ENGN2225 DESIGN PORFOLIO

Take-Home Exam Option: Problem A – Heating and Cooling

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1.0 Abstract

In order to help a client heat and cool the living spaces in their house, systems engineering analysis methods are applied to provide greater understanding about the projected system. An engineering requirements analysis is conducted applying pairwise and house of quality analysis techniques to rank customer requirements. A system function analysis is conducted defining the client's interaction to activate, maintain, and deactivate the projected system. Subsystem integration analysis is conducted to identify the projected subsystems and their interaction. A system attributes analysis identifies different attributes required to satisfy the design requirements. Various heater and air-conditioning designs are evaluated to identify the optimal solution for the client. The chosen solution is verified using an analytical model which determines whether the chosen system will provide climate control services for the client. Conclusions are drawn and a design solution uses separate heating and air-conditioning devices is proposed.

2.0 Introduction

Problem Statement

A client has sought heating and cooling advice and solution for the living spaces in a 180m two-bedroom single-brick house in north Canberra. The client is primarily concerned about the aesthetics and ongoing costs of the system, and is also concerned with safety. It is desired that the system can dry clothes in winter, and can be "set and forget". The client would like the system to be useful in both winter and summer, however understands that this may best be satisfied utilising two separate devices.

3.0 Requirements Engineering

Client brief indicates that they are primarily concerned about the aesthetics and ongoing cost of the proposed system. Additionally, the client is concerned about safety, and seeks a "set and forget" solution, hoping that the solution is useful in summer and winter, and hopes to utilise heat generated by the system to dry clothes in winter.

From the client's requested requirements and engineering performance measures considered necessary for a general climate control solution in a home, thirteen customer requirements were determined for the system. These requirements include:

- Adjustable: The system has adjustable climate control and direction settings.
- Aesthetic: The overall design is aesthetically pleasing.
- Durable: The system is designed such that it is able to withstand pressure or damage.
- Dry clothes: The system will provide the client a means to dry their clothes during winter.
- Easy to use: The client can "set and forget" the system. Additionally, the client's interaction with the system is basic/simple.
- Effective performance: The proposed solution is effective in controlling the climate in the client's home.
- Heats and cools: The proposed solution will be useful in summer and winter and will able to heat and cool the client's home.
- Low costs: The installation costs are low, and ongoing costs are minimised.
- Low maintenance: The system is resistant to wear when under normal use.
- Low noise: The idle and operation noise of the system are as low as possible.
- Safety: Proper and normal use conditions are safe.
- Single system: A single device solution will heat and cool the client's home.
- Size: The system is not obstructive to the client or object within the client's home.

A pairwise analysis was conducted to compare and prioritise the customer requirements. This is seen in Table 3.0 below.

Table 3.0 – Pairwise Analysis

	Adjustable	Aesthetic	Durable	Dry clothes	Easy to use	Effective performance	Heats and cools	Low costs	Low mainte-nance	Low noise	Safety	Single system	Size	Score	Rank
Adjustable		0	0	0	0	0	0	0	0	0	0	0	1	1	12
Aesthetic	1		1	1	1	1	1	0	1	1	0	1	1	10	3
Durable	1	0		1	1	1	1	0	1	1	0	1	1	9	4
Dry clothes	1	0	0		0	0	0	0	0	0	0	1	1	3	10
Easy to use	1	0	0	1		1	1	0	1	1	0	1	1	8	5
Effective performance	1	0	0	1	0		0	0	0	1	0	1	1	5	8
Heats and cools	1	0	0	1		1		0	1	1		1	1	7	6
Low costs	1	1	1	1	1	1	1		1	1	0	1	1	11	2
Low maintenance	1	0	0	1	0	1	0	0		1	0	1	1	6	7
Low noise	1	0	0	1	0	0	1	0	0		0	1	1	5	9
Safety	1	1	1	1	1	1	1	1	1	1		1	1	12	1
Single system	1	0	0	0	0	0	0	0	0	0	0		1	2	11
Size	0	0	0	0	0	0	0	0	0	0	0	0		0	13

From the pairwise analysis, it was identified that the order of most important to least important customer requirements are: (1) safety, (2) low costs, (3) aesthetic, (4) durable, (5) easy to use, (6) heats and cools, (7) low maintenance, (8) effective performance, (9) low noise, (10) dry clothes, (11) single system, (12) adjustable, and (13) size. Hence, in the delivered solution, the design should prioritise the customer requirements in the ranking order determined.

A house of quality analysis is conducted and seen in Figure 3.0 below.

Legend:

Type of correlation (+/-)

1 – Weak relationship

3 – Medium relationship

9 – Strong relationship

	Dimensions	Installaion Time	Lifetime	Moving Components	Noise level	Number of Components	Production Cost	Powers Consumption	Simplicity	Toughness	Weather Resistance	Weight
Weight												
Weather Resistance												
Toughness											+	+
Simplicity												
Powers Consumption												
Production Cost										+	+	+
Number of Components							+	+	-			+
Noise level						+	-	+				
Moving Components					+	+	+	+				
Lifetime				-		-	+	-		+	+	
Installaion Time				+		+			-			+
Dimensions		+		+		+	+					+

