HVAC Options
Energy Modelling Report
for
Advantage Air P/L

by

Steven Moller

Thermal and Ventilation Engineering

CSIRO Manufacturing and Infrastructure Technology

May 2004

CONFIDENTIAL
Doc. No. CMIT(C)-2004-230

CSIRO

Please direct all enquiries to:

The Chief CSIRO Manufacturing and Infrastructure Technology P.O. Box 56 Highett, Victoria 3190 Australia	Attn: Walter Kimble AdvantageAir P/L 32 Ewing St Bentley, WA PO Box 334, Willetton, WA 6102 Australia

Background

Advantage Air builds air conditioning systems for the residential market. This study aims to evaluate a range of HVAC design options for an example house in Perth.

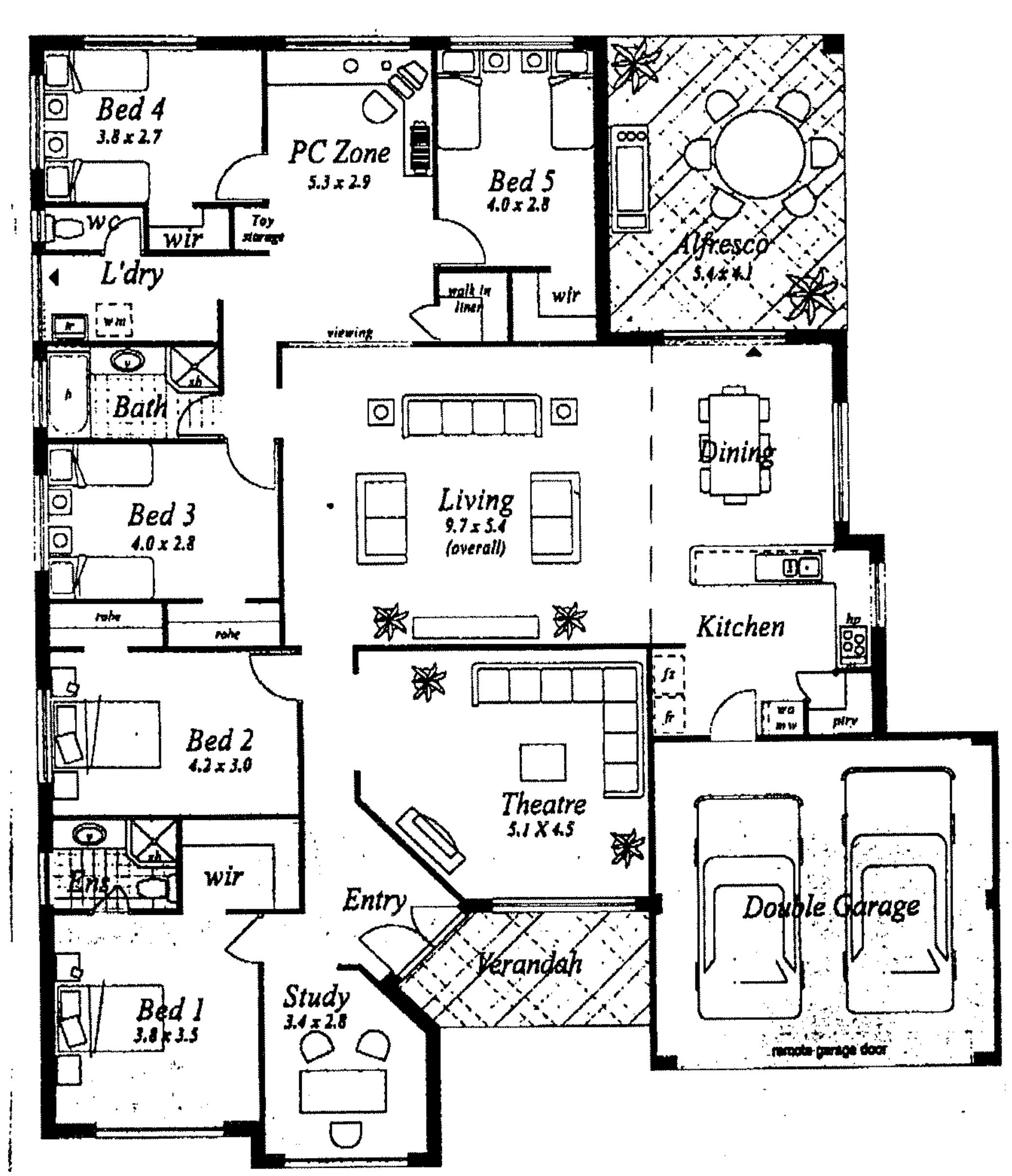
Objectives

Calculate the annual energy consumption of a typical house in Perth for 4 variations of an air conditioning system:

