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REVISION STATUS AND APPROVAL					
REVISION	**DATE**	**STATUS**	**AUTHOR**	**PROJECT ENGINEER**	**APPROVED**
5	4/8/99	Final	TJE		

Executive Summary

This report has been prepared to provide comparative energy consumption data for various air conditioning systems ranging from conventional variable air volume systems commonly used in Melbourne CBD buildings to systems featuring active chilled beams and chilled ceilings.

A typical floor of a Melbourne CBD office building with a multizone VAV system was used as a base case for the comparison of systems. Loads onto the various air conditioning systems were derived from thermal models with typical tenancy heat loads and recorded Melbourne weather data.

The study shows that the systems may be ranked in terms of energy performance from lowest to highest as follows:

Option No.	***System Type***	***Ranking***	***Energy Consumption*** (MJ/a.m²)
4	Induction Units (Perimeter) & Active Chilled Beams (Centre)	1	117
5	Induction Units (Perimeter) & Chilled Ceilings (Centre)	1	117
3	Induction Units (Perimeter) & VAV (Centre)	3	147
2	Twin Duct	4	157
1a	VAV with Temperature Optimisation	5	161

The base case multizone VAV system was shown to perform poorly when compared to the other systems modelled. The system was originally designed for a tenant equipment load of 7.5 W/m². When the systems capacity is limited to the original design capacity and the tenant equipment load increased to 35 W/m² the results show that, for the selected zone, the system will not maintain internal conditions on a summer design day.

1.0 INTRODUCTION

1.1 General

This report has been prepared to provide a comparison of annual energy consumption between a number of different air conditioning systems. A single floor of a CBD office building in Melbourne has been used as the basis of the study.

1.2 Purpose

The purpose of this report is to investigate the energy consumption performance, of various air conditioning system configurations. Air conditioning systems include the existing blow through multizone system, conventional variable air volume systems, active chilled beam and chilled ceiling systems. A comparison of occupant comfort between a selected number of the systems is also provided.

This report does not consider other salient factors such as capital and recurrent costs of each system, ventilation effectiveness and the like. These will be addressed by cover of a separate report.

A study was also undertaken to determine which control strategy provides the best performance in terms of energy consumption for Melbourne weather conditions.

The most appropriate outside air control strategy was applied to each of the different system configurations modelled.

1.3 Sources of Information

The following sources of information have been utilised in the collation of this report:

- ACADS BSG/CSIRO, Melbourne nominated Test Reference Year (TRY) recorded weather data.
- Project brief ref. MRB81054
- Drawings 3954 M-349E, ML249027-L36-MO1A and relevant sections of the mechanical specification for the existing system.

1.4 Limitations

This report does not consider factors such as capital and recurrent costs of each system, ventilation effectiveness and the like. These factors will be addressed in a separate report. The results presented are based on air conditioning systems as described within this report.

2.0 APPROACH

2.1 General

Our approach to this study commenced with the development of a 3D thermal computer model for a typical floor of the building (Level 6), from which peak loads and daily load profiles were established with consideration of internal loads, building envelope and weather data.

Each air conditioning system configuration was then simulated to determine both coincident plant capacity and annual energy consumption.

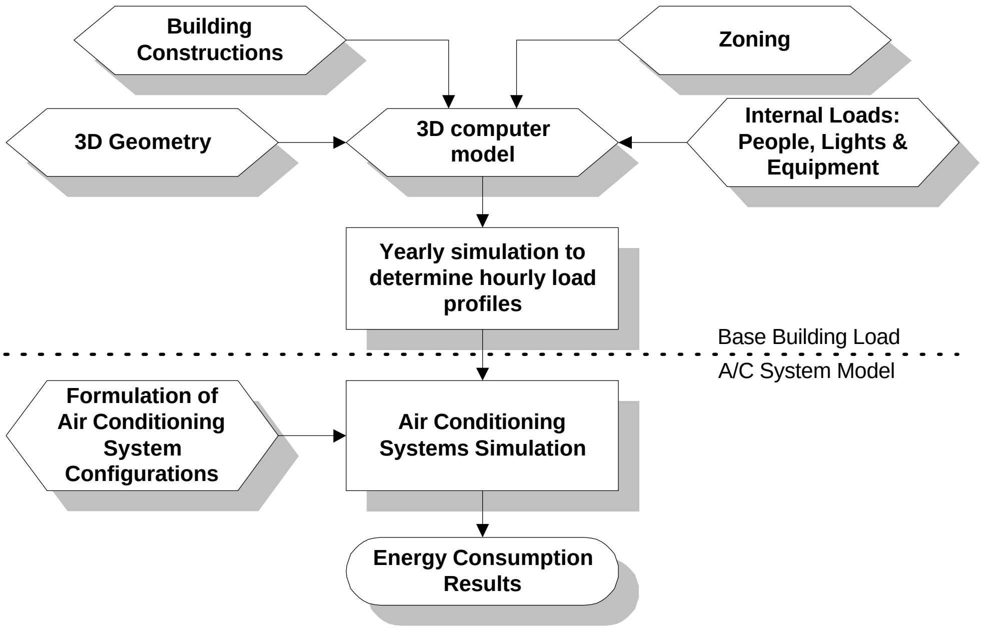


Figure 2.0 - Modelling Flow Chart

The approach taken to evaluate the performance of economy cycle operation was to model various control strategies eg enthalpy control against a base plant configuration. For the purposes of this report a VAV plant configuration with common perimeter air handling unit, typical for multi-storey type office buildings was used.

The configuration that provided the best energy performance was then adopted with all other A/C systems that incorporate economy cycle operation.

2.2 Economy Cycle Analysis

As discussed previously, a VAV system, comprising a centre zone air handling unit and common perimeter zone unit with separate electric trim heaters was used, for the comparison of various control strategies. The control strategies considered are summarised in Figure 2.1 and are described as follows with schematic diagrams of each presented in Appendix D and E:

Option 1a VAV system with fixed minimum outside air quantities and rescheduling of off-coil temperatures.

Option 1b VAV system with temperature optimised economy cycle and dry bulb temperature cut-off rescheduling of off-coil temperatures.

Option 1c VAV system with enthalpy optimised economy cycle with rescheduling of off-coil temperatures.

Option 1d VAV system with fixed minimum outside air quantities and fixed off-coil temperature. TS/A Centre = 17°C, TS/A Perimeter = 13°C.

Option 1e VAV system with temperature optimised economy cycle and dry bulb temperature cut-off with fixed off-coil temperature.

Option 1f VAV system with enthalpy optimised economy cycle with fixed off-coil temperature.

Method of Control	***Re-scheduled Off-Coil Temperature***	***Fixed Off-Coil Temperature***
Fixed O/A	1a	1d
Ambient Dry Bulb Cut Off + Temperature Optimisation	1b	1e
Enthalpy Optimisation	1c	1f

Figure 2.1 - Economy Cycle Configuration Matrix

2.3 System Configurations

The energy analysis presented herein was undertaken for the existing blow through multizone variable air volume (VAV) system, conventional VAV and systems featuring a combination of VAV, active chilled beam induction units and chilled ceiling technology.

The systems are more fully described hereunder with schematic diagrams of each presented in Appendix D and E.

Base Case System - *VAV with blow through multizone AHU*

The system comprises of two blow through multizone units per floor. Based on the specification for the existing system the following parameters were used in the modelling:

Item	*Specified*	*Modelled*
Tower A - Supply Air Quantity	4815 l/s	4815 l/s
Tower B - Supply Air Quantity	5560 l/s	5560 l/s
Tower A - Cooling Capacity Per Level	97.87 kW (TC)	97.87 kW (TC)
Tower B - Cooling Capacity Per Level	113.7 kW (TC)	113.7 kW (TC)
Tower A - O/A Quantity	10 l/s/m²	10 l/s/m²
Tower B - O/A Quantity	7.5 l/s/m²	10 l/s/m²
Main Setpoint Centre Zone	17°C	17°C

The following control parameters have been used:

- COP of Chiller = 4.9090
- COP of Boiler = 0.850
- Heating coil main control setpoint = 26°C for centre zone warm up cycle only
- Cooling coil main rescheduled based on zone return air temperature.
- Perimeter zone supply air temperature rescheduled based on zone return air temperature.
- Hot water reheat rescheduled based on zone air temperature.
- Target Enthalpy for Economy Cycle operation = 33 kJ/Kg
- Air Intake Percentage (Warm Duct) between 5% (Low Setting) - 95% (High Setting).
- Air Intake Percentage (Cold Duct) between 5% (Low Setting) - 95% (High Setting).

- Static Pressure of AHU Fans = 0.9 KPa
- Static Pressure of Spill Air Fans = 0.25 KPa

Enthalpy economy cycle with the target enthalpy of 33 kJ/kg is used for the control of outside air into the multizone units.

Rescheduling of the cooling coil is based on the return air temperature.

System Configuration 1 *- VAV with common perimeter AHU*

This system would typically comprise separate air conditioning air distribution systems and associated air handling plants arranged to serve all perimeter zones (treated as a common zone for facades of differing orientations) and the centre zone.

The VAV terminal units serving the common perimeter zone would be equipped with electric trim heaters to provide local heating as required after shutdown of the early morning warm up cycle typically handled by hot water coils in the AHU.

System Configuration 2 *- Twin Duct©*

The Twin Duct variable air volume air conditioning system is an alternative to the typical VAV type systems.

The basic principle of the system is to deliver (or make available) Cold air and Neutral air, (at variable temperatures and flow rates to suit the demand placed upon them) throughout the building.

The air conditioning system comprises a pair of matched variable temperature, variable volume air distribution networks, either of which is available to supply air to any zone.

- The system features two parallel ducts:
- the Cold duct which transports air at between 13°C and 21°C; and
- the Neutral duct in which the air temperature varies from 17°C to 32°C.
- A significant attribute of the system is the ability to handle large variations in demand for ventilation rates, via the outside air component of the Neutral duct.
- Further attributes include:
- The system uses a larger number of VAV boxes than for conventional systems and can therefore readily accommodate office churns and associated re-partitioning without the need to undertake air conditioning alterations.
- The system configuration is inherently adaptable as it incorporates neutral and cold ducts which are each run in a looped configuration making use of airside diversity to deal with local areas of high heat emission without the need for supplementary air conditioning.

- Various Code requirements demand that different functional spaces be provided with outside air ventilation rates which are related to population density. Thus when an open office space is to be converted to, say Conference Rooms, there may be a need to introduce additional outside air for ventilation purposes and this in turn may require the installation of a supplementary condenser water cooled air conditioning units.

The Twin Duct system will produce the same outcome by the addition of an additional Twin Duct box on a plug-in basis, which can simply be accomplished by the building's maintenance staff in lieu of expensive specialist contractors. The additional outside air required can be drawn from the neutral duct which runs with a higher proportion of outside air without affecting the room psychometrics.

- The Twin Duct system incorporates a greater number of VAV boxes than for a conventional system with each box typically handling no more than 220 L/s of supply air. Thus a greater level of thermal zoning is inherent in the system which is particularly suited to office areas with non-uniform heat emission from tenants equipment which can result in undesirable temperature differences between neighbouring areas noticed as hot spots.

System Configuration 3 *- VAV (Centre)+Induction Units (Perimeter)*

The system would typically comprise of separate air conditioning air distribution systems and associated air handling plant, one to serve the centre zone and one to serve the perimeter zones. The centre zones would typically be served by a conventional VAV system with the perimeter zones by induction units. The induction units rely on the discharge of primary cooled and dehumidified air being discharge at high velocity through a series of nozzles within the unit. The air flow causes a secondary stream of air to be induced into the unit via the secondary air cooling coil . A mixture of the primary and secondary air is discharged into the space for conditioning of the space.

System Configuration 4 - *Active Chilled Beams (Centre)+Induction Units (Perimeter)*

The system would typically comprise of separate air conditioning air distribution systems and associated air handling plant, one to serve the centre zone and one to serve the perimeter zones. The centre zones being served by a active chilled beams with the perimeter zones by induction units. Both the active chilled beams and the induction units rely on the discharge of primary cooled and dehumidified air being discharge at high velocity through a series of nozzles within the unit. The air flow causes a secondary stream of air to be induced into the unit through the cooling coil. A mixture of the primary and secondary air is discharged into the space for conditioning of the space.

System Configuration 5 *- Chilled Ceiling (Centre)+Induction Units (Perimeter)*

The system would typically comprise of separate air conditioning air distribution systems and associated air handling plant, one to serve the centre zone and one to serve the perimeter zones. The centre zones being served by chilled ceilings with the perimeter zones by induction units. Chilled ceilings rely on chilled chilled surfaces (either flat surfaces or finned elements) with chilled water/heating hot water reticultated to provide comfort conditions. Cooling / heating is achieved by means of these radiant elements. Preconditioned outside air would be separately distributed throughout the space to provide fresh air for ventilation purposes. For purposes of system assessment, a chilled ceiling with a radiant cooling proportion of 60% has been used.

The induction units rely on the discharge of primary cooled and dehumidified air being discharge at high velocity through a series of nozzles within the unit. The air flow causes a secondary stream of air to be induced into the unit via the secondary air heat exchanger . A mixture of the primary and secondary air is discharged into the space for conditioning of the space.

2.4 Night Purge Operation

In order to assess whether any benefit may be derived from purging the space with cooler night time air thereby removing stored heat from the structure, the merits of an automatic night purge cycle were assessed. This study was based on a Option 1b VAV with temperature optimisation and rescheduling of the supply air temperature. During the summer months a ventilation rate of 6 air changes per hour from midnight until 7 am was used. The temperature of the outside air during this period was not considered.

2.5 Thermal Comfort

To provide an assessment of the difference in occupant comfort between traditional VAV systems and systems which incorporate induction/radiant cooling technologies the following systems were analysed

- *Option 1b - Standard VAV System*
- *Option 5 - Chilled Ceiling (Centre)+Induction Units (Perimeter)*

A 'comfortable' environment is subjective as it relies on an individual's perception of a space. To define the basis for a comfortable space it is essential to appreciate the series of heat exchanges which occur between the human body and it's environment.

- **Convective 35%.** The body is in continual contact with the surrounding air so the amount and direction of heat flow is dependent on the air temperature relative to the body.
- **Radiant 40%.** The body is continually radiating and receiving heat from it's surroundings. The amount and direction of radiant heat exchange is dependent on the temperatures of the surfaces in the space relative to the body's surface temperature.
- **Evaporative 25%.** The body loses heat through the evaporation of perspiration from the surface of the skin. The humidity of the air has a strong influence on this process so that high humidity reduces the amount of evaporative cooling taking place.

In addition to the above, air velocities have a profound effect on the perceived comfort of an individual.

Comfort levels of a space cannot, therefore be accurately defined by air temperature alone and each of the following parameters should be carefully examined:

- air temperature
- air velocity
- mean radiant temperature
- humidity
- Indoor Air Quality - sufficient quantities of fresh air must be introduced into the space to prevent it feeling 'stuffy'.

ISO 7730-1993 is an international standard which defines a comprehensive method of predicting occupant satisfaction within a space. It addresses physical activity, level of clothing, air temperature, mean radiant temperature, air velocity and humidity.

This standard uses a statistical base to determine the Predicted of Percentage of Dissatisfied (PPD) of occupants.

2.6 Basis of Calculations

2.6.1 Internal Conditions

Two distinct internal load profiles were simulated for both design calculations and energy calculations.

