement cost	4.1. Initial disruption	4.2. Ongoing maintenance	5.1. Visibility	5.2. Aesthetics
Direction		Down	-	Down	Down	Down	Down	Down	Down	Down	Down	Up
1. Lower electricity bills	3	9	3	1	1	9	3	9		1		
2. Retain existing reliability of supply	5	1	9	9	9	3	1	1		1		
3. Affordable	4	1				9	9	9			1	1
4. Minimal impact on day-to-day living	2	1	3	3	3	1	1	1	3	9		
5. Unobtrusive	1					3					9	9
Metric		kWh/year	Volts	Mins/year	No.	$	ea$/year	$/year	days	days/year	-	Integer
Target		-	216.2 – 253	91	1.2	≤ 5000	≤ 50	≤ 200	≤ 10	≤ 2	Minimal	-

Figure 4: House of quality analysis for household

Based on the importance placed on affordability, it was determined that prior to continuing the design process, it would be prudent to temporarily jump to testing and evaluation confirming whether the battery storage and solar generation ideas were able to meet the maintenance and replacement costs. This was achieved by analysing the resident's electricity bills for the past two years, then conducting a unit testing to confirm these requirements (refer to section 8.1 Unit Testing & Appendix A for the assumed consumption and billing details). Firstly, the viability of the battery system in isolation was investigated – base on savings verse life cycle cost (refer to Appendix C). Secondly, a payback period analysis of solar generation in isolation as well as with the battery system was conducted by populating the Solar Choice estimator tool, 'Solar PV & Battery Storage System Sizing & Payback Estimator' (Solar Choice 2016). The results clearly highlight that although an average 3kW solar system had a reasonable payback period of 6.3 years, the battery system payback back period exceed the expect life of the batteries as well as the warranty period.

6. Logical and Functional Analysis

Logical and functional analysis was conducted to breakdown the household electrical system and highlight the decisions / actions performed to obtain a deeper understanding of the opportunities available as well as how the ideas generated interact with the system. The analysis focused on both the existing and proposed systems, considering the remaining two ideas: reduced consumption and solar generation (i.e. as stated earlier, unit testing identified that the battery systems idea, either in isolation or combined with solar generation, would not meet the design requirements, therefore it was excluded from further analysis).

6.1. Logic Flow Diagrams

Firstly, a logical flow diagram was produced for the consumption of electricity in the home based on the existing household electricity system (refer to Appendix B). This identified two key decisions that may affect the household electricity costs, as well as the three main subsystems. The two key decision were, whether the task/activity required electricity at all and if so, whether there was an opportunity to reduce electricity costs through considering when the tasks/activities were performed. As for the three subsystems, they were the tasks/activities, the electricity grid and the internal household electricity network, which consists of the household switches, wiring and switchboard. The logical flow diagram for the existing household electricity system confirmed that there was potential opportunities to reduce electricity costs through both reducing tasks requiring electricity, reduced consumption, and reducing the cost of the electricity, installing solar generation and/or using off-peak rates.

To obtain a better understanding of the affect that solar generation may have on the system, another logical flow diagram was produced based on the existing household electricity system with the addition of solar generation (refer to Appendix B). This identified another key decision that may affect the household electricity costs, as well as introducing another main subsystem. The additional decision was whether local electricity was available from the solar panels and if so, whether there was an opportunity to reduce electricity costs through considering when the tasks/activities were performed (i.e. make us of the local electricity when available). Whereas, the introduced subsystem was solar generation, which was found to interact with both the internal electricity network and the electricity grid subsystems. The logical flow diagram for the existing household electricity system with solar generation confirmed that this idea would provide additional opportunities to reduce electricity costs, but it also highlighted the need to carefully consider how the solar generation subsystem would interact with both the internal electricity network and the electricity grid.

6.2. Functional Flow Block Diagram (FFBD)

A functional block diagram was produced to outline the functional steps required in the household electrical system with solar generation. This was achieved by firstly producing a top level FFBD (refer to figure 5), which was broken down into more detail considering second and third level steps. The subsystems, functions and interactions were then used to form a subsystem interface in the following design stage.