		Dimensions	Installaion Time	Lifetime	Moving Components	Noise level	Number of Components	Production Cost	Powers Consumption	Simplicity	Toughness	Weather Resistance	Weight
	Max or Minimise	-	-	+	-	-	-	-	-	•	+	+	-
	Units	m^3	Hours	Years	Integer	dB	Integer	$	kWh	(-)	J/m^3	Years	kg
Adjustable	12	1			3	3		3	9				
Aesthetic	3	3						1		3			
Durable	4	1		9				9			9	9	9
Dry Clothes	10	1				1			1				
Easy to use	5									9			
Effective performance	8			3		3			9				
Heats and cools	6	3			3	1	9	9	3	3			3
Low costs	2	3	1	3			3	9	9				
Low maintenance	7			3			3		3		3	9	
Low noise	9				3	9	3						
Safety	1	1			3	3	3		3		3	3	
Single system	11	9	3	3	9		9	9		9			3
Size	13	9			3		3			1			3
	Rank												

Figure 3.0 – House of Quality

In the house of quality analysis, high level design requirements were identified and compared to the customer requirements. It was found that there is a strong relationship between the design requirement low production cost and customer requirements durable, heats and cools, low costs and single system. It was also seen that the dimensions, the number of components, and power consumption in the design is linked to more than half of the customer requirements. This shows that these particular aspects in the design need to be optimised in the delivered solution to satisfy many of the customer requirements.

Correlation of high level design requirements provides an illustration of their interaction in an integrated system. Specifically, it was found that the production costs will increase when the dimensions, lifetime, number of moving components, number of components, toughness, weather resistance, and weight of the design increases, and when the noise level is minimised. Furthermore, it was found the lifetime of the system will decrease with an increase in the number of moving components, number of components, and power consumption, and will decrease with an increase in production cost, toughness, and weather resistance. These are aspects which need to be considered when proposing a solution for the client. Specifically, a system which is high in power consumption will have a low product life cycle as consumers migrate to towards more energy efficient technologies when competitively priced. Thus in the final design it is important to find a solution which is not energy intensive but still has effective performance.

4.0 System Function Definition

A description of the design synthesis activities for the client to activate, utilise, and deactivate the climate control system are identified by constructing functional flow block diagrams (FFBD). A high level FFBD is seen in Figure 4.0 below.

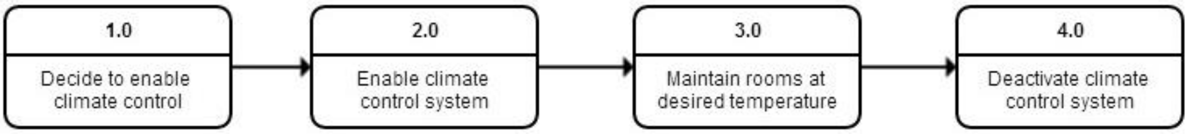

Figure 4.0 – High-level Functional Flow Block Diagram

The client must first decide to enable the delivered system, enable the client control system, maintain the selected rooms at a desired temperature, and then finally deactivate the climate control system when it is no longer required.

When enabling the climate control system, the client must decide which rooms require climate control. Once this has been decided, the client has an option to adjust the room openings to set the desired system-control environment boundary. This is depicted in Figure 4.1 below.

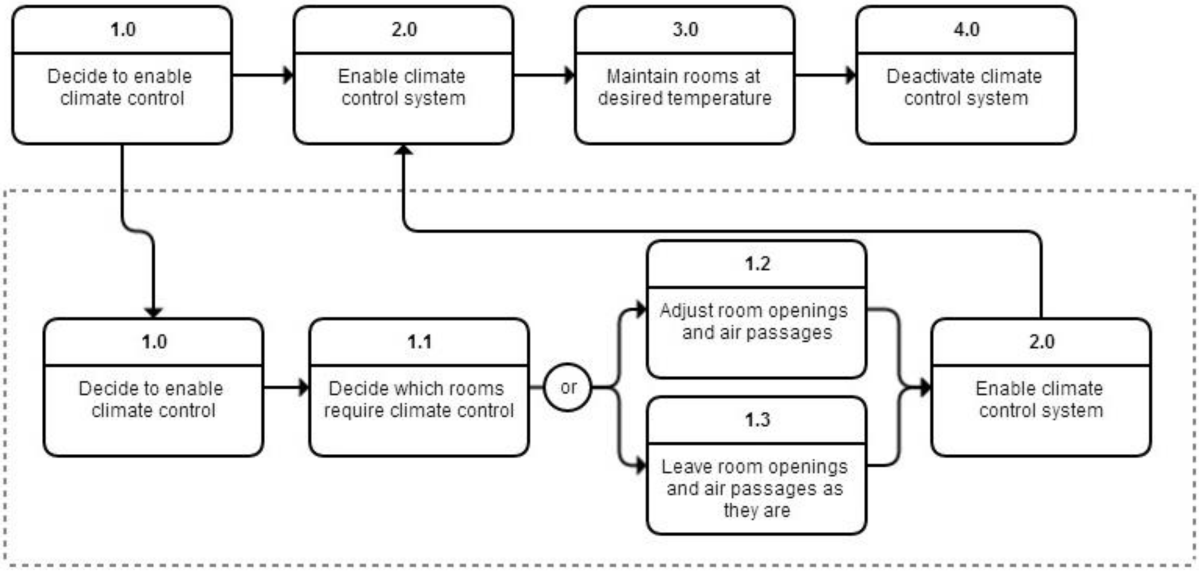

Figure 4.1 – FFBD of 'Decide to enable climate control'

Once the client has decided which rooms require climate control, the client must enable the climate control in the selected rooms and set the desired temperature. This is depicted in Figure 11.0 in the Appendix.