1. Constant air volume
2. Constant air volume with economy cycle
3. Variable air volume
4. Variable air volume with economy cycle

Input Data – provided by client

Detailed specifications and drawings were provided by the client – see Appendix 1.



The total floor area is 251m², including the garage. 201m² is heated and cooled.

No curtains or external shades were fitted. Therefore no strategy of closing curtains/shades to reduce solar gains in summer was employed.

Electrical equipment and lighting usage was specified by the client. The resulting energy consumption for light and power was approximately 5500 kWh per annum, (15 kWh per day), which would cost approximately $800/annum, using the specified tariff.

Modelling Assumptions

Weather data for a typical year in Perth was used for the simulation; this dataset was constructed using five actual years of measured data.

Reference: MOLLER S.K., MUNRO, M.C. and CUGURA, N. – Production and Plotting of a Reduced Weather Data Set. CSIRO Division of Energy Technology Technical Report – DET 83/29.

CSIRO's building energy simulation program, Energy Express, was used for this study.

House

The house was assumed to be built on flat land and not shaded by surrounding trees , hills or buildings.

The house was assumed to be fairly air-tight – 0.5 air changes per hour was assumed for occupied zones.

The house was assumed to be continuously occupied, according to the schedule supplied. i.e. no allowances was made for holidays, weekends away etc.

No ventilation for cooling was assumed. i.e. the air conditioning was operated even when the ambient temperature and prevailing breeze may have been sufficient to keep the house comfortable, by opening windows or external doors.

Air Conditioning

The air conditioning was operated from 3pm through to 8am, 7 days per week, 365 days per year, for all options.

The variable volume options were modelled by dividing the house into separate zones as specified. The bathroom, laundry and garage were not air-conditioned.

The constant volume options were modelled by combining all conditioned zones into a single zone, in order to model the return air thermostat.

The economy cycle, where fitted, admits extra fresh air, when there is a call for cooling and the ambient air temperature is less than the return air temperature. If the ambient air is too cold, the quantity of fresh air is modulated.

Energy Express has two HVAC models:

Constant volume reheat: Supply air is cooled or heated as much is required by the warmest zone. Since there is only one zone, in this case, there is no need for reheat.

Variable volume reheat: Supply air is cooled as much is required by the warmest zone. Zones with lower cooling demands or heating demands, first reduce the volume of supply air down to the minimum level. If the space load is not satisfied, the air is reheated. In order to minimise the amount of reheat, the minimum supply air quantity was set to 1 L/s.m². When the zone temperature is in the deadband (18°C to 24°C) it receives the minimum supply air quantity at the prevailing supply temperature.

General HVAC Assumptions (all systems)

Cooling COP:	2.7
Heating COP:	2.86 (reverse cycle)
Minimum fresh air quantity:	0.1 L/s.m²
Minimum supply air temperature:	12 °C
Duct loss/gain:	3% of space load.

The supply fan is assumed to operate even when the house does not require heating or cooling.

As a first step in the simulation, Energy Express performs a peak load calculation using a summer design day. (clear sky, 36.6 °C at 3pm) This sets the air flow rate and HVAC capacity for the energy calculation.