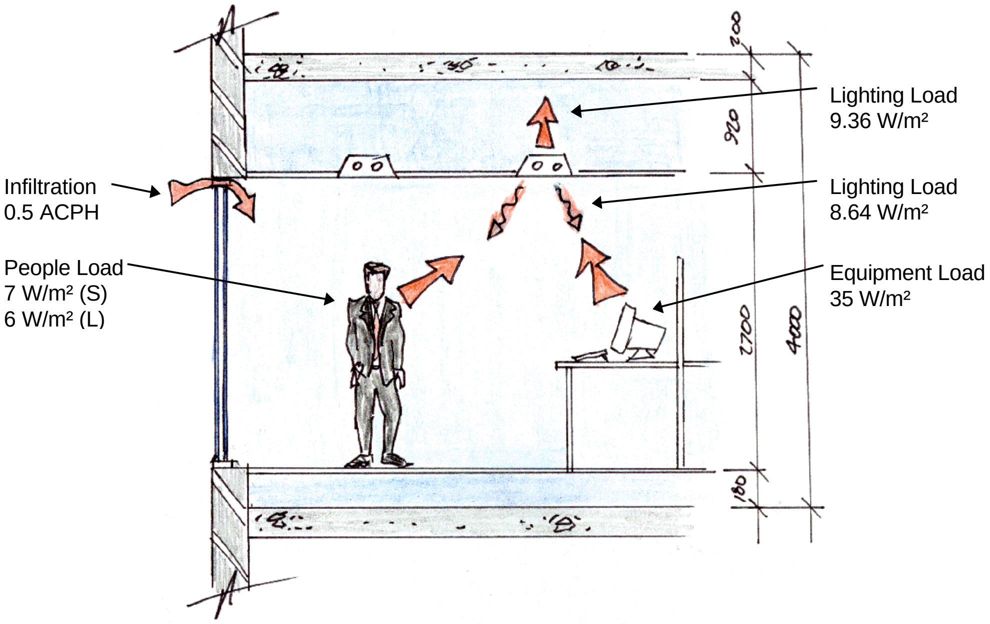


Figure 2.2 - Design Internal Loads

Internal design loads depicted in Figures 2.3 and 2.4 below were used in the calculation of peak design loads, while diversified internal loads (Figures 2.5 & 2.6) representative of building usage, were used in the calculation of annual energy consumption.

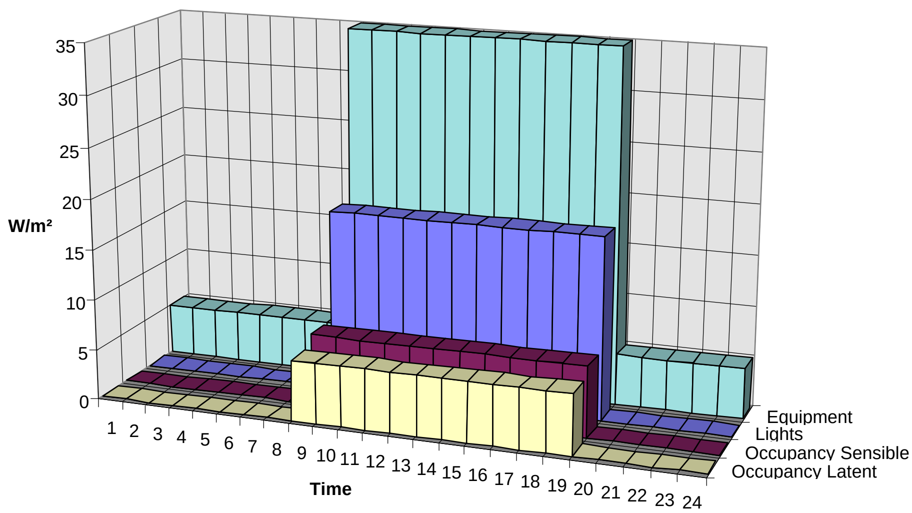


Figure 2.3 - Design Space Loads

Internal Conditions - Design				
Occupation Period	***Lighting Gains*** *(W/m²)*	***Occupancy Sensible Gains*** *(W/m²)*	***Occupancy Latent Gains*** *(W/m²)*	***Equipment Sensible Gains*** *(W/m²)*
1-8	0	0	0	5
9	18	7	6	35
10	18	7	6	35
11	18	7	6	35
12	18	7	6	35
13	18	7	6	35
14	18	7	6	35
15	18	7	6	35
16	18	7	6	35
17	18	7	6	35
18	18	7	6	35
19	18	7	6	35
20-24	0	0	0	5

Figure 2.4 - Design Internal Loads

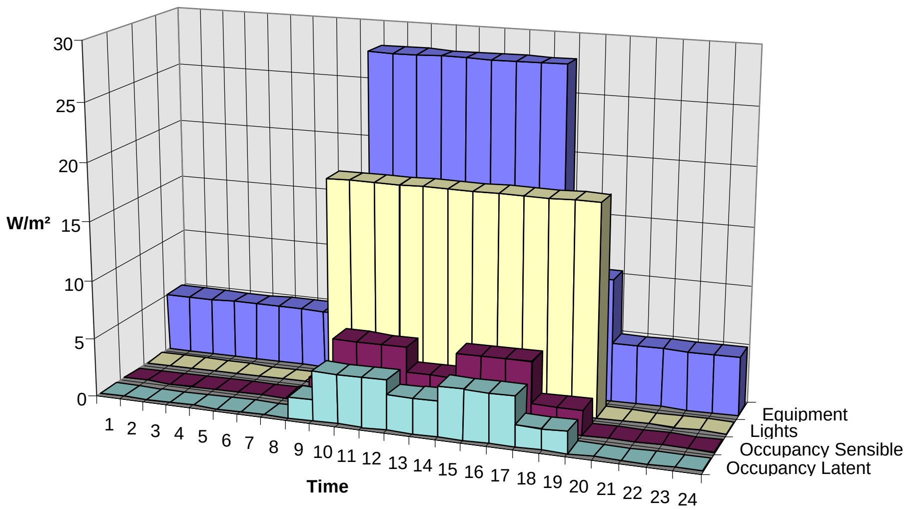


Figure 2.5 - Diversified Space Loads

Internal Conditions - Diversified				
Occupation Period	*Lighting Gains (W/m²)*	*Occupancy Sensible Gains (W/m²)*	*Occupancy Latent Gains (W/m²)*	*Equipment Sensible Gains (W/m²)*
1-8	0	0	0	5
9	18 (100%)	2.1 (30%)	1.8 (30%)	10.5 (30%)
10	18 (100%)	5.6 (80%)	4.2 (80%)	28 (80%)
11	18 (100%)	5.6 (80%)	4.2 (80%)	28 (80%)
12	18 (100%)	5.6 (80%)	4.2 (80%)	28 (80%)
13	18 (100%)	3.5 (50%)	3 (50%)	28 (80%)
14	18 (100%)	3.5 (50%)	3 (50%)	28 (80%)
15	18 (100%)	5.6 (80%)	4.2 (80%)	28 (80%)
16	18 (100%)	5.6 (80%)	4.2 (80%)	28 (80%)
17	18 (100%)	5.6 (80%)	4.2 (80%)	28 (80%)
18	18 (100%)	2.1 (30%)	1.8 (30%)	10.5 (30%)
19	18 (100%)	2.1 (30%)	1.8 (30%)	10.5 (30%)
20-24	0	0	0	5

Figure 2.6 - Diversified Internal Loads (% from design)

2.4.2 Building Construction

The following building constructions were assumed for the purposes of energy calculations.

Glazing: Pilkington 6mm Suncool Monolithic TS30 on Clear (External)

10mm Cavity

6mm Clear Float

Total U-Value 2.679 W/m²°C

Total Shading Coefficient 0.353

Total Solar Transmittance 0.307

Total Light Transmittance 0.267

NB. Values calculated using Pilkington parameters.

2.6.3 Zoning and Generic Building Plan

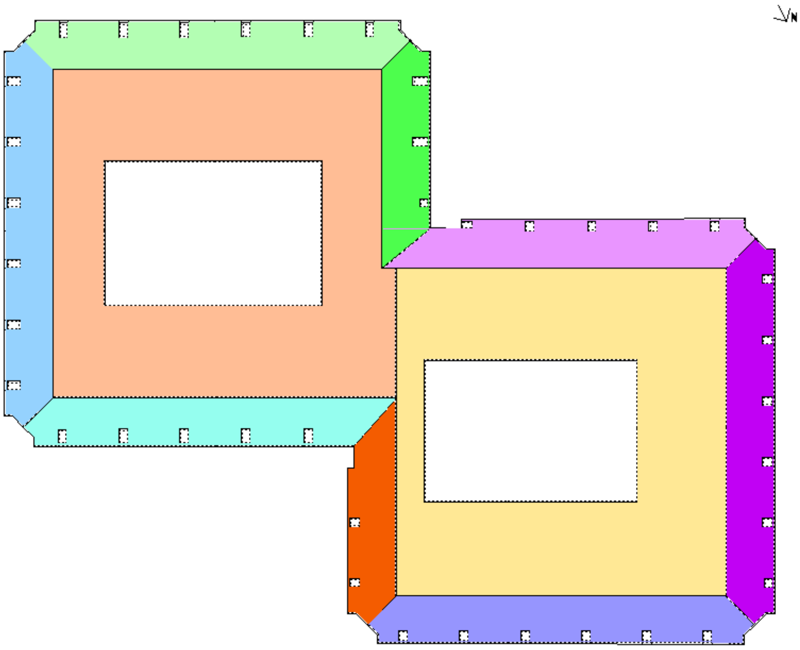


Figure 2.7 - Typical Zoning

2.6.4 Calendar

Plant operation:	Start 7am / Stop 7pm 5 Days/week
Mixed mode plant operation:	Start 7am / Stop 7pm 5 Days/week

Public holidays have not been included.

2.4.5 Plant Performance

AHU Fans: 900Pa External Static
Variable Speed

Spill Air Fans: 250 Pa External Static

Chiller: Full load COP = 4.9
Distribution Efficiency = 95%
Part Load Performance refer Figure 2.8

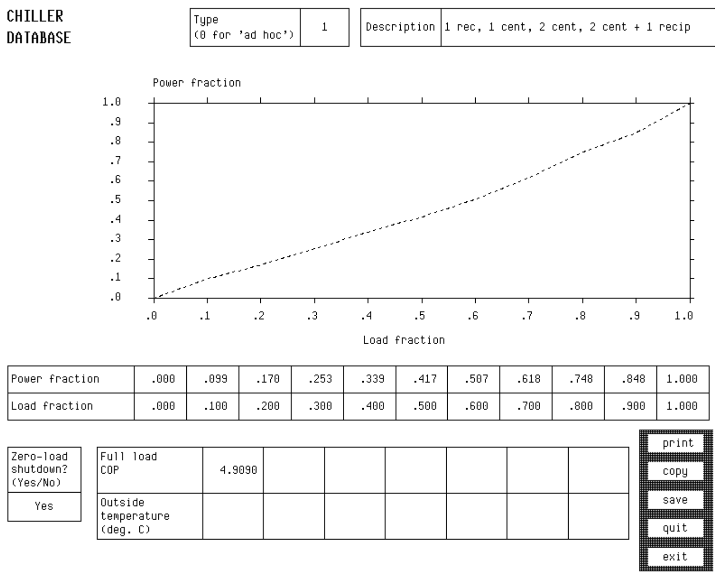


Figure 2.8 - Chiller part load performance

Boiler: Full load Efficiency = 85%
Distribution Efficiency = 95%

Cooling Tower Fans : Chiller Load x 0.01

Chilled Water Pumps: Chiller Load x 0.04

Hot Water Pumps: Boiler Load x 0.02

O/A Quantity: 10l/s/person @ 1person/10m² = 1 l/s/m²
Minimum outside air quantities have been taken to be 1 l/s/m² for the purposes of modelling.

VAV Duties: Perimeter Zones 6 $l/s/m^2_{min}$
Centre Zone 6 $l/s/m^2_{min}$

Secondary chilled water temperature (Induction Units) = 15°C

2.4.6 Energy Costs

Electricity = $0.105/kWh

Natural Gas = $0.036/kWh

3.0 RESULTS

3.1 Design Space Loads

Design space loads were calculated for each month to determine the peak space loads for each zone. The results are presented in Figure 3.1 below.

Zone No.	Zone Name	Dec/Mon (kW)	Dec/Fri (kW)	Jan/Mon (kW)	Jan/Fri (kW)	Feb/Mon (kW)	Feb/Fri (kW)	Mar/Mon (kW)	Mar/Fri (kW)	Maximum (kW)
1	Centre (East)	32.73	26.83	32.67	26.79	27.76	26.5	30.18	26.25	32.73
2	Centre (West)	32.51	26.7	32.48	26.68	27.63	26.4	30.1	26.17	32.51
3	South 2	12.95	12.32	12.49	11.73	10.02	9.73	8.33	7.82	12.95
4	West 2	8.14	7.64	8.23	7.79	7.76	7.69	7.61	7.25	8.23
5	North 2	11.68	10.44	12.24	11.1	11.72	11.61	12.73	11.81	12.73
6	East 2	15.36	13.52	15	13.12	11.92	11.52	10.31	9.17	15.36
7	South 1	11.66	11.07	11.29	10.59	9.1	8.85	7.7	7.23	11.66
8	West 1	15.4	14.51	15.67	14.86	15.11	15.02	15.25	14.58	15.67
9	North 1	12.68	11.43	13.32	12.18	12.92	12.84	14.19	13.26	13.32
10	East 1	7.38	6.54	7.25	6.39	5.87	5.69	5.21	4.66	7.38

Figure 3.1 - Peak Design Space Loads

Based on the peak space loads the following VAV duties were established for each zone.

Zone No.	Zone Name	Space Load	Design Flow Rate		Area	Space Load	Flow	Minimum Flow Rate	Design Flow Rate
		(kW)	(kg/s)	(l/s)	(m²)	(W/m²)	(l/s/m²)	(kg/s)	(kg/s)
1	Centre (East)	32.73	3.241	2678.2	522	63	5.1	3.792	3.792
2	Centre (West)	32.51	3.219	2660.2	521	62	5.1	3.783	3.783
3	South 2	12.95	1.282	1059.7	110	117	9.6	0.801	1.282
4	West 2	8.23	0.815	673.4	60	136	11.2	0.438	0.815
5	North 2	12.73	1.260	1041.6	104	122	10.0	0.755	1.260
6	East 2	15.36	1.521	1256.9	110	140	11.4	0.799	1.521
7	South 1	11.66	1.154	954.1	104	112	9.2	0.755	1.154
8	West 1	15.67	1.551	1282.2	111	141	11.6	0.806	1.551
9	North 1	13.32	1.319	1089.9	110	121	9.9	0.799	1.319
10	East 1	7.38	0.731	603.9	58	127	10.4	0.421	0.731

Figure 3.2 - Design Flow Rates

3.2 Economy Cycle Analysis

The study on economy cycle analysis yielded the following results. A breakdown of the results by system component is contained in Appendix B.

- Savings in annual energy use are achieved by the rescheduling of the supply air temperature. The fixed off coil temperature limits the scope for free cooling using outside air.
- Inspection of the monthly plant energy consumption figures shows that savings in chiller load and electric reheat on the perimeter zones are the dominant factors in the reduction of plant energy input.
- Option 1b with temperature optimisation economy cycle and rescheduling of supply air temperatures produced the greatest savings in energy consumption. The energy savings being marginally better than Option 1c enthalpy optimisation economy cycle and rescheduling of supply air temperatures.
- A dry bulb temperature of 23°C was found to the optimum setpoint for outside air cut off. That is, the point at which the occurrence of outside air with a higher enthalpy than the return air is minimal, whilst not reducing the availability of outside air for free cooling.