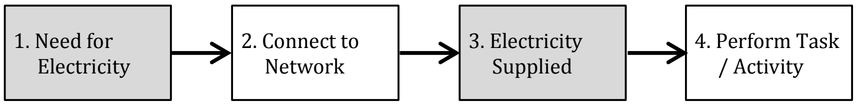


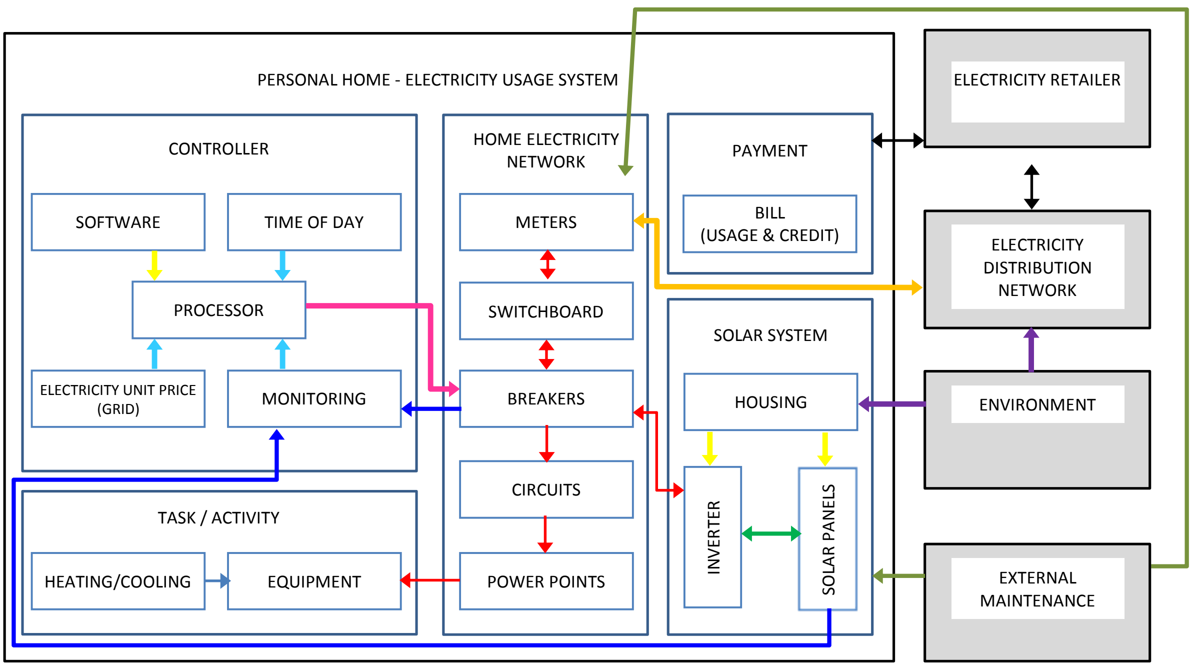
Figure 5: Household Electricity Journey Map

7. System Architecture

Moving onto the system architecture stage of the design cycle, the subsystem interface was constructed for the household electricity system. This was based on the subsystems and interactions identified during the logic and functional analysis adding the relationships between them. Subsystem mapping was then used to trace the design requirements to the functions and the functions to the subsystems.

7.1. Subsystem Interface

The following subsystem interface was constructed starting with the four subsystems and other components identified during the logic and functional analysis (refer to figure 6). These were tasks/activities, the electricity grid and the internal household electricity network, which consists of the household switches, wiring and switchboard as well as the solar system consisting of solar panels and an inverter. Relationships were then added as well as other relevant internal and external systems, subsystems and components to complete the system interface. Constructing the system interface diagram highlighted the inputs and outputs of the household electrical system and subsystems clearly showing the relationships and interactions between them.



Legend

RED CONNECTIONS – Power (AC),
GREEN CONNECTIONS – Power (DC),
BLUE CONNECTIONS – Status,
ORANGE CONNECTION – Power (AC) & Data,
BLACK CONNECTION – Information & Cash,
PURPLE CONNECTION – Weather,
GREY CONNECTION – Human Input,
PINK CONNECTION – API,
LIGHT BLUE CONNECTION – Data

Figure 6: Subsystem for household electricity network

The final system interface diagram was strongly influenced by the design requirements and system boundary chart established earlier in the design process. This was quite valuable as it provided a check of the requirements offering an opportunity to confirm whether the requirements should be reviewed as well as shifting the focus away from the areas that were excluded. Examples of excluded components would be areas, such as heating hot water, lighting and other electrical devices used in the household as well as the building structure itself.

8. Testing, Valuation & Evaluation

The testing, valuation and evaluation stage of the design cycle was used to measure generated ideas against the customer and design requirements. This was achieved by conducting unit testing at the various stages throughout the design process to refine/exclude ideas as soon as possible. The final solution was selected using an evaluation matrices to determine the most effective solution.

8.1. Unit Testing

The predominate forms of unit testing conducted to measure potential ideas against the customer and design requirements was analytical testing and proof of concept testing. These tests were designed to assess the ideas against individual design requirements and in some cases were customised for a single idea (refer to table 4).