Results

Peak Load Calculation:

Cooling Capacity:	19.8 kW (Total Heat)
Air flow rate:	1036 L/s

Energy consumption (kWh/annum)

	CAV	CAV + Econ	VAV	VAV + Econ
Heating	154	154	403	403
Cooling	4667	3619	4309	3780
Air Handling	8235	8235	1761	1761
Lighting	1400	1400	1400	1400
Equipment	4200	4200	4200	4200
Total	**18656**	**17608**	**12073**	**11544**
Energy Savings (kWh)		1048	6583	7112
		6%	35%	38%

Energy Cost ($/annum)

	CAV	CAV + Econ	VAV	VAV + Econ
All Consumption	2587	2441	1687	1614
Supply Charges	90	90	90	90
Electricity SubTotal	**$2677**	**$2531**	**$1777**	**$1704**
Cost Savings		$146	$900	$973

Discussion

The calculated cooling capacity (19.8 kW) is approximately one third larger than the capacity specified by the client. (14.3 kW) Similarly, the calculated air flow rate (1036 L/s) is larger than the specified value. (750 L/s) This may be due to the increase in internal loads which was requested by the client after an initial simulation.

The energy consumption pattern is dominated by cooling and air handling (the supply fan).

The variable volume system offers substantial savings over the constant volume system due mainly to fan energy savings (79%) coupled with some cooling savings (8%) due to reduced fan heat gains.

The economy cycle works fairly well for this house in Perth, saving 22% of cooling energy for the constant volume system and 12% for the variable volume system. The lower saving is due to colder air supply temperatures (one zone requiring colder air than the house average), reduced volume of air being cooled and reduced fan heat gain.

Fan energy consumption is 44% of the total for the constant volume case. This high proportion reflects the fact that the whole house is being heated and cooled for 17 hours per day every day of the year, even though the living areas are unoccupied overnight and the bedrooms unoccupied during the day. While the VAV design addresses this in part, by handling small loads more efficiently, other solutions are:

a. switch off the supply fan when the house is comfortable,
b. use two separate systems or
c. use an A/B bypass arrangement to only provide cooling when zones are occupied.

Fan Power Sensitivity Analysis

The initial specification for the supply fan was:

Evaporator fan: 4amps, 1phase

At full load, this fan will draw approximately 0.96 kW, which is 1.28 W/L/s for the specified flow rate of 750 L/s.

In view of the dominance of the fan energy consumption, the sensitivity of the assumption was explored by repeating the simulations at half that value:

Supply Fan specific power = 0.64 W/L/s.

Energy consumption (kWh/annum) using 0.64 W/L/s fan

	CAV	CAV + Econ	VAV	VAV + Econ
Heating	318	318	433	433
Cooling	4078	3263	4075	3568
Air Handling	4177	4177	882	882
Lighting	1400	1400	1400	1400
Equipment	4200	4200	4200	4200
Total	**14173**	**13358**	**10990**	**10483**
Energy Savings (kWh)		815	3183	3690
		6%	22%	26%

Naturally the "Air Handling" energy consumption is halved. Cooling energy for the CAV option is reduced by 589 kWh/annum (13%) Heating energy is slightly higher. The overall energy savings for the "VAV+Econ" option reduce from 38% to 26%. Thus it will be important to determine the realistic value for specific fan power.

Conclusion

This study estimates that for a given house in Perth, a variable volume air conditioning system with economy cycle controls can save up to 38% of total energy consumption compared to a constant volume system. The actual savings are highly dependent on the actual power of the supply air fan and the operating strategy employed.

Appendix 1: Input Data

Italics show data provided by client

1. Scale Drawings showing:
   - Location: Perth
   - Floor plans. *As per attached plan (1:100), assume North "up the page"*
   - Elevations *Allow for a pitched roof of 26 degrees. Allow all window heights to be 1.55 meters.*
   - Key Sections showing ceiling and shading arrangements. *Allow all ceiling heights to be 2.6 meters. Allow 600mm eaves on all windows. Eaves 150mm above top of window.*

2. Construction information for each element type:
   - Material layers & thickness, including insulation
   - *External Walls – double brick with cavity. 10mm rendered plaster on inside.*
   - *Internal Walls – single brick with 10mm rendered plaster on both sides*
   - *Roof – tiles with 50mm thick fibre glass insulation on top of 10mm thick plasterboard ceiling*
   - *Floor – concrete slab on ground, carpeted throughout.*
   - *Glass 6mm clear. SC 0.95 no internal shading devices*