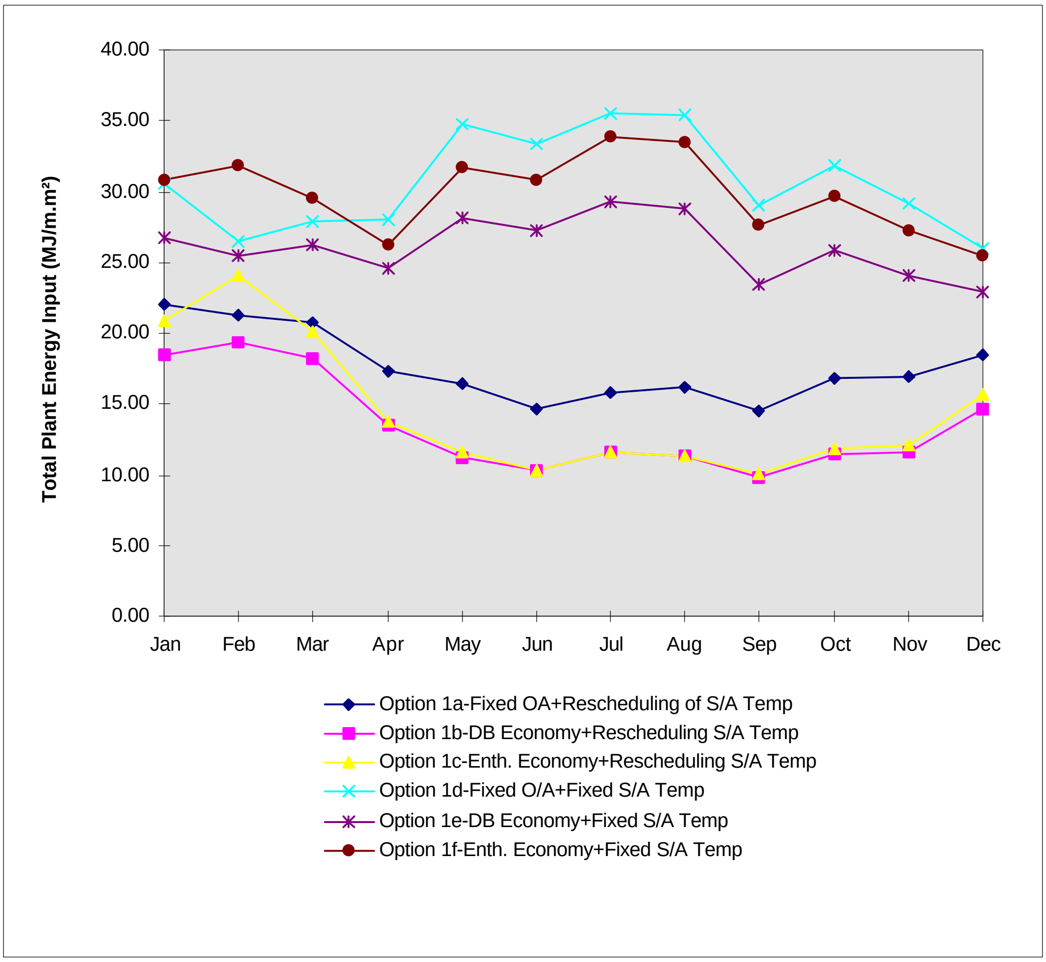


Figure 3.4 - Economy Cycle Monthly Plant Energy Input

Energy Performance Summary				Plant Capacity		
Option	Energy Input (MJ/a.m²)	Energy Cost ($/a.m²)	CO_2 Emission (kg/a.m²)	Chiller (W/m²)	Boiler (W/m²)	Electric Reheat (W/m²)
Option 1a - Fixed O/A + Rescheduling S/A Temp	211.06	5.97	56.87	117.01	30.80	1.65
Option 1b - DB Economy + Rescheduling S/A Temp	161.58	6.52	43.54	117.10	31.81	1.65
Option 1c - Enth. Economy + Rescheduling S/A Temp	177.32	7.95	47.78	266.50	32.11	1.66
Option 1d - Fixed O/A + Fixed S/A Temp	367.13	10.71	98.92	119.53	0.00	42.44
Option 1e - DB Economy + Fixed S/A Temp	313.12	9.13	84.37	145.67	0.00	42.44
Option 1f - Enth. Economy + Fixed S/A Temp	359.22	10.36	96.79	272.67	19.81	42.62

Figure 3.5 - Energy Performance Summary

3.3 System Configurations

Temperature optimisation economy cycle was applied and the system configurations yielded the following results: A breakdown of the results by system component is contained in Appendix C.

- There is little difference between the performance of Option 4 Induction Units (Perimeter) & Active Chilled Beams (Centre) and Option 5 Induction Units (Perimeter) & Chilled Ceiling (Centre). This implies that there is little difference between the performance of Active Chilled Beams and Chilled Ceilings for the centre zones. Inspection of the monthly plant energy consumption figures shows that for both Option 4 and Option 5 (when compared against the other systems) a reduction in AHU fan loads is the dominant factor in the reduction of plant energy input.
- When comparing Option 3 Induction Units (Perimeter) & VAV (Centre) with Option 1b VAV (Perimeter) & VAV (Centre), during the summer months there is a clear reduction in energy use for the induction units. This can be attributed largely to a reduction in AHU fan loads.
- When comparing Option 3 Induction Units (Perimeter) & VAV (Centre) and Option 4 Induction Units (Perimeter) & Active Chilled Beams (Centre) there is a reduction in the annual energy use between the two systems. This can be attributed to the use of Active Chilled Beams in the centre zones and the corresponding reduction in AHU fan load.
- With regard to all options where Induction Units have been modelled on the perimeter zones we note that due to undersizing of the Induction Units on a single Western zone internal conditions are not maintained.
- When comparing Option 1b VAV (Perimeter) & VAV (Centre) and Option 2 Twin Duct, in terms of annual energy use these systems are comparable.
- The existing base case multizone system performs poorly in comparison to the other systems.

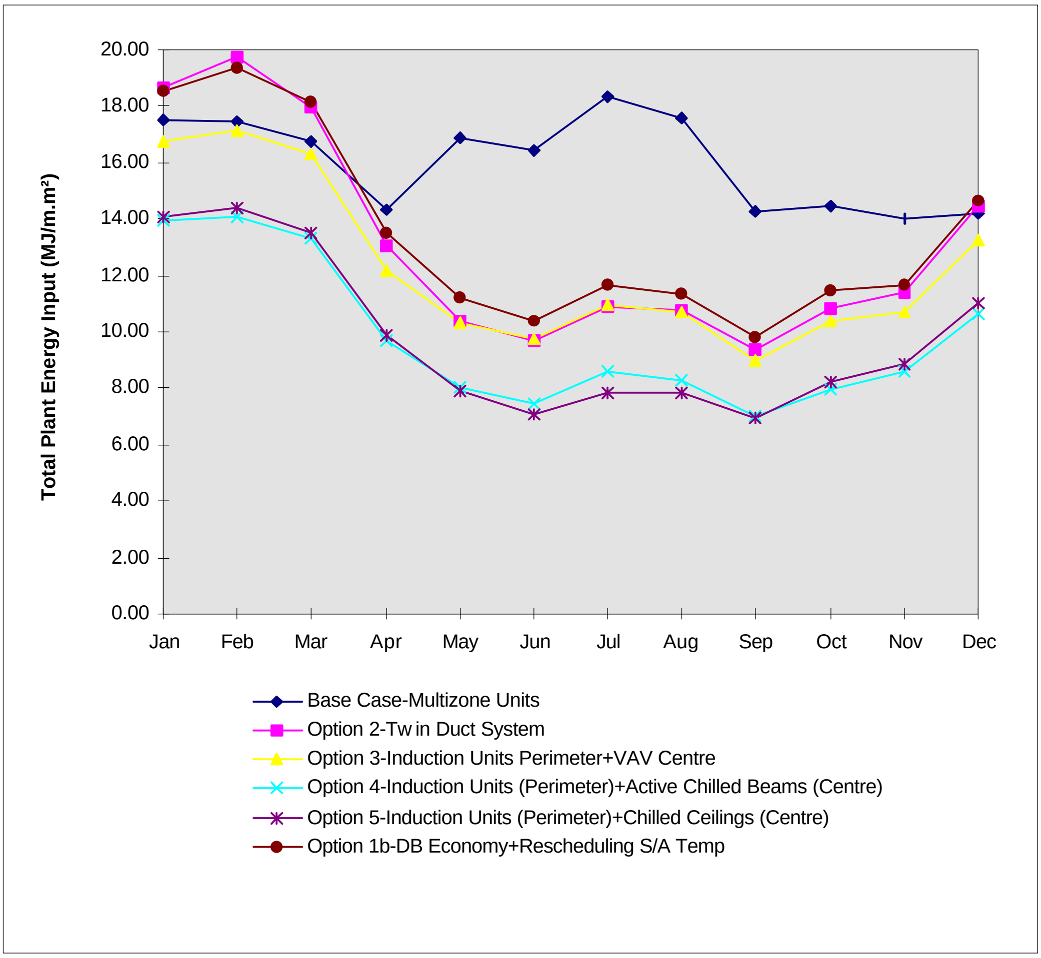


Figure 3.6 - Monthly Plant Energy Input

Energy Performance Summary				***Plant Capacity***		
Option	***Energy Input*** *(MJ/a.m²)*	***Energy Cost*** *($/a.m²)*	***CO_2 Emission*** *(kg/a.m²)*	***Chiller*** *(W/m²)*	***Boiler*** *(W/m²)*	***Electric/Hot Water Reheat*** *(W/m²)*
Base Case-Multizone Units	193.56	5.62	52.15	105.38	6.26	34.01
Option 2-Twin Duct System	157.18	4.36	42.35	117.13	30.40	0.00
Option 3-Induction Units (Perimeter)+VAV (Centre)	147.39	4.04	39.71	105.90	25.65	0.00
Option 4-Induction Units (Perimeter)+Active Chilled Beams (Centre)	117.43	3.17	31.64	98.38	27.28	0.00
Option 5-Induction Units (Perimeter)+Chilled Ceilings (Centre	117.67	3.28	31.71	101.13	21.41	0.00

Figure 3.7 - Energy Performance Summary

3.4 Night Purge Cycle Analysis

A standard VAV system (Option 1b) was used as the basis of the night purge cycle assessment. The results for the summer months of January, February and March can be summarised as shown in figure 3.8 below:

Rialto Towers - Option 1b - Standard Operation			
Plant Component	***Annual Energy Input***		
	(kWh//level)	*(kWh/m²)*	*(MJ/m²)*
Chiller	10,039.00	5.55	19.97
Boiler	1.00	0.00	0.00
AHU Fans	11,626.00	6.42	23.12
Electric Reheat	0.00	0.00	0.00
Cooling Tower Fans	553.00	0.29	1.06
Pumps	2,213.00	1.18	4.25
Spill Air Fans	1,966.00	1.09	3.91
	TOTAL	14.53	52.32

Rialto Towers-Option 1b - Night Purge Cycle Operation			
Plant Component	***Annual Energy Input***		
	(kWh//level)	*(kWh/m²)*	*(MJ.m²)*
Chiller	9,594.00	5.30	19.08
Boiler	395.00	0.22	0.79
AHU Fans	11,602.00	6.41	23.08
Night Purge AHU Fans	6,566.00	3.63	13.06
Electric Reheat	0.00	0.00	*0*
Cooling Tower Fans	533.00	0.31	1.10
Pumps	2,139.00	1.22	4.40
Spill Air Fans	*1931*	1.07	3.84
	TOTAL	18.15	65.34

Figure 3.8 - Comparison of Night Purge Cycle

Whilst the load on the chiller is reduced there is an increase in the heating load. The increase in the heating load can be attributed to the cooling effect of the outside air night purge system and the additional heating required to achieve internal conditions. Additionally, 13 MJ/a.m² of additional energy is required for the operation of the AHU's fans for night purge cycle operation. Night purge cycle operation does not demonstrate any savings in annual energy use. Control systems could be put in place which would be used to sense the internal air temperature thereby preventing overcooling from the night purge cycle operation.

3.5 Thermal Comfort

A standard VAV system (Option 1b) and system incorporating Chilled Ceiling (Centre) and Induction Units (Perimeter) were used as the basis of the study.

The following Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices were obtained:

System	***PMV***	***PPD (%)***
Standard VAV		
Centre Zone	0.64	13.7
Perimeter Zone	1.28	39.1
Chilled Ceilings (Centre) & Induction Units (Perimeter)		
Centre Zone	0.05	5.1
Perimeter Zone	1.15	33

Figure 3.9 - Assessment of Comfort Criteria

These results indicate that overall the Chilled Ceiling and Induction Unit option provides a greater degree of occupant comfort with a PMV of 0.05 and PPD of 5.1% for the Centre Zone and PMV of 1.15 and PPD of 33% for the Perimeter Zone. For the centre zone this can be attributed to the radiant cooling affect and the lower air velocities of the chilled ceiling. For the perimeter zone this can be attributed to lower air flow velocity.

Based on the PMV indices both systems showed the Centre Zone would be regarded as neutral whilst the Perimeter Zone would be regarded as slightly warm by occupants.

3.6 Capacity of Base Case Multizone VAV System

The capacity of the base case multizone VAV system was limited to the design capacity and the tenant equipment load increased from 7.5 W/m² to 35 W/m². The model was simulated for a summer design day. As the results in figure 3.11 demonstrate, a deviation from the specified internal temperatures will occur on the selected perimeter zone. As shown in Figure 3.12 there is sufficient capacity to maintain internal conditions in the centre zone.

North Zone			
Time	*Design Condition (°C)*	*Internal Air Temperature (°C)*	*Deviation Above Design Condition (°C)*
8:00 AM	24	24.3	0.30
9:00 AM	24	24.6	0.60
10:00 AM	24	26.9	2.90
11:00 AM	24	27.1	3.10
12:00 PM	24	27.1	3.10
1:00 PM	24	26.8	2.80
2:00 PM	24	26.7	2.70
3:00 PM	24	26.8	2.80
4:00 PM	24	26.8	2.80
5:00 PM	24	26.7	2.70
6:00 PM	24	24.3	0.30
7:00 PM	24	23.9	0.00

Figure 3.11 - Internal Air Temperatures - North Zone

Centre Zone			
Time	*Design Condition (°C)*	*Internal Air Temperature (°C)*	*Deviation Above Design Condition (°C)*
8:00 AM	24	23	0
9:00 AM	24	23.3	0
10:00 AM	24	23.7	0
11:00 AM	24	23.9	0
12:00 PM	24	23.7	0
1:00 PM	24	23.4	0
2:00 PM	24	23.2	0
3:00 PM	24	23.1	0
4:00 PM	24	22.9	0
5:00 PM	24	22.8	0
6:00 PM	24	22.3	0
7:00 PM	24	22.3	0

Figure 3.12 Internal Air Temperatures - Centre Zone

4.0 CONCLUSIONS

Assessment of the results of the computer modelling studies leads to the following conclusions:

Economy Cycle

The ideal control strategy for Economy Cycle operation with VAV systems in Melbourne is temperature optimised control with dry bulb temperature cut off. A dry bulb temperature of 23°C and rescheduling of the supply air temperature is recommended.

System Configurations

In terms of annual energy use Option 4 Induction Units (Perimeter) & Active Chilled Beams (Centre) and Option 5 Induction Units (Perimeter) & Chilled Ceiling (Centre) were the best performing and performed equally well.

Capacity of Base Case Mutizone VAV System

The original system was designed for an internal equipment load of 7.5 W/m². There is insufficient capacity in the existing system to maintain internal conditions with an equipment load of 35 W/m² on a summer design day. For the selected zone, a temperature increase of some 3 °C above design can be expected.

Night Purge Cycle

Due to the additional heating required and the operation of the AHU fans night purge cycle operation does not demonstrate any saving in annual energy use. This is increased.

Thermal Comfort

Option 1b Standard VAV and Option 5 Induction Units (Perimeter) & Chilled Ceilings (Centre) were used as the basis of the comparison. Option 5 was found to provide a greater degree of occupant comfort within the space. This can be attributed to the radiant cooling effect of the chilled ceilings and lower overall air velocities.