Maintaining the selected rooms at a desired temperature is a more complicated process, which includes two Go (G) or No Go (~G) operations. The client can continue with desired activities as usual if satisfied with the room temperature. However, if the client is not satisfied with the room temperature, the client has the option to either adjust the room openings and air passages, or adjust the system set temperature. As a result, the room temperature will adjust accordingly. This leads to the client to continue with desired activities whilst rooms are maintained at programmed temperature or until the client no longer requires climate control. If climate control is no longer required, the client can deactivate the system. However if the user desires to continue activities within the system-control environment boundary, the rooms will be maintained at a programmed temperature. At any point, the user can adjust the temperature of the system, or room openings.

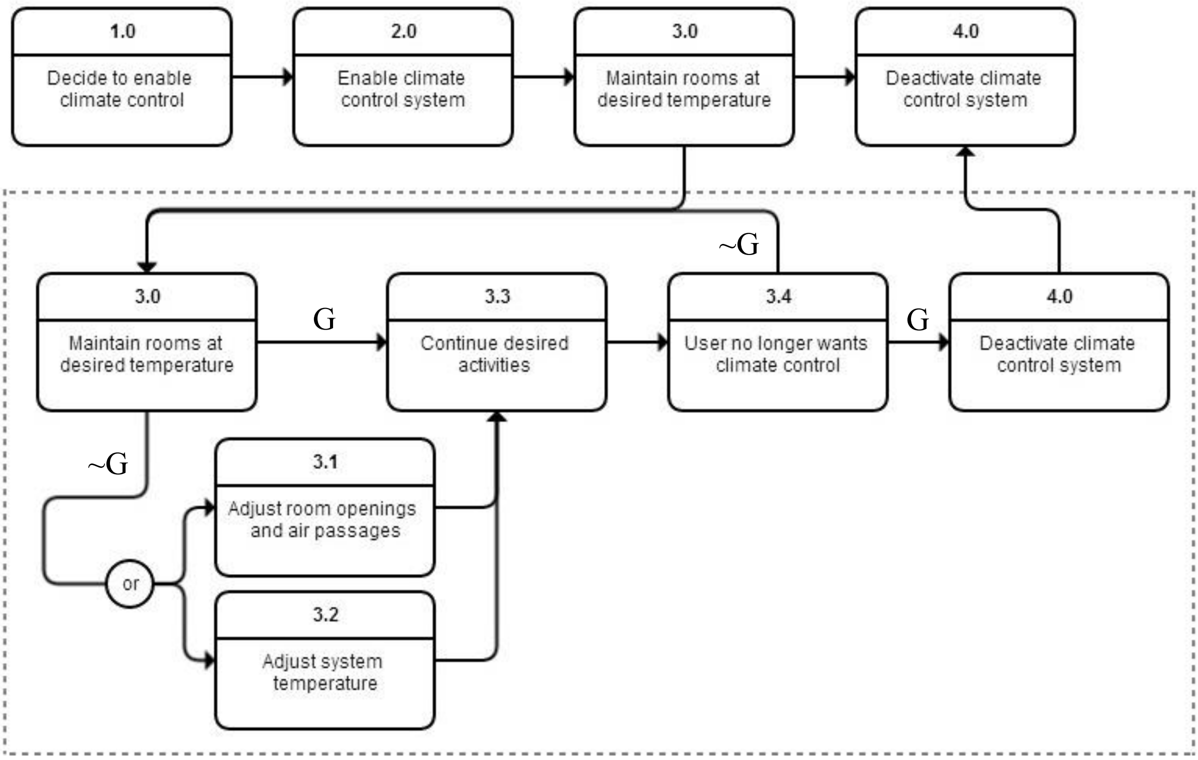

Figure 4.2 – FFBD of 'Maintain rooms at desired temperature'

From the system function analysis, graphical images defining the projected user interaction with the delivered system have been created. Overall, the user interaction with the delivered system is quite basic – the most complex interactions are to set the climate control to a particular temperature setting and to particular rooms, and to close any room openings.

5.0 Subsystem Integration

For a design to fulfil the customer requirements and the system function definition, ten subsystems which influence the developed climate control system are considered. These are:

- Casing and Enclosure subsystem: The mechanical support infrastructure of the developed system exclusive of the climate control, electrical, and display components. This includes the exterior case of the system and support stand.
- Climate subsystem: The elements of the developed system which work to provide climate control. This includes the air-conditioner, the climate-control distributor, and the heater.
- Control subsystem: The way the user interacts with the developed system to set the appropriate settings. This includes the buttons or other like control apparatus.
- Display subsystem: Provides feedback to the client current settings of the system. This includes current-setting feedback and a thermostat.
- Electronics subsystem: Provides power to all other subsystems except for the casing and enclosure subsystem. It comprises the power supply, power conditioning, and the wiring.
- Safety subsystem: Aimed at protecting the delivered design, the user, and the external environment. This includes an emergency shutdown, and electrical protection.
- System-controlled Environment subsystem: The system-control environment is the system boundary that requires climate control.
- User subsystem: The controller of the system.
- Utilities subsystem: Externally provided resources that the developed system requires to function. This includes electricity.
- Weather subsystem: An outside influence on the system beyond control of the system. This directly impacts the user and climate subsystems.

The subsystems in the climate control system are derived and categorised into internal, external and outside categories. The internal subsystems are within the design and manufacturing of the system, the external subsystems have a direct impact on the system but are not within the design of the system, and the outside subsystems are neglected within the design of the system.

The identified subsystems are seen in the system boundary chart in Table 5.0 below.

Table 5.0 – System boundary chart

Internal	External	Outside
Casing and Enclosure	System-controlled Environment	Weather
Climate	User	
Control	Utilities	
Display		
Electronics		
Safety		

A function block diagram (FBD) is created, identifying the way the different subsystems interact within the system. A system boundary is identified which distinguishes between the internal and external subsystems. The internal subsystems were broken down and some of the sub-subsystems of the system were determined. The FBD is seen in Figure 5.0 below.