Table 4: Proposed requirement unit testing

Requirements	Test	Metric	Test Type
1.1. Distribution network electricity usage	- not tested at this stage -	kWh/year	Analytical
2.1. Steady State Voltage	- not tested at this stage -	Volts	Operational
2.2. Time without electricity	- not tested at this stage -	mins/year	Operational
2.3. Frequency of electricity outages	- not tested at this stage -	No.	Operational
3.1. Capital investment	Up-front Cost	$	Analytical
3.2. Ongoing maintenance cost	Survey	$/year	Proof of Concept
3.3. Replacement cost	Payback – no generation Payback – with generation	$/year	Analytical
4.1. Initial disruption	Survey	days	Proof of Concept
4.2. Ongoing maintenance	Survey	days/year	Proof of Concept
5.1. Visibility	Visualisation	Score out of 5	Proof of Concept
5.2. Aesthetics	Visualisation	Score out of 5	Proof of Concept

<u>Payback – no generation</u>

This test was an analytical test, designed to objectively compare the lowest possible network electricity price for a 'Residential Time-Of-Use (TOU)' tariff against the customers' existing Residential single rate tariff. The purpose of the test is to verify whether the battery storage solution had the potential to reduce the overall electricity cost based solely on the off-peak network electricity pricing – i.e. batteries utilised during peak and shoulder periods and charged during off-peak periods - no solar generation (refer to Appendix C). Upon conducting the test, it was found that the Tesla 6.4kWh battery storage system would not meet the design requirement for replacement cost.

<u>Payback – with generation</u>

This test was designed to objectively determine the payback period for both solar generation as well as solar generation with battery storage. The purpose of the test is to verify whether solar generation in isolation and/or solar generation with battery storage by populating the Solar Choice estimator tool, 'Solar PV & Battery Storage System Sizing & Payback Estimator' (Solar Choice 2016). The results clearly highlight that although an average 3kW solar system had a reasonable payback period of 6.3 years, the battery system payback back period exceed the expect life of the batteries. Therefore, the solar system idea was found to potentially meet the design requirement for replacement cost, but the battery system.

Survey

This test was a proof of concept test, designed to be a quick assessment to determine the viability of both the solar generation and reduced consumption ideas. The survey test involved contacting a couple of residents with solar generation and double glazing / wall insulation to obtain an initial indication of whether these ideas would meet the design requirements for the ongoing maintenance costs, initial disruption and ongoing maintenance. The survey test confirmed that both ideas could meet the design requirements, but further testing would be required once the ideas were fully scoped to confirm this.

Up-front Costs

The up front costs of each idea were determined through desktop research as well as obtaining quotations and compared against design requirement 3.1 Capital Investment. The values were based on actual up-front cost without consideration to savings (refer to table 5 for results).

Table 5: up-front costs unit test results

Idea	Description	Quotation	Target	Pass / Fail
Solar Generation	Average 3kW Solar System (Solar Choice 2016)	\$5,000	≤ \$5,000	Pass
Battery Storage System	Tesla battery storage system 6.4kW (Doyle & Barnes 2016)	\$12,000	≤ \$5,000	Fail
Reduce Consumption (Option 1)	Replace window panels with double glazing (All) - Quotation from Just-rite dated 11/05/2016	\$9,650.00	≤ \$5,000	Fail
Reduce Consumption (Option 2)	Retrofit 3mm Acrylic to window panels – double glazing (All) - Quotation from Magnetite dated 07/05/2016	\$7,401.00	≤ \$5,000	Fail
Reduce Consumption (Option 3)	Retrofit 3mm Acrylic to window panels – double glazing (All) - Estimated from ACT Plastics, etc	≈ \$1,500.00	≤ \$5,000	Pass
	Install wall insulation - Estimate from Just-rite	≈ \$2,500.00		

Visualisation

This was another proof of concept test, designed to objectively rate the ideas out of five, on visibility and aesthetics. The solar system scored four out five for both requirements, whereas the reduce consumption idea (option 3) scored a three out of five. Base on the visualisation tests both ideas meet the design requirements.

8.2. Evaluation Matrix

The four ideas were evaluated using a weighted average evaluation method to enable a design decision to be made as to most effective idea (refer to table 6). In addition, the evaluation matrix highlighted that both the battery system and solar generation with batteries ideas did not meet the affordable requirement and therefore would not address the design opportunity.