Appendix A

Computer Modelling

A1.0 Computer Modelling

A1.1 Overview

To assess thermal performance, computer modelling was performed. TAS Software, employed exclusively in Australia by Advanced Environmental Concepts, was used to perform thermal analysis. TAS uses fully dynamic calculations to provide an accurate insight into the building envelope response as well as space and surface temperatures.

A1.2 Building Simulation

3D geometry was used to represent the building in TAS.

A1.3 Climate Data

To accurately model the dynamic nature of building thermal response, hourly recorded weather data for Melbourne was used in simulation. Such weather data contains records of radiation, temperature, humidity, sunshine duration and additionally wind speed and direction .

The Test Reference Year was chosen by an ASHRAE approved procedure. A Test Reference Year is hourly weather data for a year for use in simulation of the performance of active and passive solar energy systems, building energy consumption and indoor climate calculations. It contains hourly values of a number of weather parameters for the above mentioned purposes. The most important weather parameters have mean monthly values and monthly diurnal variations typical for the location. Because of the large amount of data (8760 hourly sets of weather parameters) Test Reference Years are used only in connection to computerised calculation methods.

Test Reference Years are selected for a specific location. However, they can be used for a limited area around the origin. With a Test Reference Year there might be differences in climate, but generally the deviations due to location will be small compared with the deviations from year to year. Very rough landscapes (eg mountains) can make the Test Reference Year for the region less representative for a specific location.

Appendix B

Economy Cycle Analysis Results

B2.0 Economy Cycle Analysis Results

Rialto Towers - Option 1a - Fixed O/A + Rescheduling S/A Temp			
Plant Component	***Annual Energy Input***		
	(kWh/a/level)	*(kWh/a.m²)*	*(MJ/a.m²)*
Chiller	40,267.00	22.25	80.09
Boiler	5,002.00	2.76	9.95
AHU Fans	47,012.00	25.97	93.50
Electric Reheat	16.00	0.01	0.03
Cooling Tower Fans	2,299.00	1.27	4.57
Pumps	9,270.00	5.12	18.44
Spill Air Fans	2,249.00	1.24	4.47
	TOTAL	58.63	211.06

Rialto Towers-Option 1b - DB Economy + Rescheduling S/A Temp			
Plant Component	***Annual Energy Input***		
	(kWh/a/level)	*(kWh/a.m²)*	*(MJ/a.m²)*
Chiller	17,218.00	9.51	34.25
Boiler	5,002.00	2.76	9.95
AHU Fans	47,016.00	25.98	93.51
Electric Reheat	16.00	0.00	0.00
Cooling Tower Fans	956.00	0.53	1.90
Pumps	3,900.00	2.15	7.76
Spill Air Fans	7,145.00	3.95	14.21
	TOTAL	44.88	161.58

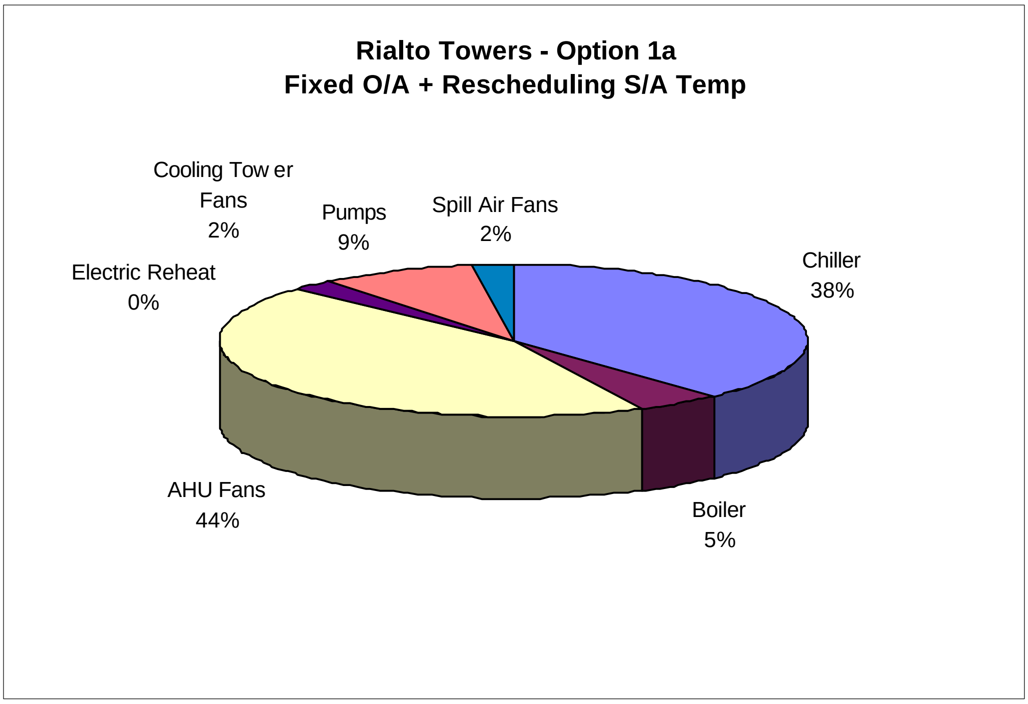
Rialto Towers-Option 1c - Enth. Economy + Rescheduling S/A Temp			
Plant Component	***Annual Energy Input***		
	(kWh/a/level)	*(kWh/a.m²)*	*(MJ/a.m²)*
Chiller	20,205.00	11.16	40.19
Boiler	10,064.00	5.56	20.02
AHU Fans	44,276.00	24.46	88.06
Electric Reheat	18.00	0.00	0.00
Cooling Tower Fans	1,133.00	0.63	2.25
Pumps	4,623.00	2.55	9.19
Spill Air Fans	8,852.00	4.89	17.61
	TOTAL	49.26	177.32

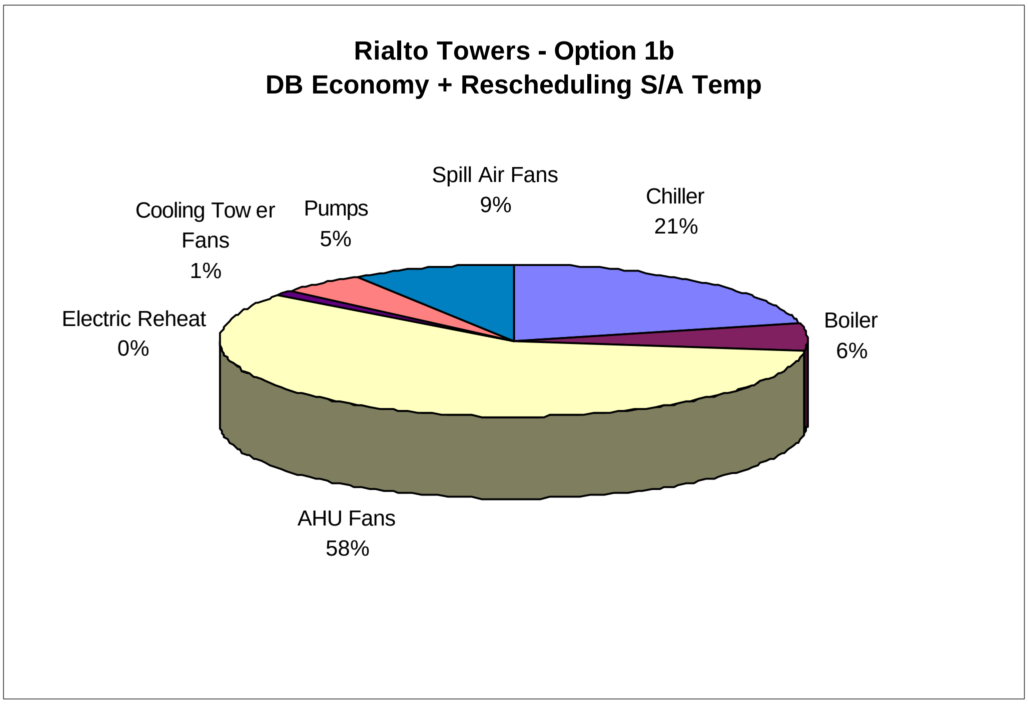
Rialto Towers-Option 1d - Fixed O/A + Fixed S/A Temp			
Plant Component	***Annual Energy Input***		
	(kWh/a/level)	*(kWh/a.m²)*	*(MJ/a.m²)*
Chiller	56,070.00	30.98	111.52
Boiler	0.00	0.00	0.00
AHU Fans	46,701.00	25.80	92.89
Electric Reheat	63,432.00	35.05	126.16
Cooling Tower Fans	3,226.00	1.78	6.42
Pumps	12,905.00	7.13	25.67
Spill Air Fans	2,249.00	1.24	4.47
	TOTAL	101.98	367.13

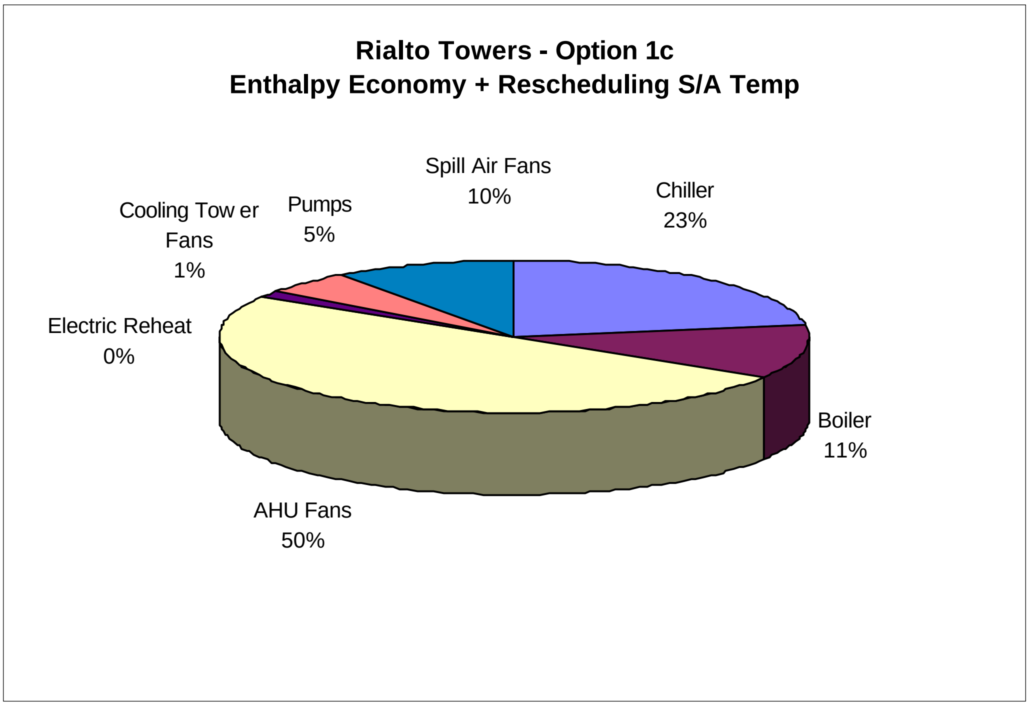
Rialto Towers-Option 1e - DB Economy + Fixed S/A Temp			
Plant Component	***Annual Energy Input***		
	(kWh/a/level)	*(kWh/a.m²)*	*(MJ/a.m²)*
Chiller	30,123.00	16.64	59.91
Boiler	0.00	0.00	0.00
AHU Fans	46,701.00	25.80	92.89
Electric Reheat	63,474.00	35.07	126.25
Cooling Tower Fans	1,679.00	0.93	3.34
Pumps	6,718.00	3.71	13.36
Spill Air Fans	8,735.00	4.83	17.37
	TOTAL	86.98	313.12

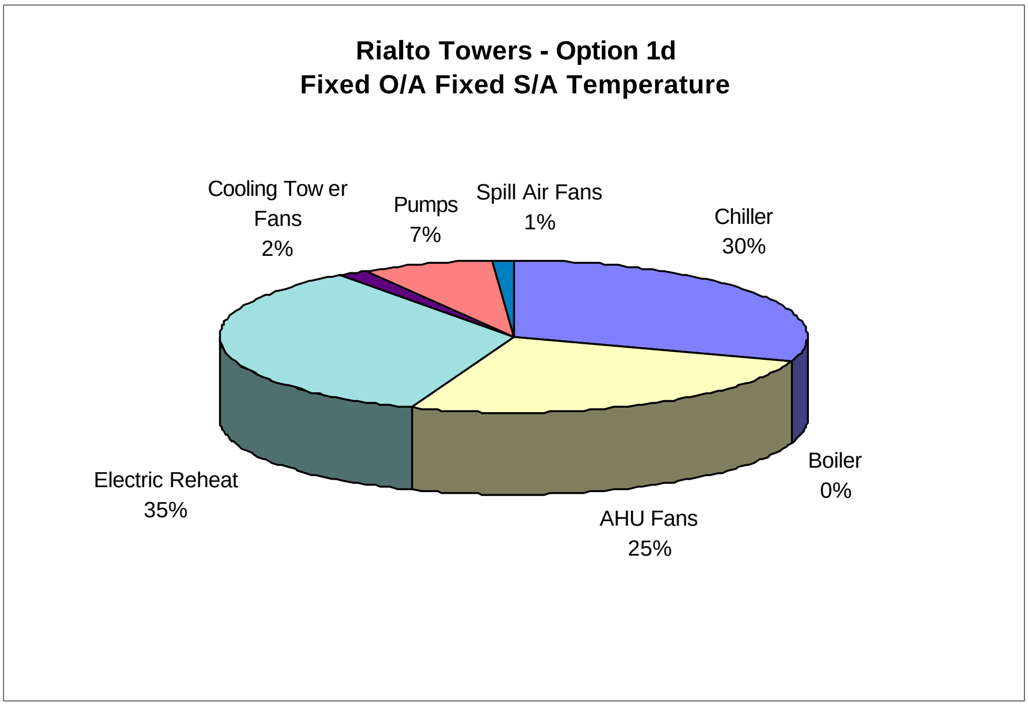
Rialto Towers-Option 1f - Enth. Economy + Fixed S/A Temp			
Plant Component	***Annual Energy Input***		
	(kWh/a/level)	*(kWh/a.m²)*	*(MJ/a.m²)*
Chiller	45,008.00	24.87	89.52
Boiler	2,982.00	1.65	5.93
AHU Fans	46,907.00	25.92	93.30
Electric Reheat	64,478.00	35.62	128.24
Cooling Tower Fans	2,477.00	1.37	4.93
Pumps	9,954.00	5.50	19.80
Spill Air Fans	8,802.00	4.86	17.51
	TOTAL	99.78	359.22