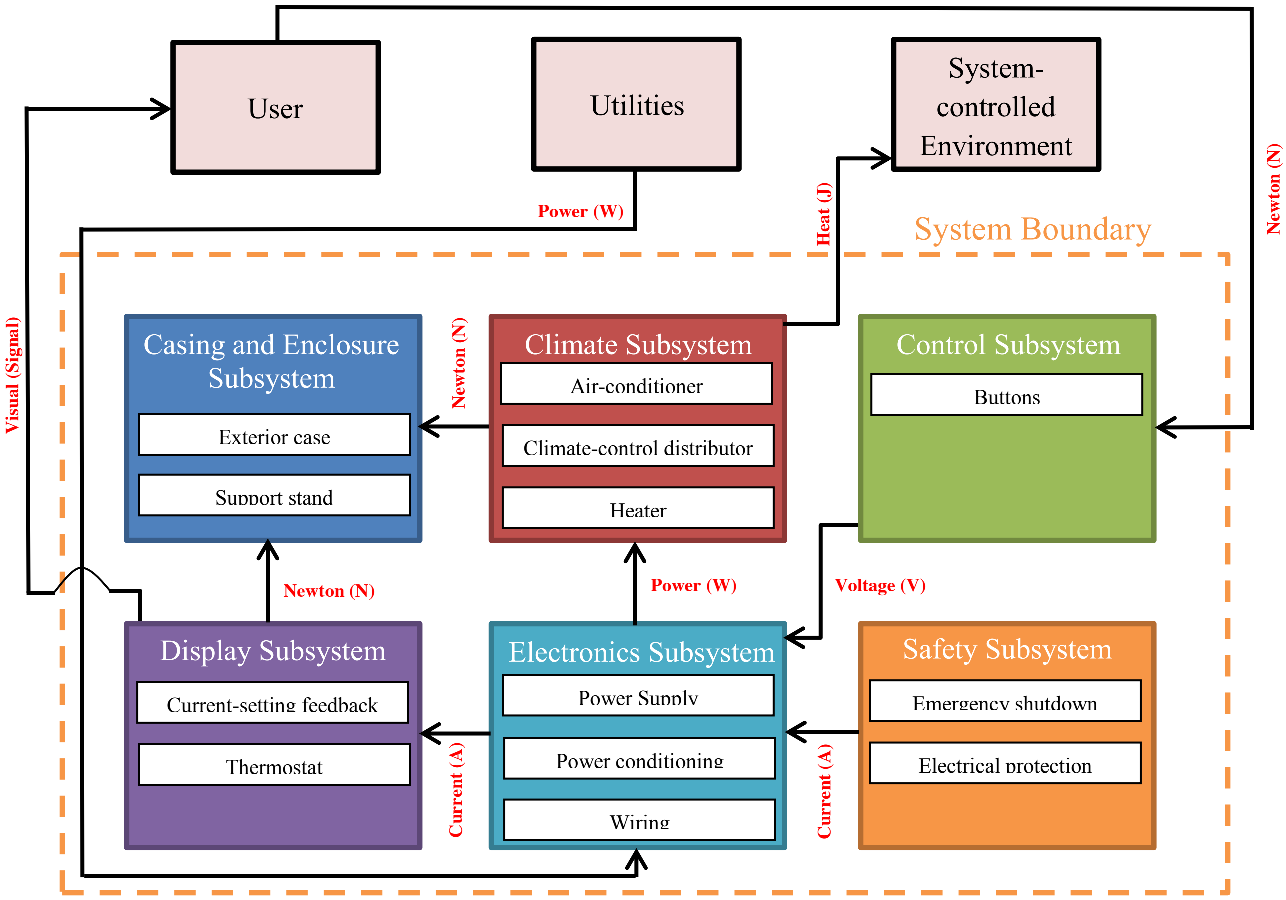

Figure 5.0 – Function block diagram

From the FBD, it is seen that the user drives the control subsystem, which feeds into the electrical subsystem. The electrical system directs any user interaction with the controls to the climate subsystem, which provides heat energy into the system-controlled environment. Additionally, the safety subsystem interacts with the electronics subsystem primarily for electrical protection and emergency shutdown purposes.

The subsystem integration analysis provides information about how the delivered design should function on a subsystem level. Furthermore, a subsystem breakdown identified a way to categorise the developed system's components, which could be useful in selecting a design for the client.

6.0 System Attributes

In order to determine the properties and characteristics the delivered design should feature, a systems attributes analysis is conducted.

The primary attributes are determined by breaking down the customer requirements into design requirements. This is seen in Table 6.0 below.

Table 6.0 – Design Requirements/Primary Attributes of the developed design

Customer Requirement	ID	Design Requirement/Primary Attribute
Adjustable	DR01-01	Adjustable temperature settings
	DR01-02	Adjustable direction
	DR01-03	Fan intensity is adjustable
Aesthetic	DR02-01	Overall design is aesthetically pleasing
Durable	DR03-01	Constructed with reliable material
Dry Clothes	DR04-01	System can dry clothes client's clothes during winter
Easy to use	DR05-01	System user interaction is basic
	DR05-02	System includes convenient control features for client
Effective performance	DR06-01	System heats effectively
	DR06-02	System cools effectively
	DR06-03	System regulates moisture content in air
	DR06-04	System effectively filters air
Heats and cools	DR07-01	System can heat and cool system-controlled environment
Low costs	DR08-01	Low installation costs
	DR08-02	Green energy rating
	DR08-03	Maintenance costs are minimal
Low maintenance	DR09-01	The system is resistant to wear
Low noise	DR10-01	Minimal noise during operation
Safety	DR11-01	Proper and normal use conditions are safe
	DR11-02	Emergency shutdown
Single system	DR12-01	A single device can provide heating and cooling
Size	DR13-01	System is not obstructive to client and other objects

In total, from thirteen customer requirements, twenty-two design requirements or primary attributes were determined for the developed system. These design requirements need to be satisfied in the delivered system.