Table 6: Weighted Evaluation Matrix

Requirements	Relative Importance	Solar		Battery		Solar + Battery		Consumption	
		Score	S x I	Score	S x I	Score	S x I	Score	S x I
1. Lower electricity bills	3	5	15	3	9	5	15	1	3
2. Retain existing reliability of supply	5	5	25	5	25	5	25	5	25
3. Affordable	4	3	12	0	0	0	0	4	16
4. Minimal impact on day-to-day living	2	4	8	3	6	3	6	4	8
5. Unobtrusive	1	3	3	5	5	3	3	1	1
	Total	**63**		**45**		**49**		**53**	

9. Design Communication

The system engineering design approach determined that the most effective solution in relation to reducing the Canberra resident's ongoing electricity bills was to install a residential grid connected 3kW solar PV system at an assumed cost of $5,000. This system would consist of an inverter and approximately twelve PV panels to be installed on the north facing tiled roof with a tilt angle of approximately 20 degrees (approximately 20m^2 of roof space).

Any unused electricity produced by the proposed PV system is assumed to be purchased by ActewAGL based on their present feed-in tariff of 7.5 cents/kWh. Installing the 3kW PV system is estimated to save around $794 per annum on based on the existing electricity bill assuming the resident works from home (day focused load profile with a peak in the evening).

It needs to be mentioned that there may be additional charges if the household electricity switchboard and/or wiring need to be upgraded to accommodate the solar PV system (i.e. the household electricity switchboard and/or wiring were excluded from the analysis).

Although the reduce consumption idea was not found to be the most effective it would assist in reducing the electricity costs. Therefore, in addition to the preferred option of installing the solar system, potential upgrades to the household have also been identified for consideration (refer to Appendix D).

9.1. Delivery and Roadmap

Next Month
It is recommended that three solar companies be contacted to provide quotations for installing a 3kW solar PV system. The quotation should include all required electrical upgrades and as well as any structural works that may be required. This will allow an informed decision as to whether to proceed with installing a solar system.

Over the Winter Period
To assist in reducing the overall electricity consumption it is recommended that the all heating requirements over 2016 winter period be recorded. This will allow an informed decision to be made in relation to installing do-it-yourself double glazing in areas that appear to require excessive heating over the winter period. For example, the bedroom verses the living areas.

10. Reflection

Taking a system engineering design approach to advise a local Canberra resident in relation to the identified design opportunity was found to be an efficient way to determine the most effective solution. As stated earlier the approach consisted of an eight stage design cycle that looked to determine, and then in turn, communicate the most effective solution.

Following are a few points for each stage of the design cycle as well the peer review process:

Needs & Opportunity & Problem Scoping
Framing the initial client request as an opportunity allowed for alternative solutions to be identified that may have been overlooked. In this case, the initial problem was what technology to invest in, but the actual opportunity was reducing electricity – i.e. reduced consumption was an alternative solution worth considering.

In addition, without problem scoping the solution to the design opportunity would more than likely not have been identified. Establishing the system boundaries, proved to be essential in allowing the most effective solution to be determined in the scheduled time frame.

Idea Generation & Requirement Analysis

Some ideas had been identified prior to the completing this stage of the design cycle, which may lead people to believe that the idea generation stage was not required, but this could not be further from the truth. Using the idea generation techniques provided a framework that enabled creative and innovative ideas to be considered. Although they may not always be found to be the most effective, they may lead to other viable ideas, as was the case in this design opportunity – reduced consumption.

Similar to ideas generation, requirements were already identified prior to commencing this stage of the design cycle and if not completed a solution may have been identified that meets them. But, by translating the customer requirements to measurable design requirements comparisons were able to be conducted to clearly confirm whether the requirements were in fact met as well as providing a means to compare the various ideas to determine the most effective solution.

Logical and Functional Analysis & System Architecture

These stages of the design cycle provided a mechanism to obtain a greater understanding of the system being analysed as well clear highlighting the relationships and interactions. The techniques used proved to quite valuable as it provided a check of the requirements offering an opportunity to confirm whether the requirements should be reviewed as well as shifting the focus away from the areas that were excluded.

Testing, Validation and Evaluation & Design Communication

Although, testing, validation and evaluation is one of the last stages of the cycle, it was also found to be quite useful during the early stages of the design. This highlighted the fact that the design stages are just that, stages that are used as required to determine the most effective solution. For example, the battery storage idea was able to be excluded early in the design process thorough unit testing, freeing up time to assess the other ideas in greater detail. Finally, the design communication techniques were found to be vital in ensuring the actual solution was communicated to the reader.

Peer review

The peer review process proved to be more valuable than first thought. Reviewing other portfolios allow a greater understanding of the system engineering design process to be obtained as well as highlighting how important it is to clearly communicate the design opportunity and in turn the solution.

11. Conclusion

Distributed generation (DG) technologies have provided Australian consumers with greater choice to meet their household electricity needs and potentially stem the ever increasing cost of electricity. This portfolio employed a system engineering design approach to advise a local Canberra resident in relation to reducing their ongoing electricity bills. The three main ideas investigated were solar generation, battery storage and reduced consumption. Battery storage provided greater flexibility, but the replacement costs proved too out way the benefits. The most effective solution for the resident was found to be installing a 3kW solar PV system with further consideration in relation to do-it-yourself double glazing to reduce electricity consumption.