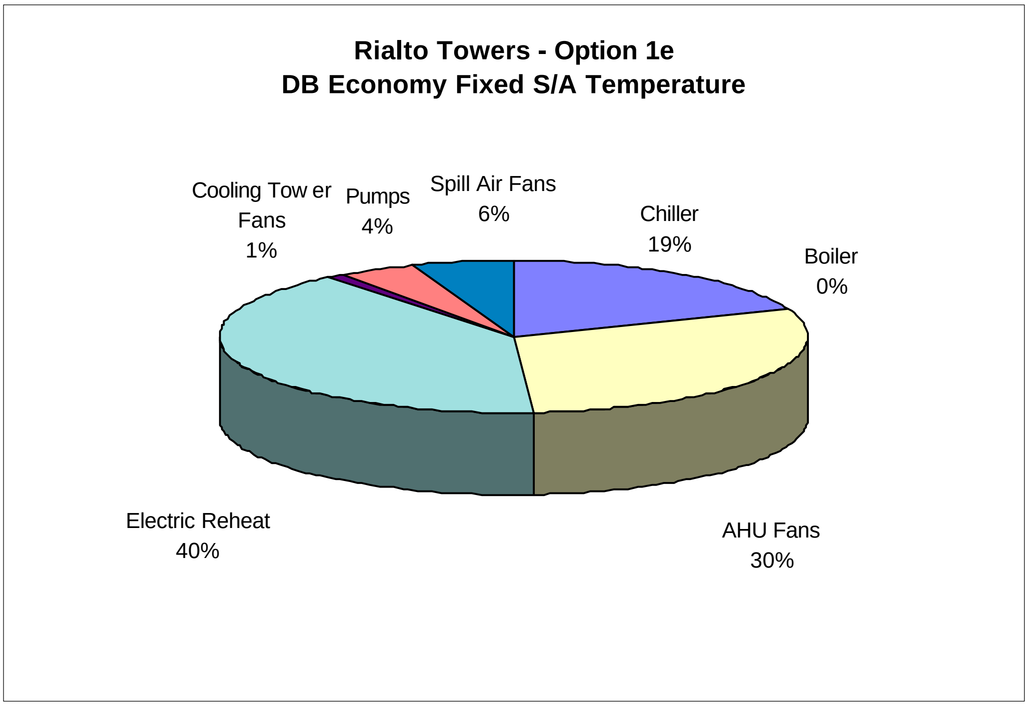
B2.1 Economy Cycle Analysis Graphs

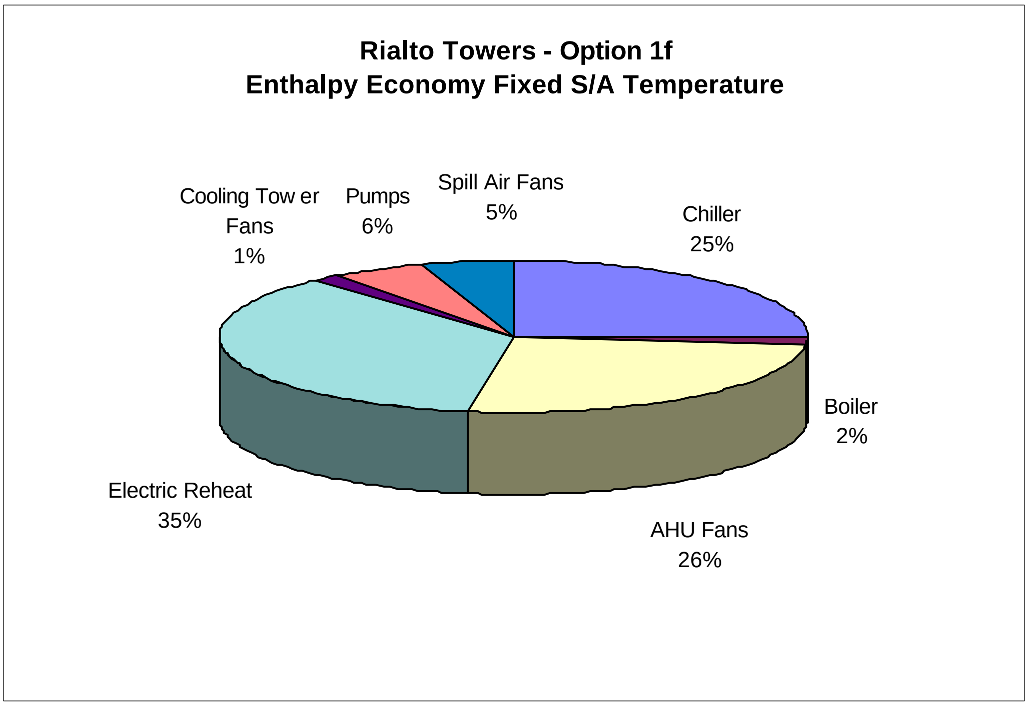





Rialto Towers - Option 1c
Enthalpy Economy + Rescheduling S/A Temp
Spill Air Fans 10%
Chiller 23%
Cooling Tow er Fans 1%
Pumps 5%
Electric Reheat 0%
Boiler 11%
AHU Fans 50%


Rialto Towers - Option 1d
Fixed O/A Fixed S/A Temperature
Cooling Tow er Fans 2%
Pumps 7%
Spill Air Fans 1%
Chiller 30%
Boiler 0%
Electric Reheat 35%
AHU Fans 25%


Rialto Towers - Option 1e
DB Economy Fixed S/A Temperature
Cooling Tow er Fans 1%
Pumps 4%
Spill Air Fans 6%
Chiller 19%
Boiler 0%
Electric Reheat 40%
AHU Fans 30%


Rialto Towers - Option 1f
Enthalpy Economy Fixed S/A Temperature
Cooling Tow er Fans 1%
Pumps 6%
Spill Air Fans 5%
Chiller 25%
Boiler 2%
Electric Reheat 35%
AHU Fans 26%

Appendix C

System Configuration Analysis Results

C3. System Configuration Analysis Results

Rialto Towers - Base Case-Multizone Units			
Plant Component	**Annual Energy Input**		
	(kWh/a/level)	(kWh/a.m²)	(MJ/a.m²)
Chiller	21,016.00	11.61	41.80
Boiler	698.00	0.39	1.39
AHU Fans	33,299.00	18.40	66.23
Hot Water Reheat	30,206.00	16.69	60.08
Cooling Tower Fans	1,168.00	0.65	2.32
Pumps	4,681.00	2.59	9.31
Spill Air Fans	6,251.00	3.45	12.43
	TOTAL	53.77	193.56

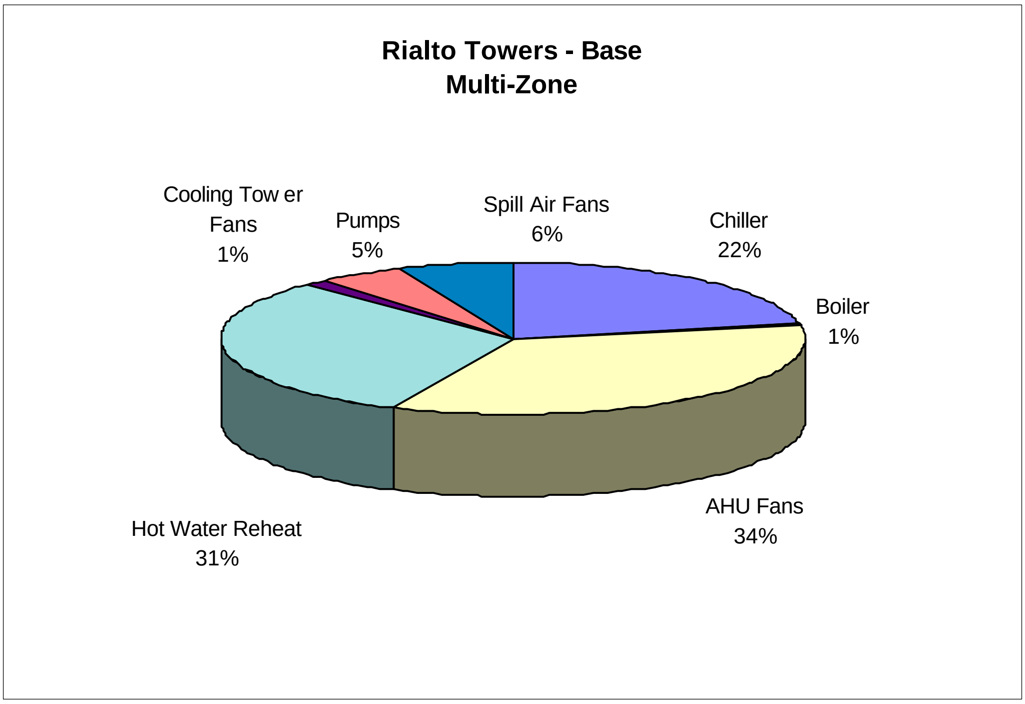
Rialto Towers-Option 2-Twin Duct System			
Plant Component	**Annual Energy Input**		
	(kWh/a/level)	(kWh/a.m²)	(MJ/a.m²)
Chiller	18,655.00	10.31	37.10
Boiler	5,757.00	3.18	11.45
AHU Fans	42,649.00	23.56	84.83
Electric Reheat	0.00	0.00	0.00
Cooling Tower Fans	1,036.00	0.57	2.06
Pumps	4,226.00	2.33	8.41
Spill Air Fans	6,702.00	3.70	13.33
	TOTAL	43.66	157.18

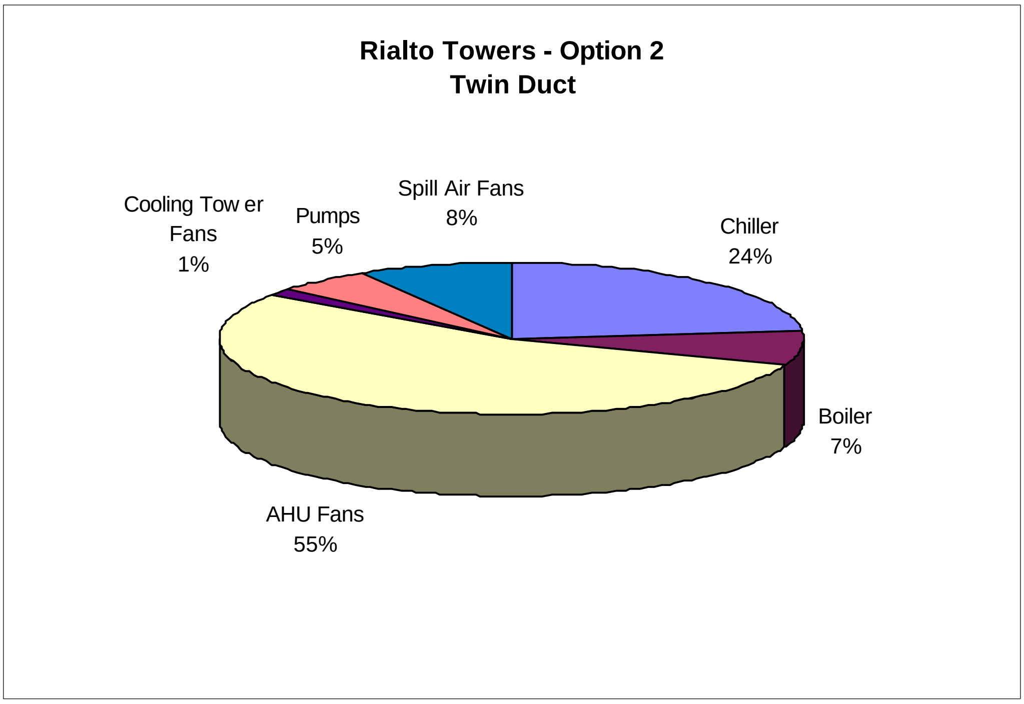
Rialto Towers-Option 3-Induction Units (Perimeter)+VAV (Centre)			
Plant Component	**Annual Energy Input**		
	(kWh/a/level)	(kWh/a.m²)	(MJ/a.m²)
Chiller	18,131.00	10.02	36.06
Boiler	6,746.00	3.73	13.42
AHU Fans	37,876.00	20.93	75.33
Electric Reheat	0.00	0.00	0.00
Cooling Tower Fans	1,004.00	0.55	2.00
Pumps	4,119.00	2.28	8.19
Spill Air Fans	6,227.00	3.44	12.39
	TOTAL	40.94	147.39

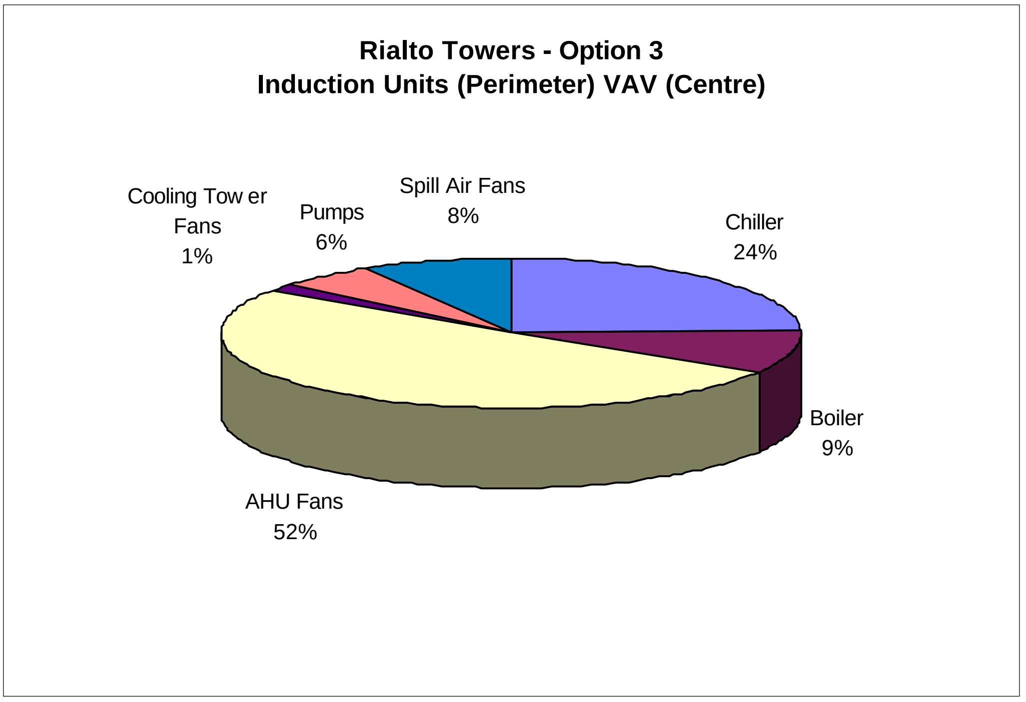
Rialto Towers-Option 4-Induction Units (Perimeter)+Active Chilled Beams (Centre)			
Plant Component	**Annual Energy Input**		
	(kWh/a/level)	(kWh/a.m²)	(MJ/a.m²)
Chiller	19,864.00	10.97	39.51
Boiler	6,661.00	3.68	13.25
AHU Fans	22,408.00	12.38	44.57
Electric Reheat	0.00	0.00	0.00
Cooling Tower Fans	1,108.00	0.61	2.20
Pumps	4,534.00	2.50	9.02
Spill Air Fans	4,466.00	2.47	8.88
	TOTAL	32.62	117.43

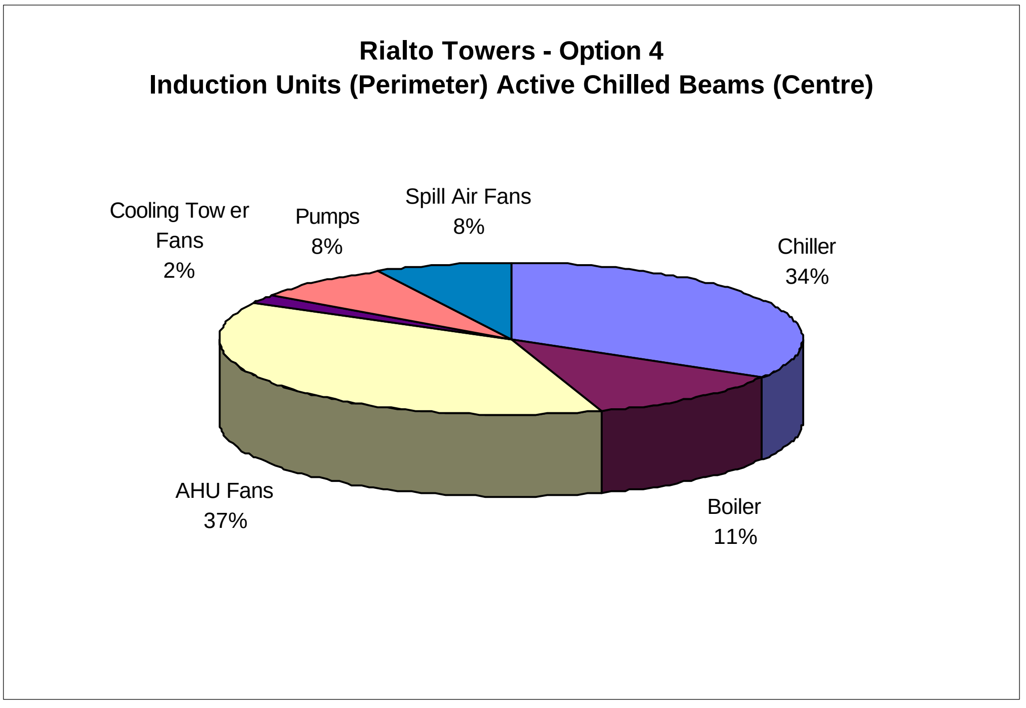
Rialto Towers-Option 5-Induction Units (Perimeter)+Chilled Ceilings (Centre)			
Plant Component	***Annual Energy Input***		
	(kWh/a/level)	*(kWh/a.m²)*	*(MJ/a.m²)*
Chiller	24,950.00	13.78	49.62
Boiler	4,010.00	2.22	7.98
AHU Fans	19,376.00	10.70	38.54
Electric Reheat	0.00	0.00	0.00
Cooling Tower Fans	1,394.00	0.77	2.77
Pumps	5,637.00	3.11	11.21
Spill Air Fans	3,797.00	2.10	7.55
	TOTAL	32.69	117.67