The primary attributes were broken down to identify thirty-four secondary attributes and fifty-four tertiary attributes. A minimised attributes cascade showing the breakdown of the ‘safety’ customer requirement is seen in Table 6.1 below. In the minimised attributes cascade, by observing the related subsystems, it is seen that the casing and enclosure, climate, and electrical subsystems are important when meeting the customer requirement of safety.

Table 6.1 – Minimised Attributes Cascade

Design Requirement/Primary Attribute	Secondary Attribute	Tertiary Attribute	Related Subsystems
A19.0 Proper and normal use conditions are safe	A19.1 Electrical components are insulated	A19.1.1 Non-circuit metallic components are earthed	Electrical, Safety
		A19.1.1 All wiring consistent with AS3000	Electrical, Safety
	A19.2 External contact areas and exterior casing of system remains cool	A19.2.1 Exterior casing is resistant to heat	Casing and Enclosure, Safety
A20.0 Emergency shutdown	A20.1 Device only operates in the proper position	A20.1.1 System has a method of detecting when device is in correct position	Casing and Enclosure, Safety
		A20.1.2 System will stop operating when device is in the incorrect position	Casing and Enclosure, Safety
	A20.2 Device has inbuilt electrical safety	A20.2.1 Device has overcurrent protection	Electrical, Safety
	A20.3 Device has thermal protection	A20.3.1 System has ability to detect when heating element has exceeded safe operating parameters	Climate, Safety
		A20.3.2 System will stop operating when device is no longer within safe thermal operating range	Climate, Safety

The complete attributes cascade is seen by referring to Table 11.0 in the Appendix. Ideally each of the secondary and tertiary attributes identified in the attributes cascade should be satisfied in the delivered design; however this is not realistic and not entirely necessary to satisfy the customer requirements.

7.0 Design Evaluation and Selection

In order to solve the client's problem, different options are compared and contrasted. The best option is recommended as the proposed solution.

7.1 Considered Solutions

Considered options are identified below. Each considered option is unique, and is selected to represent the type of climate control unit. The selected options are considered as the better option for their particular type of climate control unit after some research.

7.1.1 Option 1: Separate single cycle heating and cooling units

Name: Prima 2000W Slim Ceramic Oscillating Tower Heater

Figure 7.0 - Prima 2000W Slim Ceramic Oscillating Tower Heater

Specifications:
Price: $99.95 + ($11.96 delivery)
Supplier: www.oo.com.au
Heating Capacity: 2kW
Portable: Yes

Comments: The Prima 2000W Slim Ceramic Oscillating Tower Heater is a low priced portable heating unit which can be used to heat small to medium sized rooms. The device has two heat settings at 1200W and 2000W, has an inbuilt timer function up to 7.5 hours, and an oscillation function to heat the room across multiple directions. The device includes several safety features, including a tip-over safety switch and an overheat protection. The overall aesthetics of the device are pleasing, as it has an appropriate colour scheme and finish. The dimensions of the unit are: 23cm x 21.5cm x 77cm (length, width height). To operate the device and electrical power supply is required. The device is light and can be easily moved within and between rooms as desired. Overall, this device meets the engineering requirements, the system function and subsystem definitions, and almost all of the relevant tertiary attributes in the attributes cascade. (oo.com.au, 2014)

Name: Highlander Portable Air Conditioner (12,000 BTU)

Specifications:
Price: $349.95 + ($52.46 delivery)
Supplier: www.oo.com.au
Cooling Capacity: 3.6kW
Dehumidifier Function: Yes
Portable: Yes

Comments: This portable air-conditioner is a low priced solution to provide a cool climate solution in summer. Since the system is portable and includes built-in wheels, the client can easily setup the device in any desired location within the house – although this must be exercised with caution as the unit weighs 32kg. The device includes a remote control, features a timer mode, adjustable temperature settings, and fan and dehumidifying functions – with a dehumidifying capacity up to 1.8L/hour. The operating noise of the unit reaches up to 53dB, and the energy rating is 2.8 star. Overall, the device is aesthetically pleasing, as it has an appropriate colour scheme and finish. The unit dimensions are: 44cm x 38cm x 77cm (L, W, H). Setting up the device requires access to electricity and an open window for the outlet hose. The product specification indicates performance is satisfactory for small-to-medium sized rooms. Overall, this device meets the engineering requirements, the system function and subsystem definitions, and almost all of the relevant tertiary attributes in the attributes cascade. (oo.com.au, 2014)

7.1.2 Option 2: A reverse cycle unit

Name: Samsung - AR09FSSSBWKNSA - Split System Air Conditioner

Figure 7.1 - Samsung - AR09FSSSBWKNSA - Split System Air Conditioner

Specifications:
Price: $899
Supplier: Bing Lee
Cooling Capacity: 2.5kW
Heating Capacity: 3.2 kW
Dehumidifier Function: Yes
Portable: No