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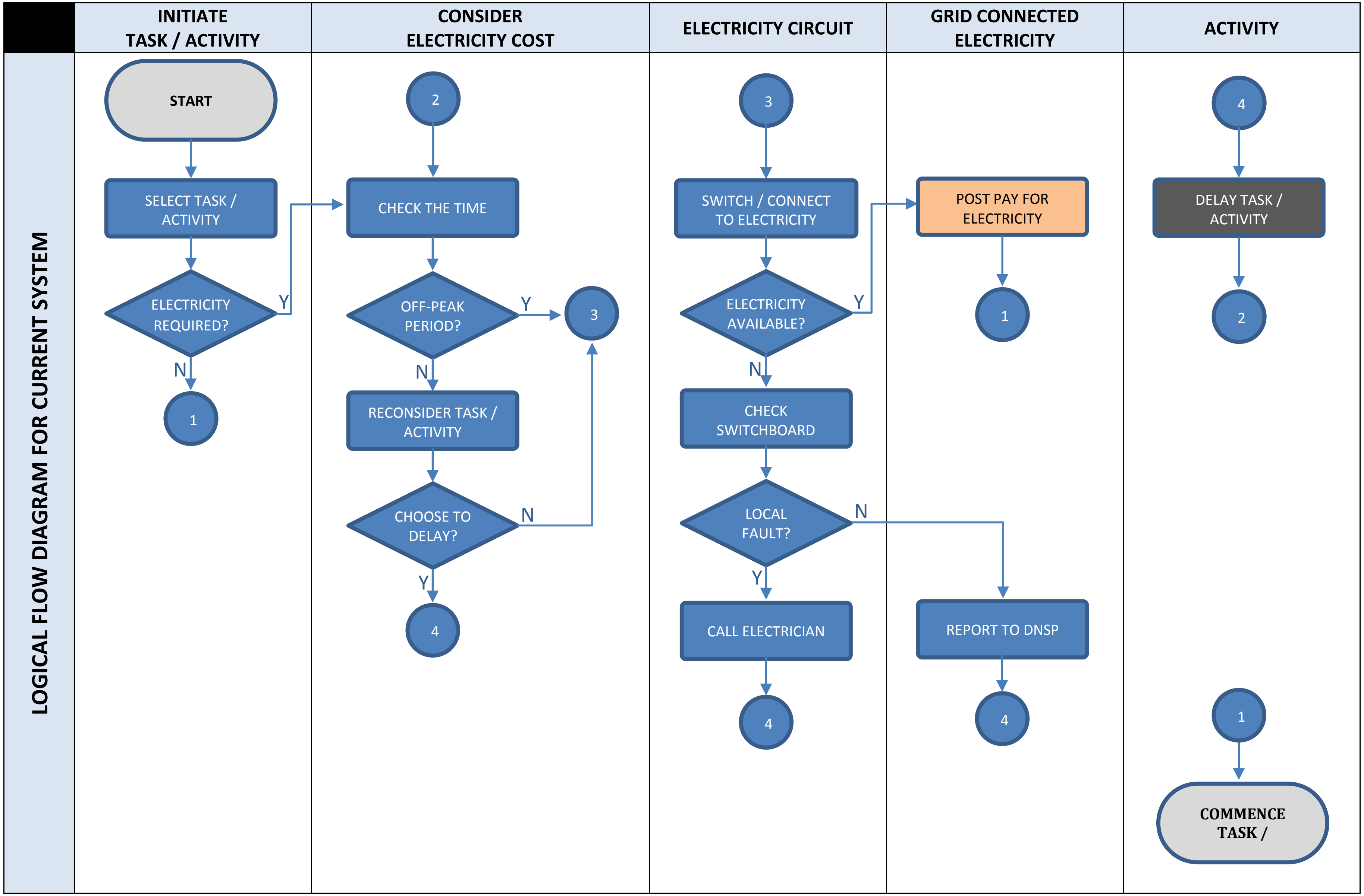
Appendix A: Resident Consumption and ActewAGL Rate Details