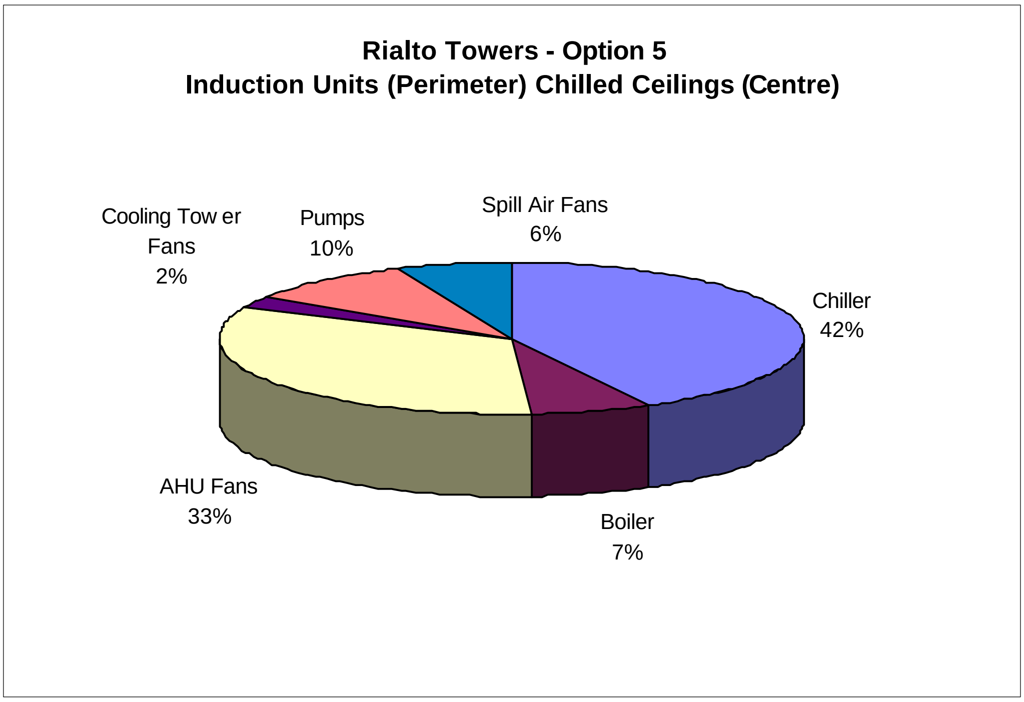
C3.1 System Configuration Analysis Graphs






Rialto Towers - Option 3
Induction Units (Perimeter) VAV (Centre)
Cooling Tow er Fans 1%
Pumps 6%
Spill Air Fans 8%
Chiller 24%
Boiler 9%
AHU Fans 52%


Rialto Towers - Option 4
Induction Units (Perimeter) Active Chilled Beams (Centre)
Cooling Tow er Fans 2%
Pumps 8%
Spill Air Fans 8%
Chiller 34%
Boiler 11%
AHU Fans 37%


Rialto Towers - Option 5
Induction Units (Perimeter) Chilled Ceilings (Centre)
Cooling Tow er Fans 2%
Pumps 10%
Spill Air Fans 6%
Chiller 42%
AHU Fans 33%
Boiler 7%