Description: The Samsung - AR09FSSSBWKNSA is a reverse cycle climate control unit which includes a heater and air-conditioner in a single device. This system is not portable and has a complex setup – as it includes an indoor and an outdoor unit. The system is aesthetically pleasing. The dimensions of the indoor unit are 89cm x 54.7cm x 28.1cm with a weight of 10.4kg, and the dimensions of the outdoor unit are 89.6cm x 54.7cm x 28.1cm with a weight of 32kg. The setup of the system is labour intensive and requires specialised personnel to complete the installation –making it a likely expensive procedure. The unit includes 3 fan speeds, a timer feature, a dehumidifier function (up to 1L/hour), an air filter function, and an oscillation function. The unit is Wi-Fi enabled, where the client is able to interact with the unit using a smartphone or tablet device. Online research indicates that the machine produces a 'rubber' smell which has resulted in customers developing headaches. Overall, the device meets most of the engineering requirements, the system function and subsystem definitions, and almost all of the relevant tertiary attributes in the attributes cascade. However, previous owner reviews describe a 'foul' odour produced when operating the unit is concerning, and could be unsafe and unsatisfactory to the client. (ProductReview.com.au, 2014)

7.2 Proposed Solution

By comparing the two options, 'Option 1 Separate single cycle heating and cooling units' seems to be more suitable to the client. The cost of both individual products is less than the cost of the Samsung reverse cycle unit by $384.68 (disregarding any installation fees). The cooling capacity of this option is greater by 1.1kW, however the heating capacity is less by 1.2kW.

The 'Prima 2000W Slim Ceramic Oscillating Tower Heater' and 'Highlander Portable Air Conditioner (12,000 BTU)' generally satisfy the customer requirements, meet the system function and subsystem definitions, and meet the majority of the system attributes.

The heater can be used to help dry some of the clothes of the customer. This can be done by placing the drying clothes in the same room as the heater, or specifically, pointing the heater (at a safe distance) at the drying clothes in the room.

If the heating or cooling service provided by these units is insufficient, the user can simply purchase an additional unit. Since the home is rented, the solution is generally better for the client as it does not require permanent changes to the home. Additionally, if the client is to relocate to another address, the client can take the purchased units into the new residence.

7.2.1 Supplementary Option

Air-leakage in homes is a significant factor to loss of heat retainment within a home. In order to minimise the heating and cooling requirements in the home, the client can make some minor adjustments within the home to minimise the amount of air-leakage. To decrease air-leakage, the client can place rubber seals and weather stripper beneath all of the doors in the room. The client can also increase the thermal resistance of the windows of the house by investing in quality sheer curtains. This resultantly decreases the amount of heat energy travelling through the windows of the house and decreases convection currents within the house. These suggestions will likely decrease the overall running costs of the proposed solution, reducing ongoing costs and increasing effective performance in the delivered system.

8.0 Verification

To verify if the proposed solution adequately meets the customer requirements, an analytical model is created which hypothetically tests the operation of the proposed solution. Since the proposed devices are found on the international market, it is assumed that they are fully operational on a functional level. The analytical model will focus on testing if the Prima 2000W Slim Ceramic Oscillating Tower Heater will deliver adequate heat for the client's home, and if the Highlander Portable Air Conditioner (12,000 BTU) will effectively cool the client's home. This analysis will utilise basic principles of thermodynamics.

8.1 Model Assumptions

This analysis will assume a typical August day, where the daily mean temperature is estimated to be 8.6^{o}C (BOM, 2013). Furthermore, the analysis will assume a heated room temperature of 20°C. The model will assume that the room has an area of roughly 13 square metres, with appropriate carpeting, Gyprock plasterboard walls and ceiling, terracotta roof tiles, wooden doors, and singled glazed aluminium framed windows, having an overall thermal resistance of roughly 0.0030K/W. Air leakage in the home will be approximated as equal to 30% of the thermal heat loss in the room (roughly accurate for an entire house). This analysis will neglect heat gains due to solar gains in the room, and the thermal mass of the house. The analysis will assume the heater operates for 6 hours per day.

8.2 Estimate of Heating Requirements

An estimate of heating requirements for one day (6 hours) can be identified by determining the thermal heat loss of the room. This is determined through the following formula.

$$Thermal\ heat\ loss = \frac{(Room\ temperature - Average\ Ambient\ Temperature)}{Thermal\ Resistance\ of\ Room}$$

$$= \frac{20 - 8.6}{0.0030}$$

$$= 3.800\ kW$$

Thus, considering a 30% air-leakage, the thermal heat loss is 4.94 kW.

Hence the heating requirements for one day (for 6 hours) is determined as

$$Heating\ requirements = Thermal\ loss \times 6\ hours$$

$$= 29.64\ kWh/day$$

Thus the operating duration required for the system to produce this amount of energy is

$$Operating\ duration = \frac{Heating\ requirements}{Heating\ capactity\ of\ heater}$$

$$= \frac{29.64\ kWh/day}{2kW}$$

$$\approx 14.82\ hours/day$$

Thus in order to sustain a 20°C temperature in the room for 6 hours during the day, the heater must operate for approximately 14.82 hours. This duration seems extreme; however is an overestimate since the solar gains in the house and the thermal mass within the house are not considered within the model. Additionally, the air-leakage factor is likely overestimated, as 30% is accurate for the air-leakage for an entire home closed boundary and considers leaks under garage doors etc. As a result, the operating duration is expected to be significantly lower by these 3 factors – and close to 6 hours.

8.3 Analytical Model Conclusions

The analytical model has identified that the heater will be able to sustain a 13m room at 20°C for 6 hours if it is operating for roughly 6 hours. This seems quite reasonable considering that sustaining a room at 20°C for 6 hours during a winter day is expected to be very power demanding. As a result, the analysis verifies that the heater is suitable to heat a medium sized room in the client's house.