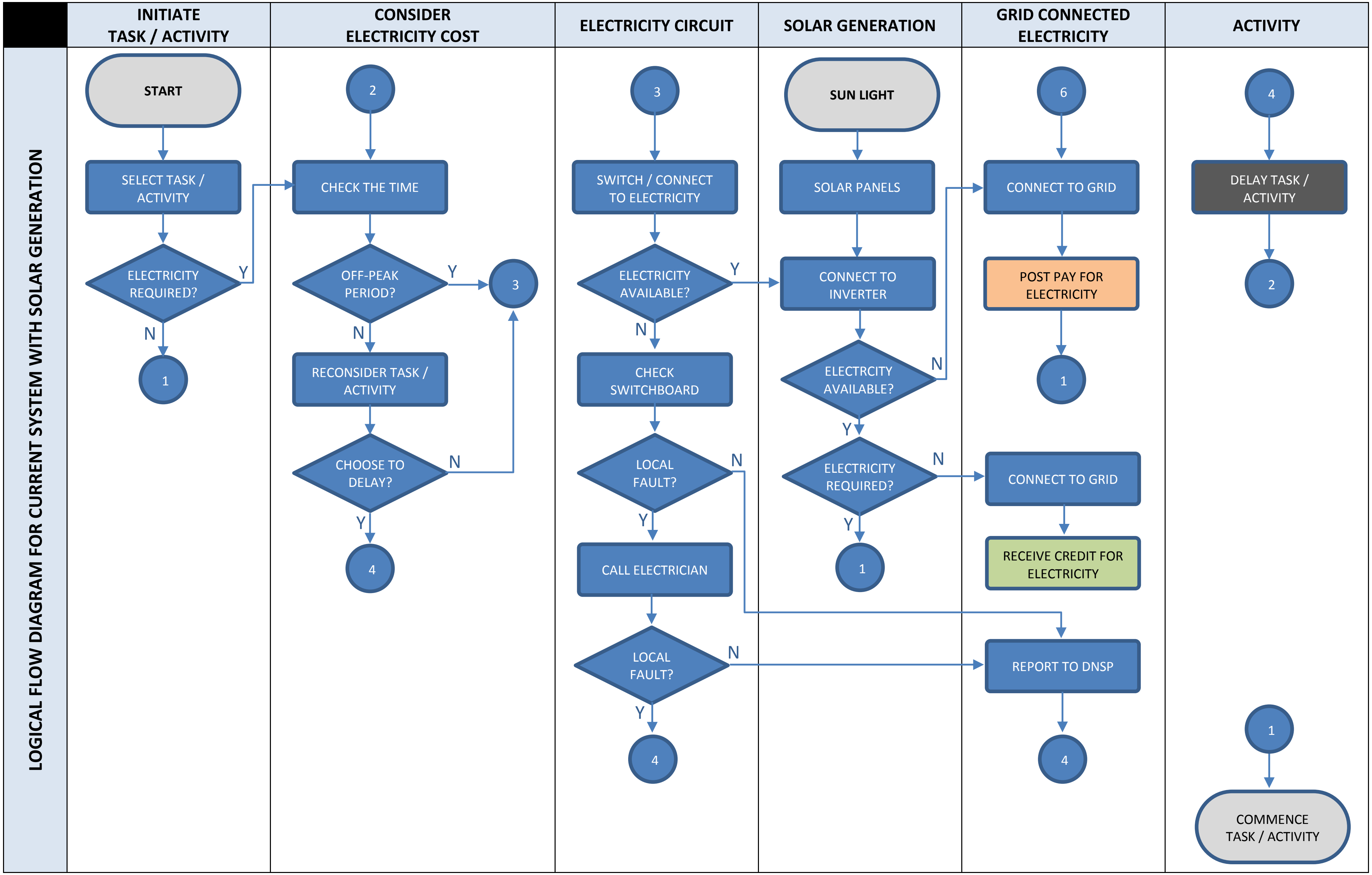
Local Canberra Resident's Electriccity Consumption & Bill Details							
Date Read	**Season**	**Num Days**	**Electricity Used**	**Network Cost (incl. GST)**	**Usage Charge (incl. GST)**	**Total Bill (incl. GST)**	**Daily Usage**
20/06/2014	**Autumn**	92	1056	69.73	182.37	252.1	11.5
30/06/2014	**Winter**	10	228	7.58	39.38	46.96	
16/09/2014	**Winter**	78	1782	59.11	307.75	366.86	22.8
17/12/2014	**Spring**	92	676	69.73	116.74	186.47	7.3
18/03/2015	**Summer**	91	794	68.97	137.13	206.1	8.7
		363	4536	275.12	783.37	1058.49	12.5
20/06/2015	**Autumn**	94	1078	71.25	186.18	257.43	11.5
30/06/2015	**Winter**	10	225	7.58	38.86	46.44	
18/09/2015	**Winter**	80	1801	60.63	311.04	371.67	22.5
18/12/2015	**Spring**	91	644	68.97	111.22	180.19	7.1
22/03/2016	**Summer**	95	796	72.01	137.47	209.48	8.4
		370	4544	280.44	784.77	1065.21	12.3