Appendix D

Economy Cycle System Schematics

D3. Economy Cycle Configuration Schematics

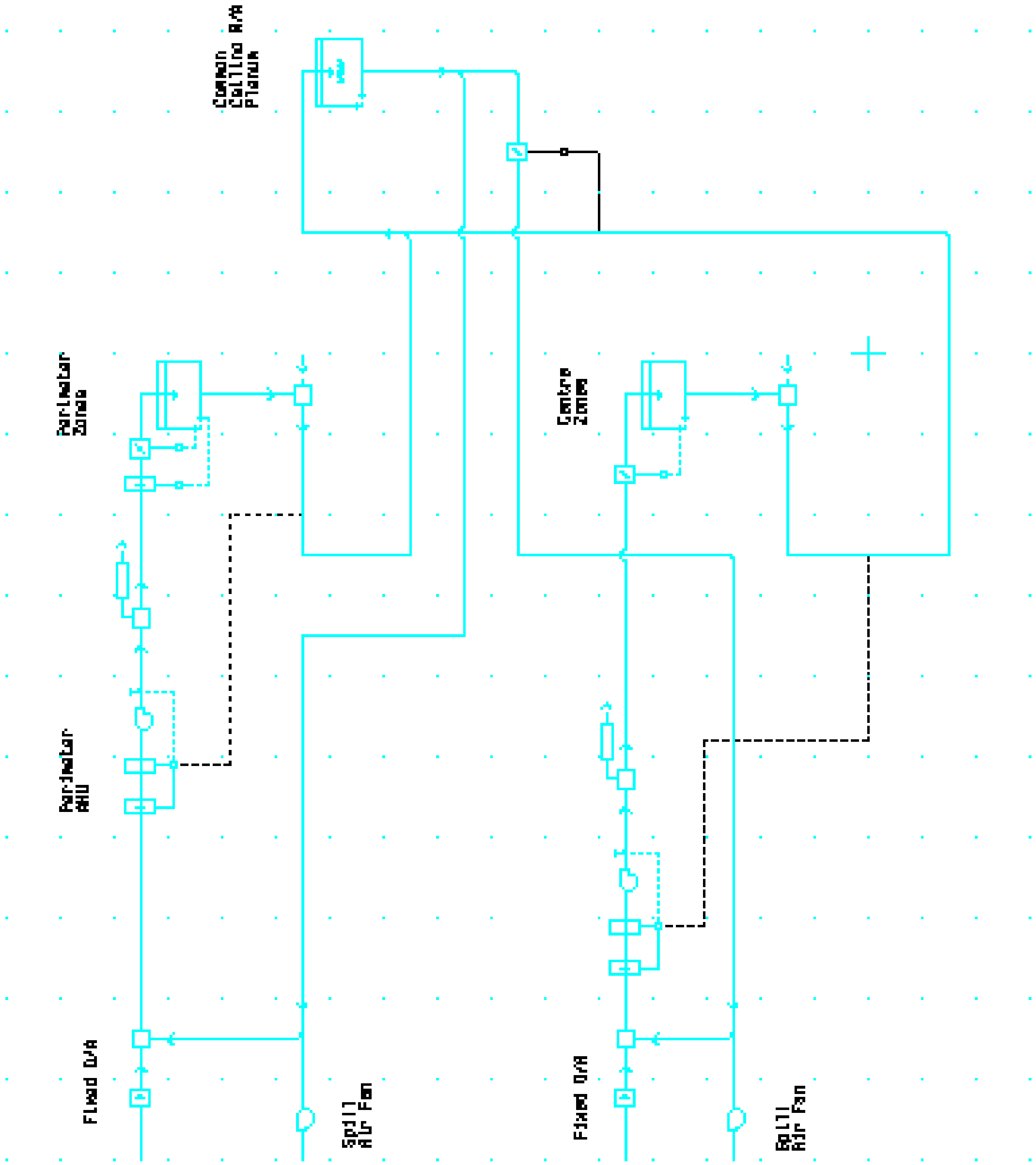


Figure D 4.1 - Fixed O/A + Rescheduling of S/A Temp

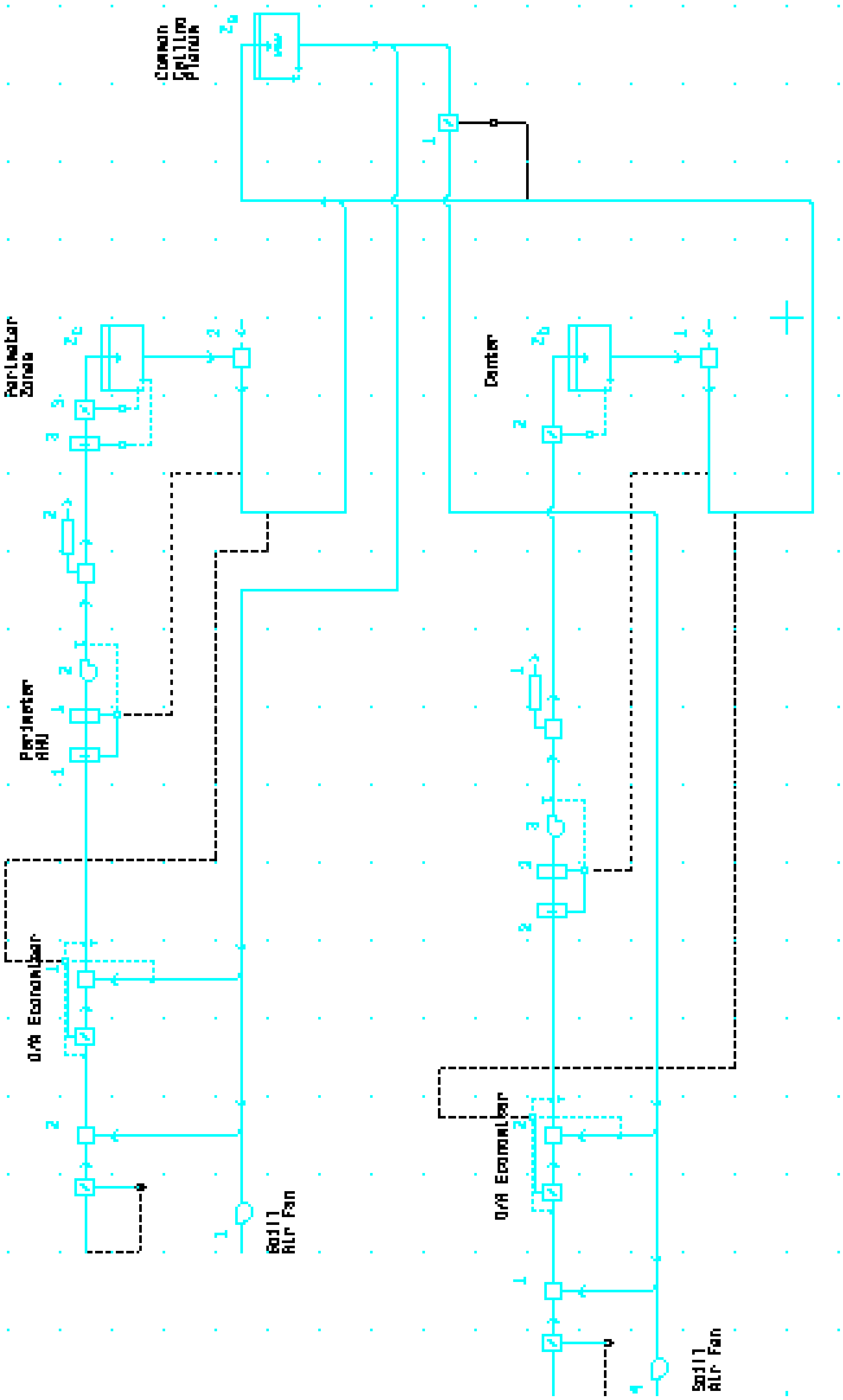


Figure D 4.2 - Option DB Economy + Rescheduling of S/A Temp

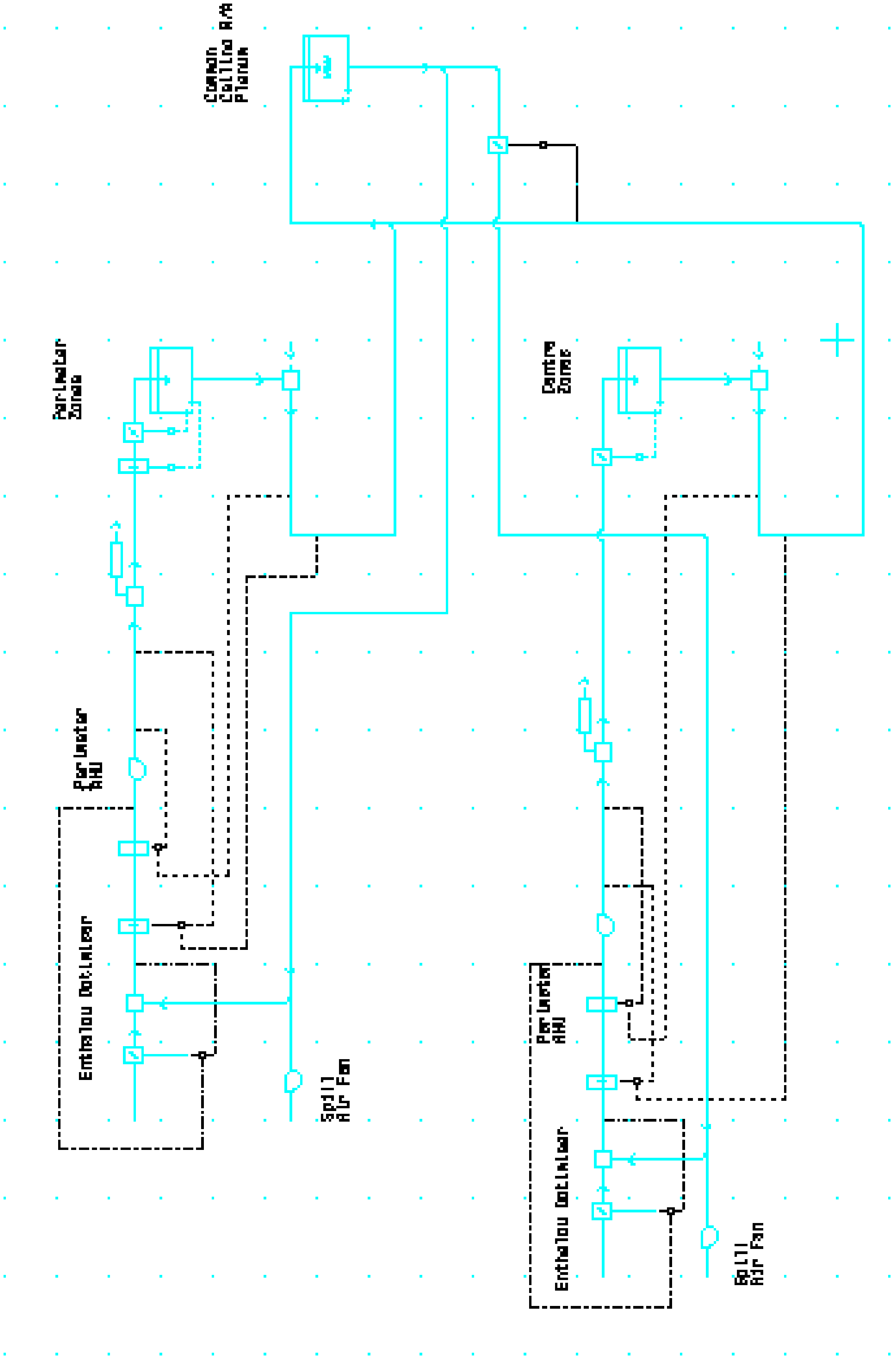


Figure D 4.3 - Option 1c - Enthalpy Economy + Rescheduling of S/A Temp

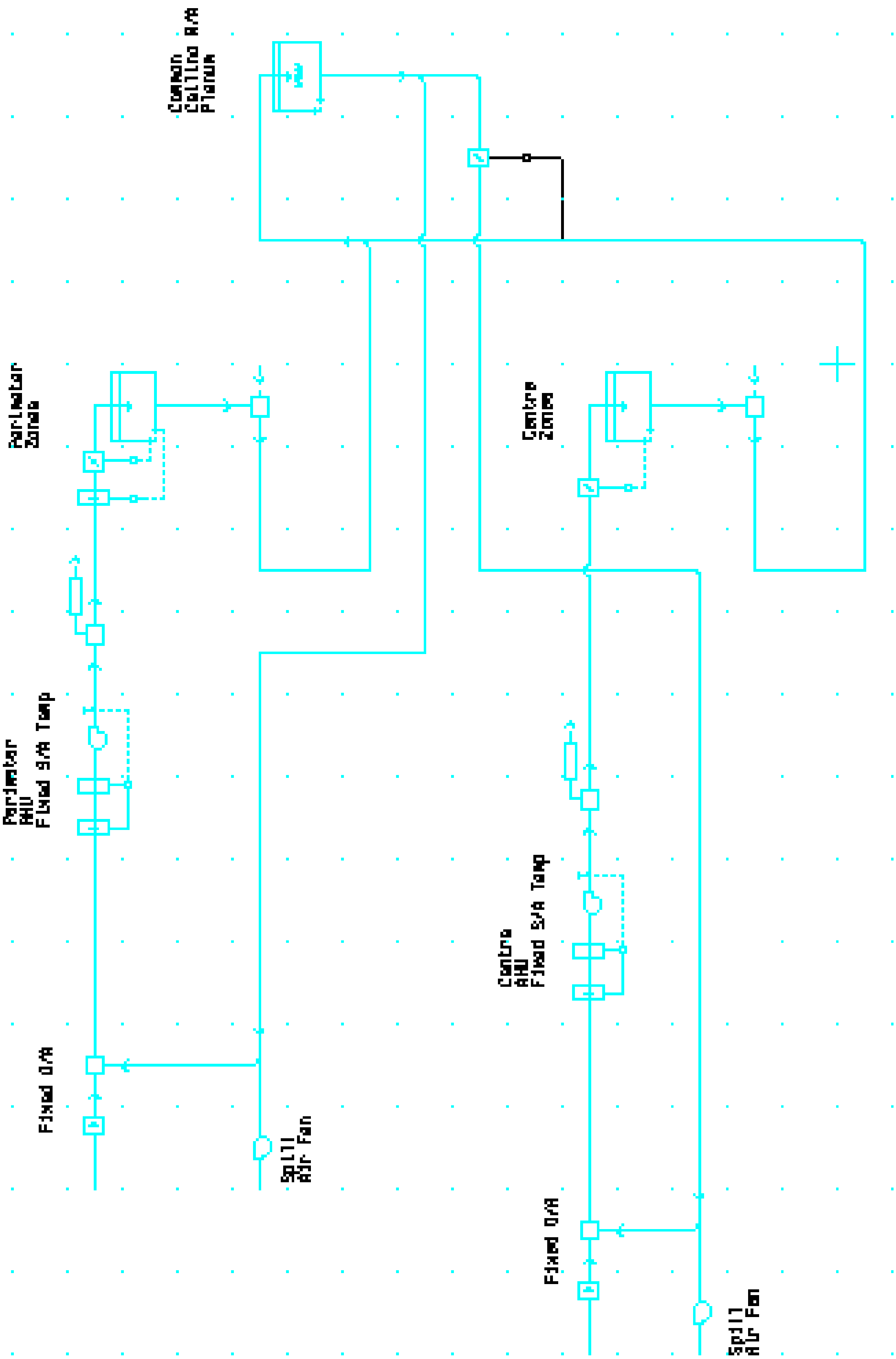


Figure D 4.5 - Option 1d - Fixed O/A + Fixed S/A Temp

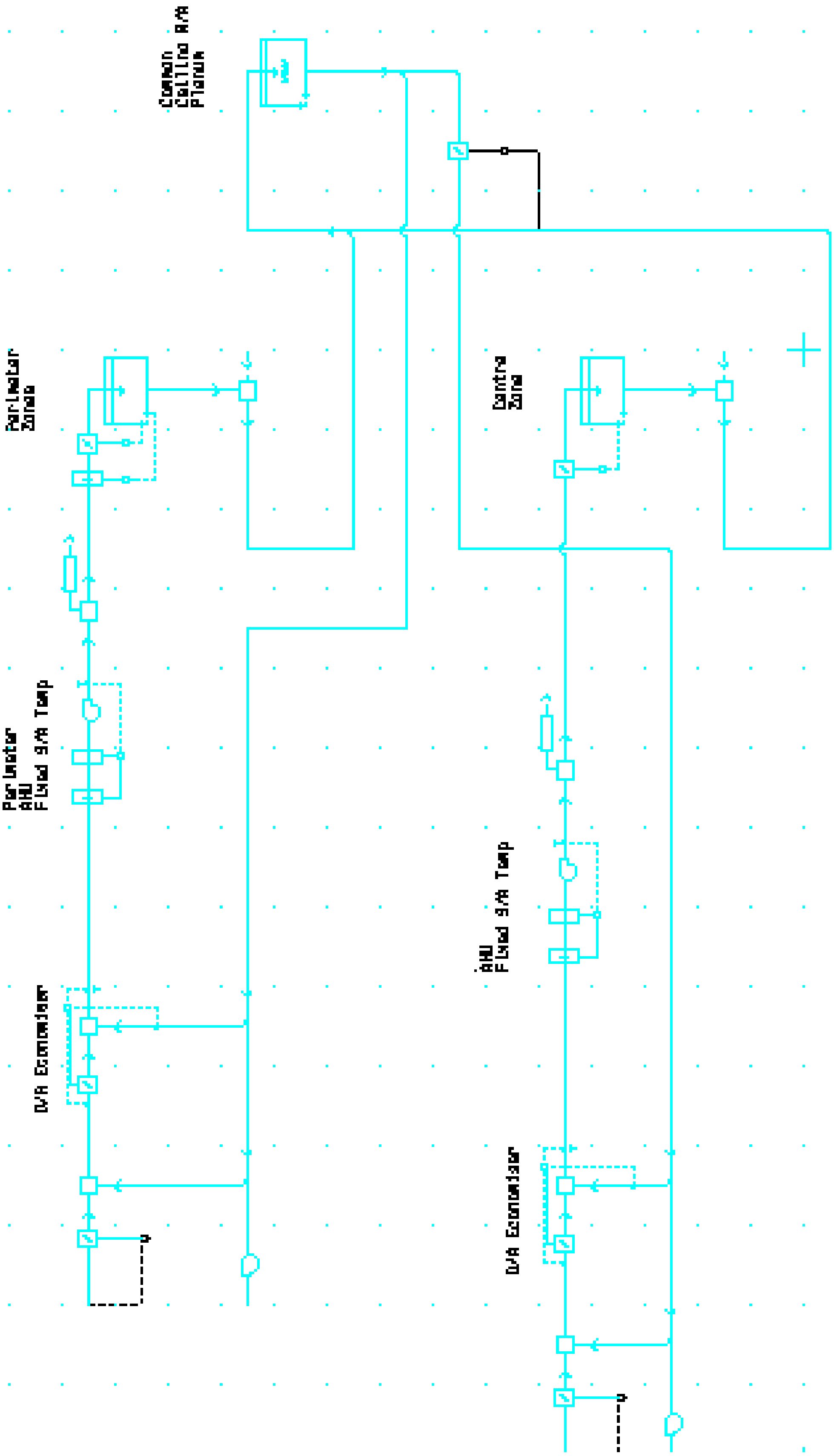


Figure D 4.6 - Option 1e - DB Economy + Fixed S/A Temp

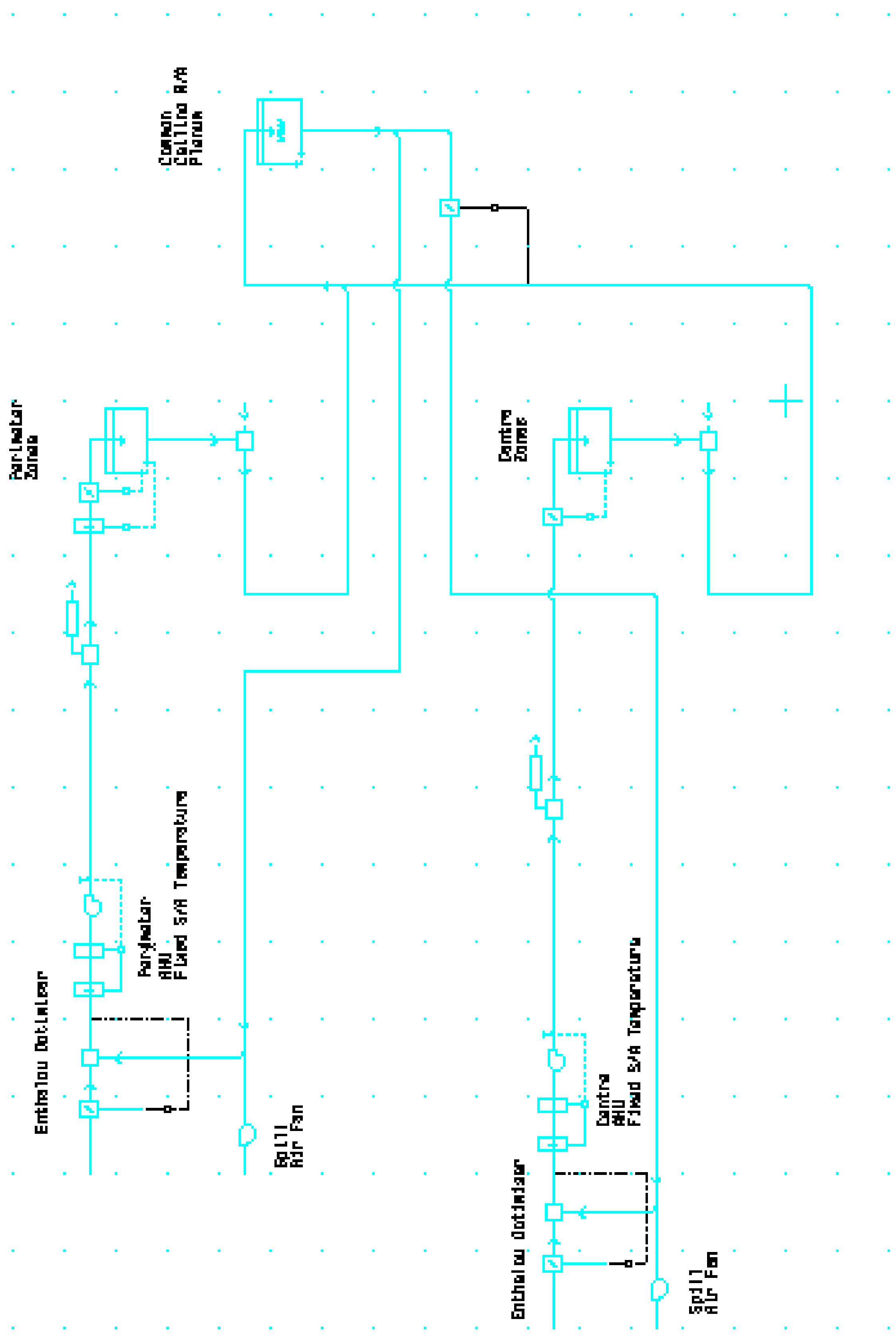