   - Solid roof over "al fresco" area and front verandah.
   - External colours *roof dark colour. Walls medium colour*
   - Glazing selection(s) and blinds if any. *Glass 6mm clear. SC 0.95, no internal shading devices*

4. *Schedules of operation* (provided by client)

Occupancy (persons)

	6am to 8am	8am to 3pm	3pm to 6pm	6pm to 9pm	9pm to 6am
Bedrooms 2,3,4,5	1	0	0	0	3
Bedroom 1	0	0	0	0	2
Kitchen/Dining	2	0	1	0	0
Living	2	0	1	2	0
Theatre	0	0	0	1	0
PC Zone	0	0	1	1	0
Study	0	0	0	1	0
TOTAL	**5**	**0**	**3**	**5**	**5**
Percent of Max	100	0	60	100	100

Lights (watts)

	6am to 8am	8am to 3pm	3pm to 6pm	6pm to 9pm	9pm to 6am
Bedrooms 2,3,4,5	180	0	0	0	0
Bedroom 1	120	0	0	0	0
Kitchen/Dining	120	0	60	120	0
Living	120	0	100	120	0
Theatre	0	0	0	200	0
PC Zone	60	0	60	60	0
Study	60	0	0	60	0
TOTAL	**660**	**0**	**220**	**560**	**0**
Percent of Max	100	0	33	85	0
Hours	2	7	3	3	9
WattHours	1320	0	660	1680	0

Equipment (watts)

	6am to 8am	8am to 3pm	3pm to 6pm	6pm to 9pm	9pm to 6am
Bedrooms 2,3,4,5	50	50	50	50	50
Bedroom 1	20	20	20	20	20
Kitchen/Dining	200	200	200	200	200
Living	150	0	150	150	0
Theatre	0	0	0	150	0
PC Zone	0	0	150	200	0
Study	0	0	0	100	0
TOTAL	**420**	**270**	**570**	**870**	**270**
Percent of Max	48	31	66	100	31
Hours	2	7	3	3	9
WattHours per day	840	1890	1710	2610	2430

Bathroom/Laundry (watts)

	6am to 8am	8am to 3pm	3pm to 6pm	6pm to 9pm	9pm to 6am
Lights	0	0	0	120	0
Equipment	0	0	500	50	0
TOTAL	**0**	**0**	**500**	**170**	**0**
Percent of Max	0	0	25	8	0
Hours	2	7	3	3	9
WattHours	0	0	1500	510	0

7. Tariffs for electricity and gas (if any). (Required to calculate operating energy cost) *Supply charge 25.57 cents per day. Consumption charge 13.94 cents per kWhr.*

8. For each separate HVAC system:

Schematic drawing *See attached*

Key design data: *See attached*

Cooling capacity: 14.3kW TH & 9kW SH

Heating capacity: 14.6kW

Thermostat settings: Cooling: 24°C, Heating 18°C.

Airflow rates including fresh air, *evaporator 750 l/s . Fresh air 100% when on economy cycle and 0 l/s when economy cycle is not active.*

Control sequences:

1. A calculation of the house with a standard constant volume ducted reverse cycle air conditioning system installed with the following characteristics. Control of the refrigeration by a single return air sensor located in the passage100% recirculation. (As discussed this can be calculated a single zone ie all areas that are required to run at that time. Use temp setpoint as average of the zones operating)

2. A calculation of the house with a standard constant volume ducted reverse cycle system installed with the following characteristics. Control of the refrigeration by a single return air sensor located in the passage. Economy cycle fitted.

3. A calculation of the house with a variable air volume ducted reverse cycle system installed with the following characteristics.

Control of the refrigeration via high / low select from each wall mounted sensor in each zone, 100% recirculation. (as discussed please allow VAV to close as far as possible to minimise reheat. deduct reheat from energy calc)

4. A calculation of the house with a variable air volume ducted reverse cycle system installed with the following characteristics. Control of the refrigeration via high / low select from each wall mounted sensor in each zone. Economy cycle fitted.

- Input power for fans, pumps, compressors, etc.
- *Evaporator fan 4amps 1phase*
- *Compressor 6.5amps 3 phase*
- *Condenser fan 1.2amps 1 phase*
- *Total input power for system Cooling 5.31kW Heating 5.1kW*