ActewAGL Time Of Use Tariff (TOU)					
Period	**Start Time**	**End Time**	**Start Time**	**End Time**	**Price (inc GST)**
Off-Peak	10pm	7am	-	-	11.55 cents per kWh
Shoulder	9am	5pm	8pm	10pm	15.785 cents per kWh
Peak	7am	9am	5pm	8pm	23.375 cents per kWh
Supply Charge					75.79 cents per day

ActewAGL Singel Rate (FLAT)					
Period	**Start Time**	**End Time**	**Start Time**	**End Time**	**Price (inc GST)**
Flat					17.27 cents per kWh
Supply Charge					75.79 cents per day

Appendix B: Logical Flow Diagrams – Household Electricity System




LOGICAL FLOW DIAGRAM FOR CURRENT SYSTEM WITH SOLAR GENERATION
INITIATE TASK / ACTIVITY
CONSIDER ELECTRICITY COST
ELECTRICITY CIRCUIT
SOLAR GENERATION
GRID CONNECTED ELECTRICITY
ACTIVITY
START
SELECT TASK / ACTIVITY
ELECTRICITY REQUIRED?
Y
N
1
2
CHECK THE TIME
OFF-PEAK PERIOD?
Y
3
N
RECONSIDER TASK / ACTIVITY
CHOOSE TO DELAY?
N
Y
4
3
SWITCH / CONNECT TO ELECTRICITY
ELECTRICITY AVAILABLE?
Y
N
CHECK SWITCHBOARD
LOCAL FAULT?
N
Y
CALL ELECTRICIAN
LOCAL FAULT?
N
Y
4
SUN LIGHT
SOLAR PANELS
CONNECT TO INVERTER
ELECTRCITY AVAILABLE?
N
Y
ELECTRICITY REQUIRED?
N
Y
1
6
CONNECT TO GRID
POST PAY FOR ELECTRICITY
1
CONNECT TO GRID
RECEIVE CREDIT FOR ELECTRICITY
REPORT TO DNSP
4
4
DELAY TASK / ACTIVITY
2
1
COMMENCE TASK / ACTIVITY

Appendix C: Payback – no generation

Overview

This test is an analytical test, designed to objectively compare the lowest possible network electricity price for a 'Residential Time-Of-Use (TOU)' tariff against the customers' existing Residential single rate tariff.

Note: the purpose is to verify whether an energy storage solution has the potential to reduce the overall electricity cost based solely on the off-peak network electricity pricing (i.e. batteries utilised during peak and shoulder periods and charged during off-peak periods - no solar generation).

Definitions

Time-Of-Use (TOU): electricity pricing varies with time

- Peak 7am – 9am and 5pm – 8pm on working weekdays
- Shoulder 9am – 5pm and 8pm – 10pm on working weekdays
- Off-Peak All other times

Single Rate (FLAT): a single flat rate for all consumption

- Single Rate All times

Required Documents

- Four customer bills – bills are to be reflective of the customers typical usage
- Relevant Electricity Network Price List for the residence

Testing Procedure

For each of the customer bills, determine the actual electricity usage and calculate the expected electricity charges based on TOU at off-peak rates. Then determine the profit margin for each bill and in turn over a year. Multiple the estimated yearly profit, if any, by the expected lifespan of the storage system comparing the results against the replacement cost of the system.