Figure D 4.7 - Option 1f - Enthalpy Economy + Fixed S/A Temp

Appendix E

System Configuration Schematics

E5. System Configuration Schematics

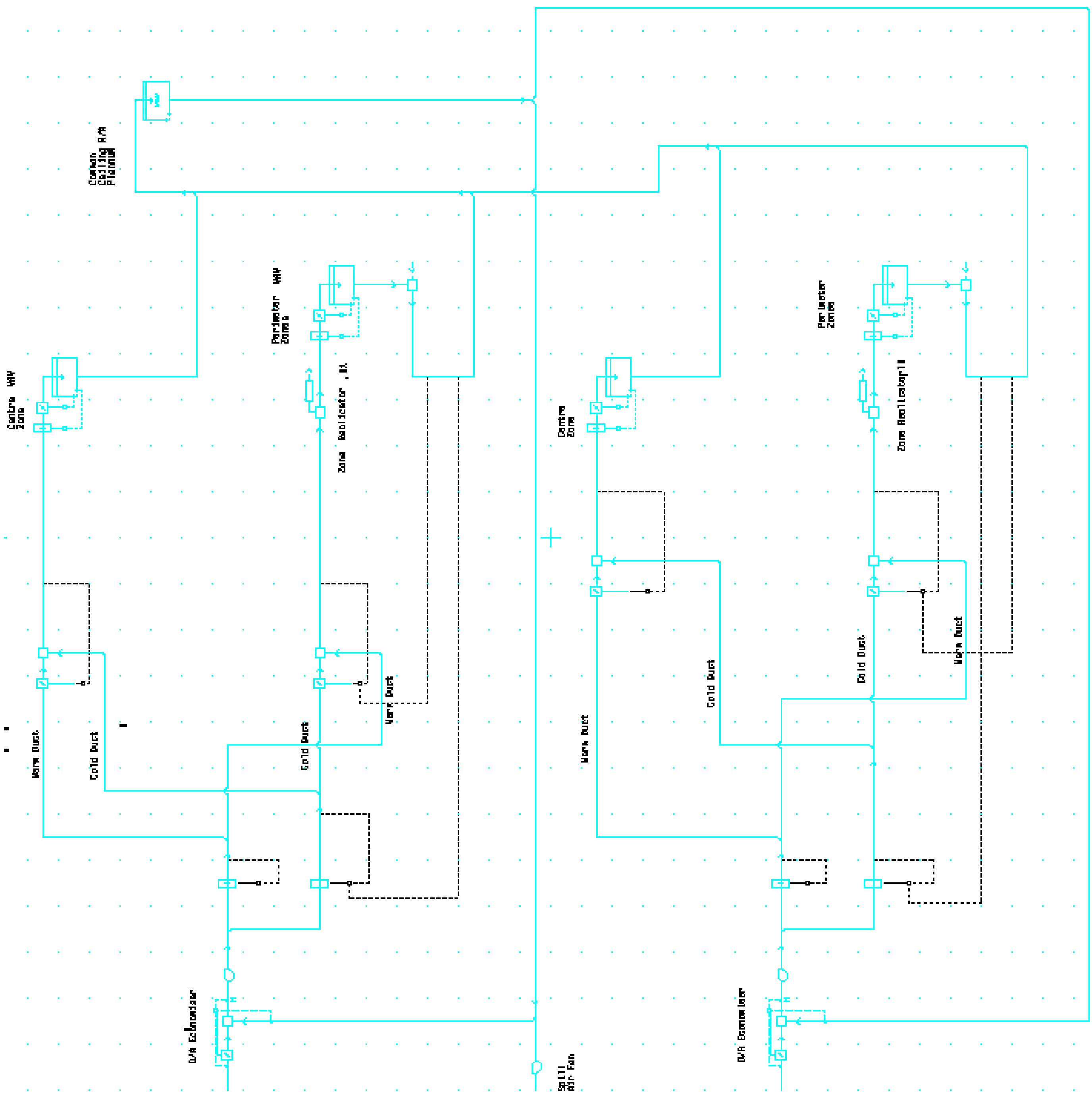


Figure E 4.1 - Base Case - Multizone System

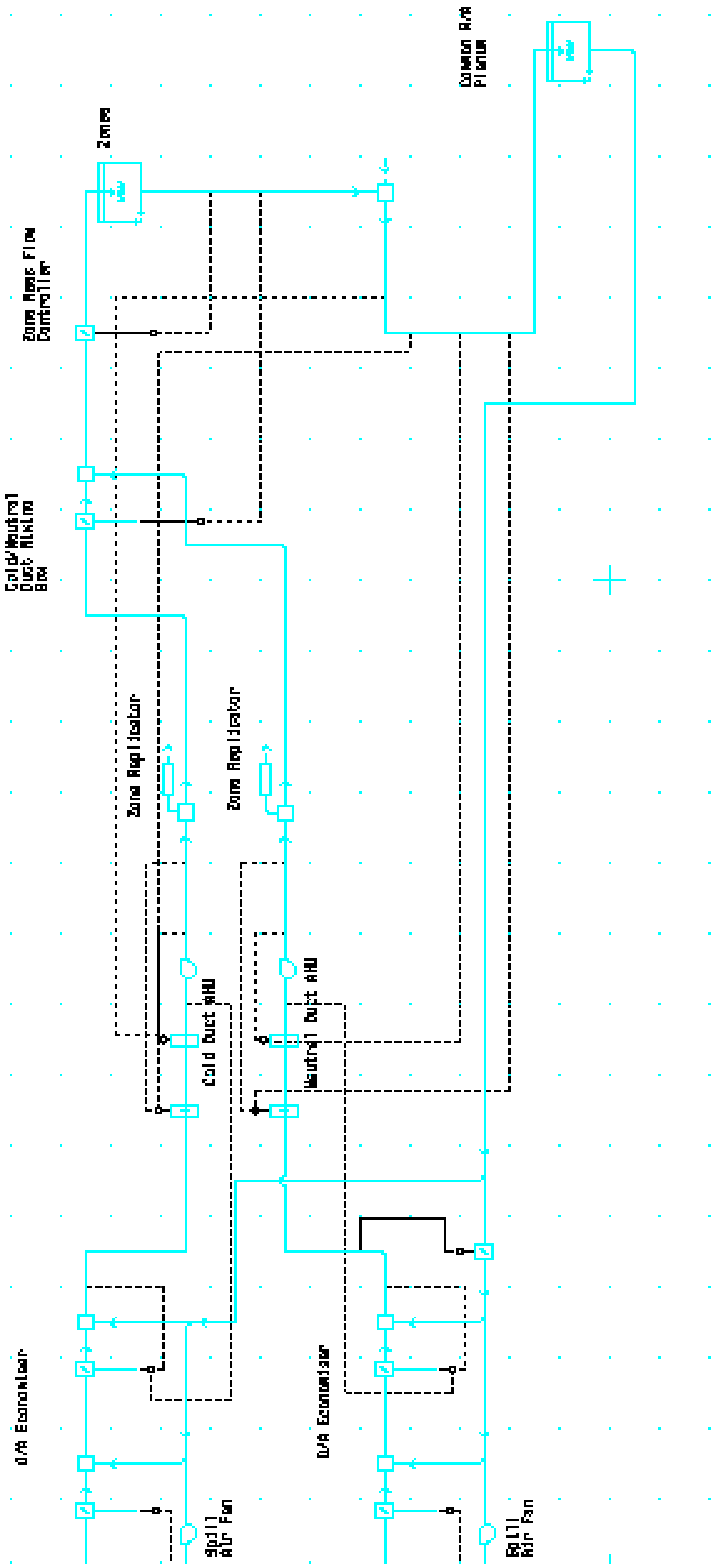


Figure E 4.2 - Option 2 - Twin Duct System

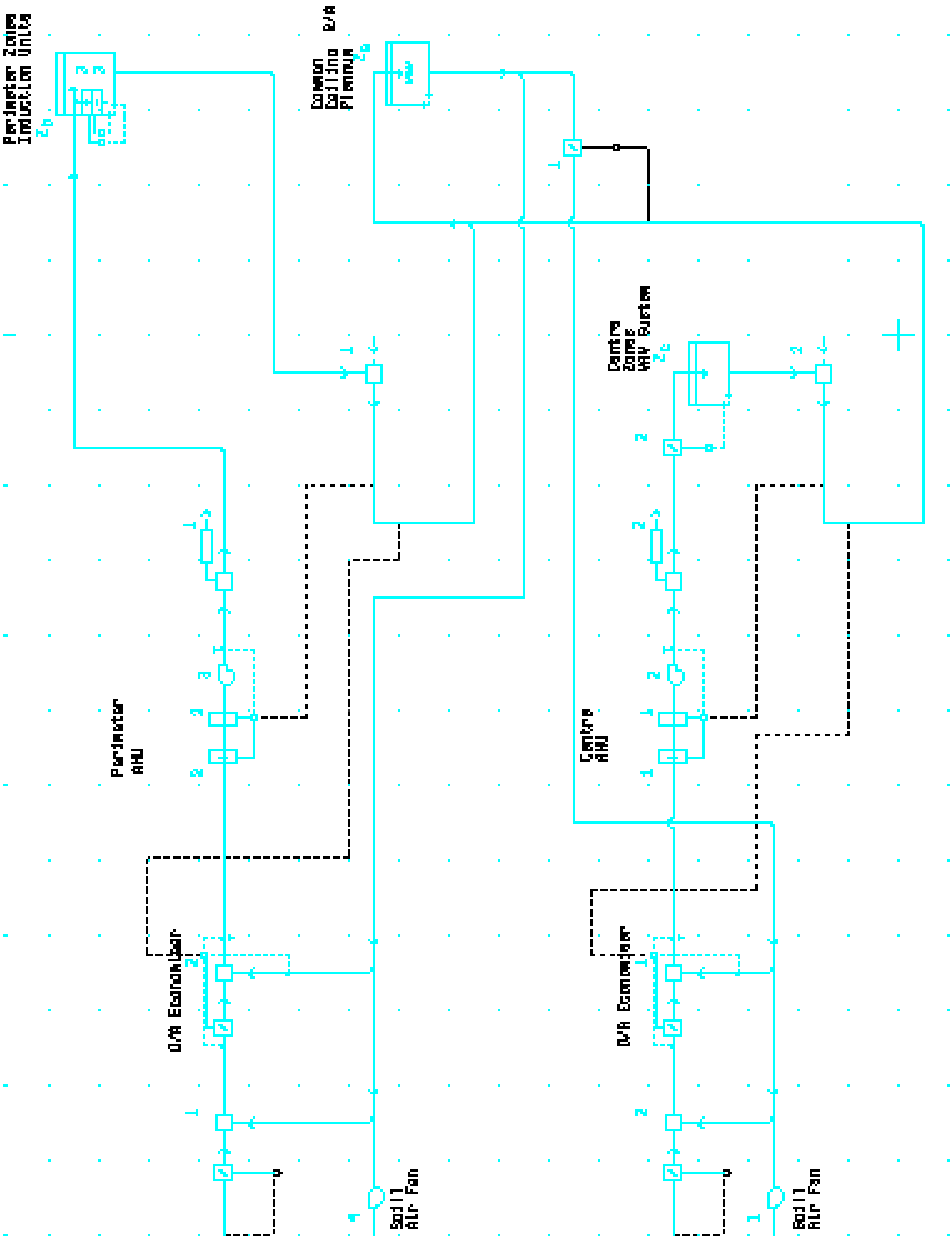


Figure E 4.3 - Option 3 - Induction Units (Perimeter) + VAV (Centre)

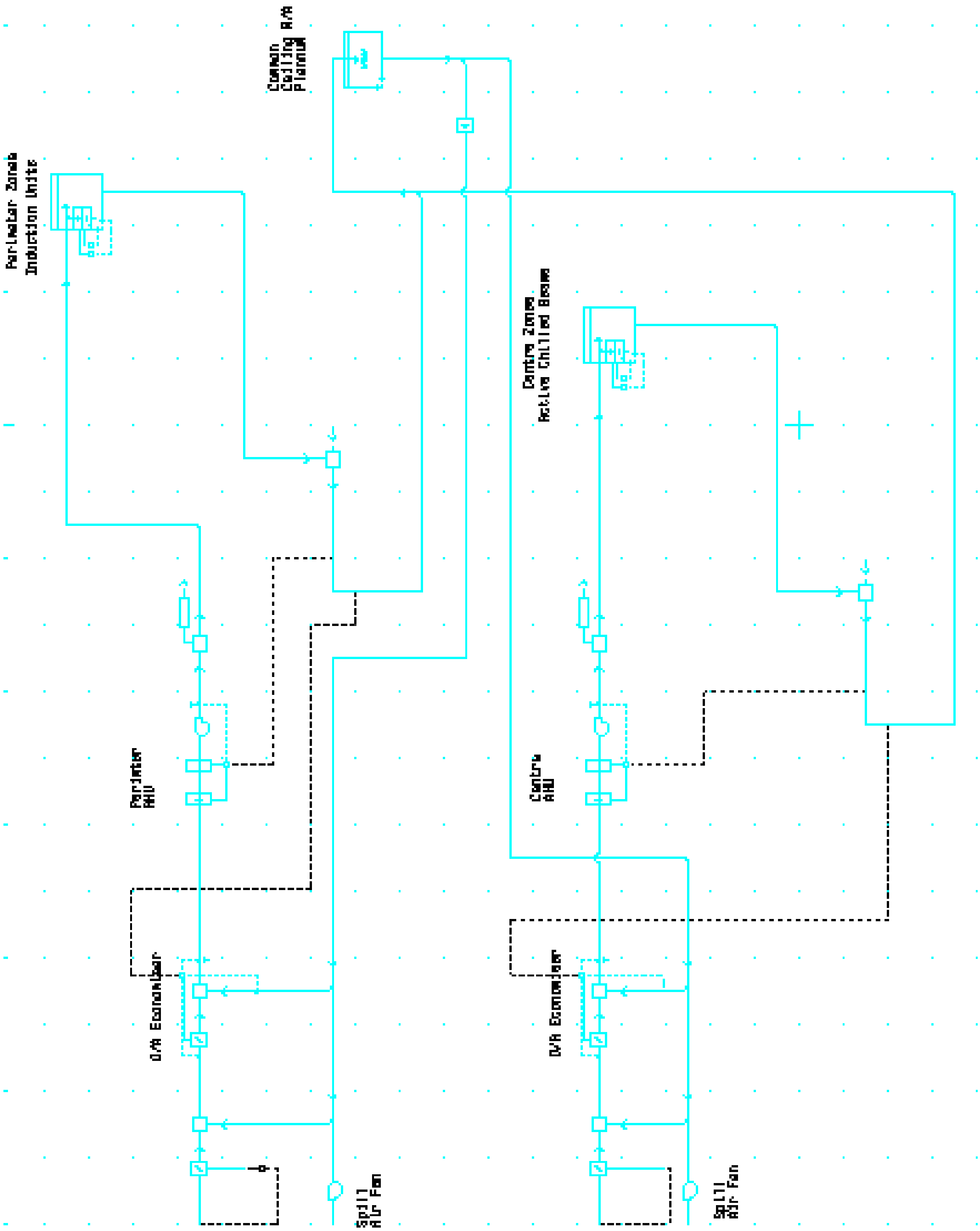


Figure E 4.4 - Option 4 - Induction Units (Perimeter) + Active Chilled Beams (Centre)

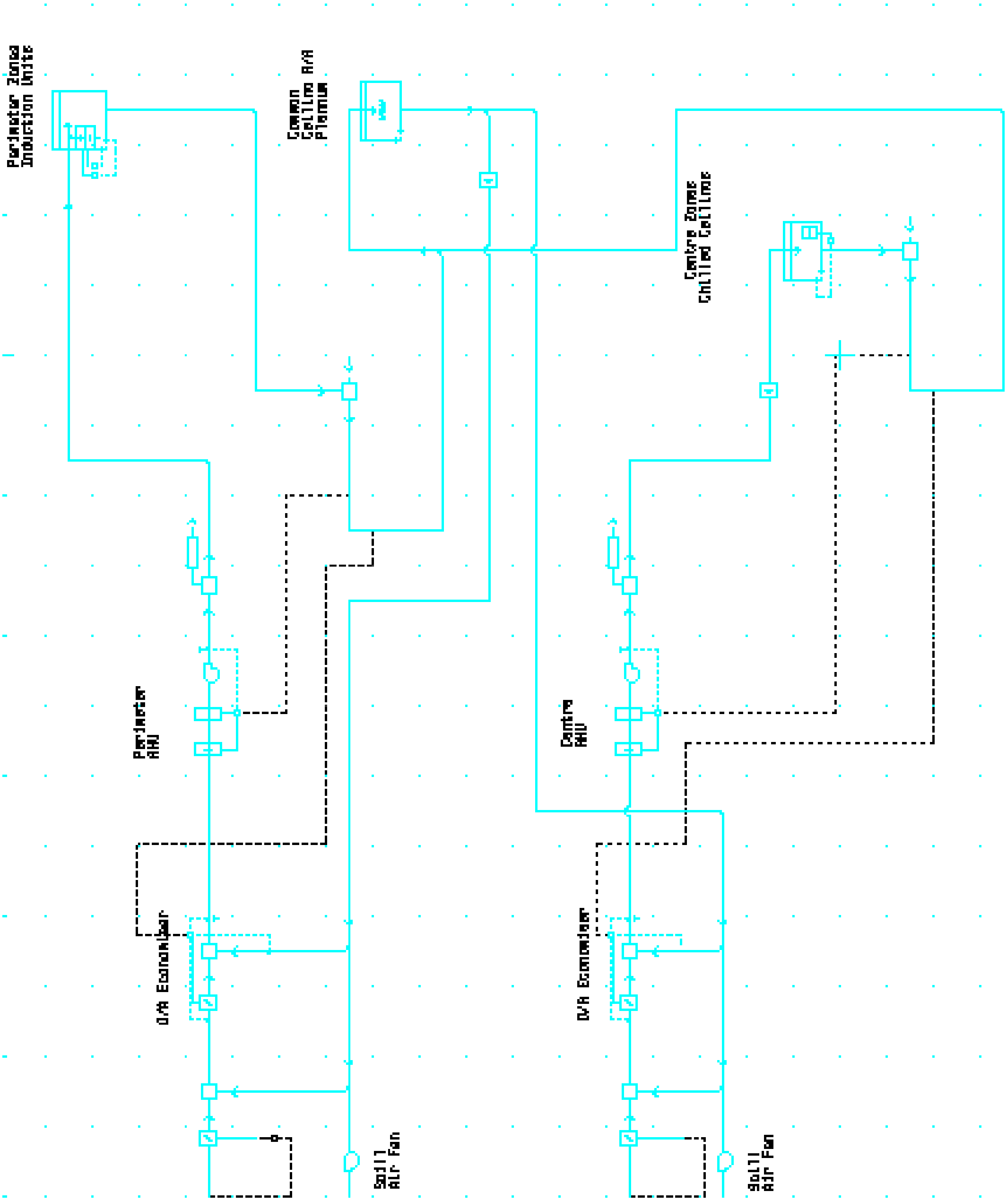


Figure E 4.5 - Option 5 - Induction Units (Perimeter) + Chilled Ceilings (Centre)