Since the Prima 2000W Slim Ceramic Oscillating Tower Heater has a lower heating capacity than the Highlander Portable Air Conditioner (12,000 BTU) has a cooling capacity, it hence follows that the air-conditioning unit will also adequately cool the room.

Thus, the proposed solution has been verified using a thermodynamics model to satisfy the climate control requirements of the client to heat a single room.

The analytical model provided numerical insight to the effect of air-leakage in the house. It has been verified that the supplementary proposal to minimise air-leakage will decrease the heating requirements. Additionally, increasing the thermal resistance in the house by improving the quality of the curtains will also decrease the heating requirements in the home.

If the client desires to heat or cool more than one room, the client can purchase additional units to place in other rooms.

9.0 Conclusion

By applying system engineering methods through engineering requirements analysis, system function analysis, system attributes analysis, design evaluation, and verification, an adequate design solution has been proposed for the client. Requirements engineering analysis identified that safety, low costs, and aesthetics are the most important customer requirements. This was determined by pairwise and house of quality analysis techniques. Systems functions analysis identified the projected user interaction with the delivered system. Subsystem integration analysis identified how the delivered system should behave on a subsystem level. By applying system attributes techniques, twenty-two design primary attributes, thirty-four secondary attributes, and fifty-four tertiary attributes were identified which describe an ideal solution for the customer. Design evaluation compared several available climate control units. Verification confirmed that the selected option in the design evaluation will satisfy the client's requirements through an analytical thermodynamic model.

It is proposed that the client invests in separate single cycle heating and cooling units; Prima 2000W Slim Ceramic Oscillating Tower Heater and Highlander Portable Air Conditioner (12,000 BTU) at a total cost of $514.32. Additionally, a supplementary proposal is to minimise the air-leakage in the home, and increase the thermal resistance of the home by investing in good quality sheer curtains.

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11.0 Appendix

The FFBD for enabling the climate control system is seen in Figure 11.0 below.

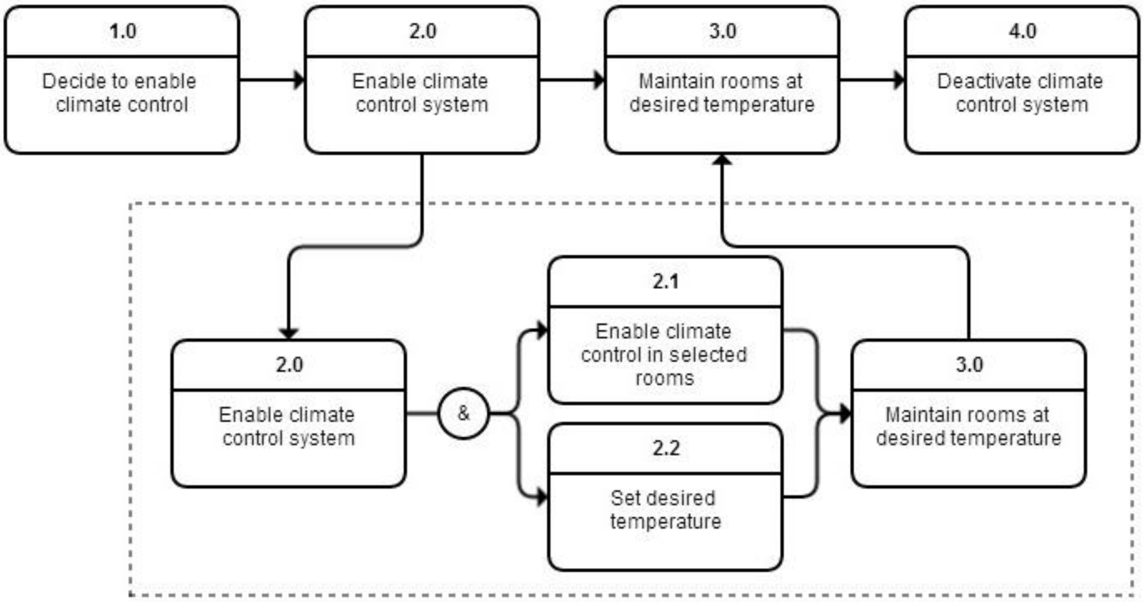

Figure 11.0 – FFBD for 'Enable climate control system'

The complete attributes cascade is seen in Table 11.0 below.

Table 11.0 – Attributes Cascade

Design Requirement/Primary Attribute	**Secondary Attribute**	**Tertiary Attribute**	**Related Subsystems**
A1.0 Adjustable temperature settings	A1.1 The system can heat to the accuracy of 0.5^0C between appropriate maximum and minimum values	A1.1.1 Heating and cooling elements quickly adapt to change in temperature	Climate, Control, Electronics, Display
A2.0 Adjustable direction	A2.1 The system can heat in any desired direction (360^0)	A2.1.1 A rotating pivot is included in the design	Casing and Enclosure, Climate
A3.0 Fan intensity is adjustable	A3.1 Variable controls	A3.1.1 Motor can operate at various speeds	Climate, Control, Electronics
A4.0 Overall design is aesthetically pleasing	A4.1 Long-lasting finish	A2.1.1 Appropriate colour scheme	Casing and Enclosure
	A4.2 Proposed solution suits the home of the client	A2.2.1 Design is stylish and elegant across all levels	Casing and Enclosure
A5.0 Constructed with reliable material	A5.1 Material is strong	A3.1.1 Strong in all temperature conditions	Casing and Enclosure, Climate, Safety
		A3.1.2 Material is not brittle	Casing and Enclosure, Climate, Safety
		A3.1.3 Material will not strain or become fatigued	Casing and Enclosure, Climate, Safety
	A5.2 Material is chemically stable	A3.2.1 Material is resistant to corrosion when under normal use	Casing and Enclosure, Climate, Safety
		A3.2.2 Material is not dangerous when exposed to certain chemicals	Casing and Enclosure, Climate, Safety
A6.0 System can dry clothes client's clothes during winter	A6.1 System can provide sufficient heat to dry wet clothing	A6.1.1 Heating element can withstand high temperatures for a long duration	Climate, Safety
		A6.1.2 System climate-control distributor can provide sufficient heat distribution	Climate
A7.0 System user	A7.1 User can easily adjust settings	A7.1.1 Single point of control	Control, Display