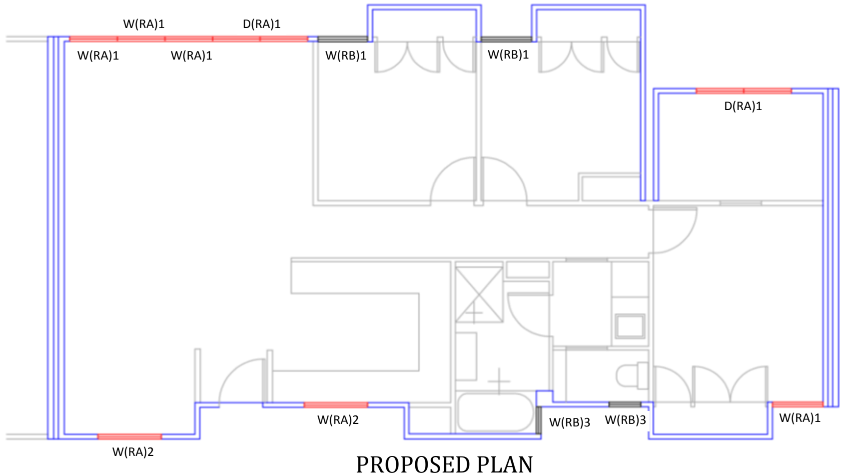
Steps

- Determine the total electricity consumption (kWh)
- Determine the TOU off-peak rate (c/kWh)
- Multiple the kWh by the TOU off-peak rate **- [ENERGY] charge**
- Determine the bill period (number of days)
- Determine the Network Access Charge (c/day)
- Multiple the number of days by the Network Access Charge **- [NETWORK] charge**
- Determine the Meter Service Charge (c/day)
- Multiple the number of days by the Meter Service Charge **- [METER] charge**
- Add the [ENERGY], [NETWORK] & [METER] charges together **- [TOU Bill]**
- Subtract the calculated [TOU Bill] total from the customer bill total **- [MARGIN]**
- Repeat for all customer bills for a single year.
- Add each [MARGIN] for bills together **- [YEARLY MARGIN]**
- Multiple the [YEARLY MARGIN] by the expected lifespan of the storage system **- [SAVING]**
- Compare [SAVING] with the replacement cost of the storage system

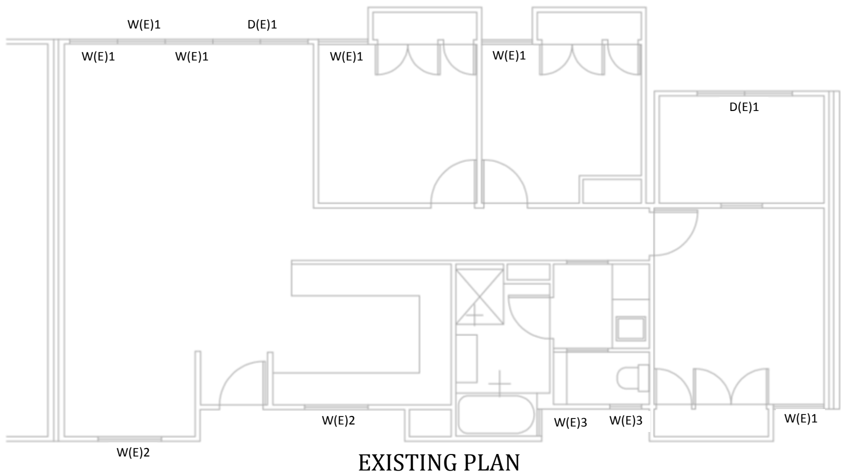
Results

- Record the [YEARLY MARGIN] for the customer.
- Record the difference between the [SAVING] and the replacement cost for the storage system.

Appendix D: Reduced Consumption – Do-It-Yourself Double Glazing



PROPOSED PLAN



EXISTING PLAN

SCOPE OF WORKS (STAGE A)

- REPLACE EXISTING GLASS PANELS FOR ALL W(RA) WINDOWS WITH DOUBLE GLAZED PANELS
- REPLACE EXISTING GLASS PANELS FOR ALL D(RA) DOORS WITH DOUBLE GLAZED PANELS
- INSTALL WALL INSTALLATION IN ALL EXTERNAL WALLS.

SCOPE OF WORKS (STAGE B)

- REPLACE EXISTING GLASS PANELS FOR ALL W(RB) WINDOWS WITH DOUBLE GLAZED PANELS

DOOR SCHEDULE

D(E)1 - EXISTING TIMBER SLIDING DOOR 2100mm X 1800mm WITH FOUR GLASS PANELS

D(RA)1 - EXISTING TIMBER SLIDING DOOR 2100mm X 1800mm WITH FOUR DOUBLE GLAZED PANELS

WINDOW SCHEDULE

W(E)1 - EXISTING TIMBER WINDOW 2100mm X 900mm WITH TWO GLASS PANELS

W(E)2 - EXISTING TIMBER WINDOW 1200mm X 1200mm WITH ONE GLASS PANEL

W(E)3 - EXISTING TIMBER WINDOW 900mm X 600mm WITH ONE GLASS PANEL

W(RA)1 - EXISTING TIMBER WINDOW 2100mm X 900mm WITH TWO GLASS PANELS

W(RA)2 - EXISTING TIMBER WINDOW 1200mm X 1200mm WITH ONE GLASS PANEL

W(RB)1 - EXISTING TIMBER WINDOW 2100mm X 900mm WITH TWO GLASS PANELS

W(RB)3 - EXISTING TIMBER WINDOW 900mm X 600mm WITH ONE GLASS PANEL

NOTE: ALL WINDOW AND DOOR MEASUREMENTS ARE ESTIMATES ONLY – TO BE CONFIRMED PRIOR TO PURCHASING ANY PANELS

RECOMMENDED HOME ENERGY EFFICIENCY IMPROVEMENTS TO REDUCE ENERGY COSTS