interaction is basic		manipulation	
		A7.1.2 Control manipulation is not technical	Control, Display
A8.0 System includes convenient feature for client	A8.1 System includes a timer control settings	A8.1.1 System includes a controlling contact for program switching	Control, Display
	A8.2 System is controlled remotely	A8.2.1 System includes signal receptors	Control
A9.0 System heats effectively	A9.1 System includes reliable heating element	A9.1.1 Heating element can withstand high temperatures for a long duration	Climate
		A9.1.2 System climate-control distributor can provide sufficient heat distribution	Climate
A10.0 System cools effectively	A10.1 System includes reliable cooling element	A10.1.1 Cooling element can withstand low temperatures for a long duration	Climate
		A10.1.2 System climate-control distributor can provide sufficient heat distribution	Climate
A11.0 System regulates moisture content in air	A11.1 A humidifier is included in the system	A11.1.1 Humidifier monitors moisture content in air	Climate
		A11.1.2 Humidifier adjusts moisture content appropriately	Climate
A12.0 System effectively filters air	A12.1 System can filter impurities in air	A12.1.1 Filter can remove stale air	Climate
		A12.1.2 Filter introduces fresh air to the system	Climate
A13.0 System can heat and cool system-controlled environment	A13.1 Thermostat required to monitor temperature	A13.1.1 Thermostat is positioned appropriately in the room	Climate
		A13.1.2 Thermostat is integrated with system to adjust temperature	Climate
	A13.2 Flexibility to control climate in multiple rooms	A13.2.1 Client can manually direct rooms to be climatised	Climate
A14.0 Low installation costs	A14.1 Installation is not labour intensive	A14.1.1 Client can self-install the system	Casing and Enclosure
	A14.2 Unit is cost effective	A14.2.1 Design is optimised to minimise material costs	Casing and Enclosure, Climate, Electronics
		A14.2.2 Manufacturing procedure is not	Casing and Enclosure,

		cost prohibitive	Climate, Electronics
A15.0 Green energy rating	A15.1 The system is not power intensive	A15.1.1 Heating element is appropriate to the room size	Climate
		A15.1.2 Cooling element is appropriate to the room size	Climate
		A15.1.3 Thermostat accurately adjusts power consumption	Climate
		A15.1.3 System efficiently converts power to energy	Climate, Electronics
A16.0 Maintenance costs are minimal	A16.1 System components are easily replaceable	A16.1.1 System is constructed with standard components	Casing and Enclosure, Climate, Control, Display, Electronics, Safety
	A16.2 Maintenance is not labour intensive	A16.2.1 Client can complete any necessary labour	Casing and Enclosure, Climate
A17.0 The system is resistant to wear	A17.1 Components within the system are highly reliable	A17.1.1 System components are well manufactured	Casing and Enclosure, Climate, Control, Display, Electronics, Safety
		A17.1.2 Components are integrated appropriately	Casing and Enclosure, Climate, Control, Display, Electronics, Safety
	A17.2 Easy to remove and replace components	A17.2.1 The design system incorporates maintenance strategy	Casing and Enclosure, Climate, Control, Display, Electronics, Safety
A18.0 Minimal noise during operation	A18.1 Noisy components are enclosed	A18.1.1 Noise dampening material	Casing and Enclosure, Climate
		A18.1.2 Moving components are self-lubricated	Casing and Enclosure, Climate
A19.0 Proper and normal use conditions are safe	A19.1 Electrical components are insulated	A19.1.1 Non-circuit metallic components are earthed	Electrical, Safety
		A19.1.1 All internal wiring consistent with AS3000	Electrical, Safety

	A19.2 External contact areas and exterior casing of system remains cool	A19.2.1 Exterior casing is resistant to heat	Casing and Enclosure, Safety
A20.0 Emergency shutdown	A20.1 Device only operates in the proper position	A20.1.1 System has a method of detecting when device is in correct position	Casing and Enclosure, Safety
		A20.1.2 System will stop operating when device is not in correct position	Casing and Enclosure, Safety
	A20.2 Device has inbuilt electrical safety	A20.2.1 Device has overcurrent protection	Electrical, Safety
	A20.3 Device has thermal protection	A20.3.1 System has ability to detect when heating element has exceeded safe operating parameters	Climate, Safety
		A20.3.2 System will stop operating when device is no longer within safe thermal operating range	Climate, Safety
A21.0 A single device can provide heating and cooling	A21.1 Device consists of a heater and air-conditioner	A21.1.1 Design includes a heating element	Climate
		A21.1.2 Design includes a cooling element	Climate
A22.0 System is not obstructive to client and other objects	A22.1 System has small footprint	22.1.1 System components are small	Casing and Closure, Climate, Control, Display, Electronics, Safety
		22.1.2 Component assembly is optimised to minimise space requirements	Casing and Closure, Climate, Control, Display, Electronics, Safety
	A22.2 System installed away from high traffic areas	22.2.1 System operation does not require being in a particular location	Casing and Closure, Climate, Control, Display, Electronics, Safety