University of Southern Queensland

Faculty of Health, Engineering and Sciences

The effectiveness of energy recovery ventilators (ERV) for air conditioning systems in multi-purpose halls in North Queensland

A dissertation submitted by

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Abstract

Energy costs for buildings have increased rapidly in recent history and it is expected that the rise will continue over time. Heating Ventilation and Cooling (HVAC) contributes to approximately 40% of a buildings total energy consumption (Department of the Environment and Energy 2013). Culminating with this is the increasing number of hot days being recorded which is further increasing our reliance on air conditioning. The need for energy efficient air conditioning systems is imperative to reduce energy costs and greenhouse gas emissions.

Introducing outdoor air into a building is a requirement under Australian Standards. Outdoor air is typically introduced through the air conditioning system serving the building. When large quantities of outside air are required, this can have significant effects on the heat load of a building and dramatically increase the size of the air conditioning system serving the building. When ambient air conditions are of high temperature and high humidity, typical of tropical climates like North Queensland, this further exacerbates the issue. An energy recovery ventilator (ERV) is a device which pre-treats introduced outside air through an energy transfer process in which the air is cooled and dehumidified by exhaust air being removed from inside the building. The ERV supplies the pre-cooled air to an air conditioning unit, which reduces the required cooling capacity of the system, the plant size and energy costs.

The aims of this dissertation were to analyse and compare the effectiveness of energy recovery ventilators for air conditioning systems in the North Queensland region from a performance and cost standpoint. The performance was evaluated in respect to grand total heat of a system (kW) and total energy consumption. The cost was assessed in terms of capital cost, operating cost and life cycle cost.

A minimum BCA/NCC Section J compliant multi-purpose hall building was developed and used as the reference building. The methodology inherited a comparative approach where two air conditioning systems were modelled and designed; one with and without an energy recovery ventilator. A heat load simulation was undertaken on the building using the CAMEL software. Both air-conditioning systems were then designed and documented using industry design guidelines. The effectiveness was comparatively evaluated by undertaking a building energy analysis and cost analysis of each system.

It was found that whilst the ERV had a significantly higher initial cost, the ERV option sees a 27% reduction in Grand Total Heat. The ERV option reduces annual energy consumption by 8%. The cost comparison yielded a payback period of between 6 – 7 years when implementing an ERV and the non-ERV option incurs an additional $369,101 cost over the 25-year life cycle of the systems.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

[redacted]

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Student Number: [redacted]

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Nomenclature

ABCB	Australian Building Codes Board
ADP	Apparatus Dew Point
AHU	Air Handling Unit
AIRAH	Australian Institute of Refrigeration Air Conditioning and Heating
AS	Australian Standards
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BCA	Building Code of Australia
DDL	Double Deflection Louvre
E/A	Exhaust Air
EFLM	Equal Friction Loss Method
ERV	Energy Recovery Ventilator
GST	Goods and Services Tax
GTH	Grand Total Heat
GTSH	Grand Total Sensible Heat
H.E	Heat Exchanger
HVAC	Heating Ventilation and Cooling
k	Thermal Conductivity of the Material ($W/m \cdot ℃$)
kW	Kilowatts
kWhr	Kilowatt Hours
L	Thickness of Material (m)
L/s	Litres per Second
Lvg.	Leaving
m/s	Mitres per Second
NC	Noise Criteria
NCC	National Construction Code

Ø	Diameter
O/A	Outside Air
R/A	Return Air
RH	Relative Humidity
RSH	Room Sensible Heat
S/A	Supply Air
SHF	Sensible Heat Factor
SHGC	Solar Heat Gain Coefficient
T_{DB}	Dry Bulb Temperature
T_{WB}	Wet Bulb Temperature

1 Introduction

1.1 Background

In 2017, the Queensland State government announced and initiated the 'Advancing Queensland State Schools' program which is a program to invest $200 million in constructing new and refurbishing existing school halls throughout the state (Department of Education 2018). Corresponding to this, data revealed the costs incurred by the State Government due to energy usage in schools was $67.6 million in 2018, a figure which has risen $10 million in two years (Caldwell 2018). Figures extracted from the Queensland Government data which was released in 2013 reveal that numerous school's energy usage costs are in excess of $300,000 annually (Queensland Government 2012). Significant rises in energy costs over the past 6 years have resulted in a dramatic increase in this number making it a topical issue.

The increase in energy costs can be attributed to a number of factors. One thing is certain is that Australians have become heavily reliant on air-conditioning with it becoming a constant in day to day living. Whilst air-conditioning was once considered a privilege in many buildings and houses across the country, it is now considered a necessity. This could be due to advancements in technology making air-conditioning more affordable to purchase. Another contributing factor is due to the increased number of hot days, Summers and Simmons (2009) reported data showing the number of hot days and nights is increasing with time. These temperature rises result in increased energy costs for air-conditioning systems. Typically heating, ventilation and cooling (HVAC) accounts for approximately 40% of an entire building's energy consumption (Department of the Environment and Energy 2013). From this, it is imperative for engineers to design energy efficient air conditioning systems which will significantly reduce a building's energy costs.

One method of energy efficient air conditioning system is utilizing a device called an energy recovery ventilator (ERV). Energy recovery ventilators are a relatively new technology that when incorporated into an air conditioning system can provide an energy efficient solution. Energy recovery ventilators, also known as air-to-air heat exchangers, are a device which provide pre-conditioned outside air to an air conditioning system through a heat exchange process with conditioned exhaust air drawn from the building. The supply of outside air is a requirement for a code compliant ventilation system and building. Conventional methods see outside air under ambient conditions supplied directly to a building or air conditioning system.

When designing air-conditioning systems for multi-purpose halls, there are number of issues encountered. One being multi-purpose halls are typically large structures which produce large amounts of solar heat gain resulting in a high cooling capacity requirement. Another issue is the large quantities of outside air that are required to be provided to these multi-purpose halls as per Australian Standards. Conditioning of these large amounts of ambient air dramatically increases the required cooling capacity of an air conditioning system. In tropical climates where ambient air, in peak load periods, are high humidity and high temperature conditions, cooling the outside air requires large amounts of energy. Hence why air-conditioning systems in North Queensland require large equipment, generally cost more for the same application and energy costs are higher. Utilization of an ERV is imperative for an increase in energy efficiency and a reduction in cost as mentioned above.

1.2 Aims & Objectives

The aims of this dissertation are to analyse and compare the effectiveness of energy recovery ventilators for air conditioning systems in the North Queensland region from a performance and cost standpoint.

The objectives of this study are to:

- Review existing energy recovery ventilator technology, investigate existing applications where these devices have been implemented and research the relevant Australian Standards, Building Code of Australia and industry guidelines for design of air-conditioning systems.
- Develop a Deemed To Satisfy multi-purpose hall building in accordance with the Building Code of Australia (BCA) in which the air-conditioning systems will be based upon.
- Complete a heat load simulation of the building for an air conditioning system with and without an energy recovery ventilator.
- Design and document compliant mechanical services designs for an air-conditioning system with and without an integrated energy recovery ventilator to serve the multi-purpose hall.
- Undertake an energy analysis on the building for the two system variations to determine the performance of the two systems.
- Provide a cost analysis between the two system variations.
- Analyse and interpret the results and provide outlines of the effectiveness and benefits of each system.

1.3 Outline of Chapters

The dissertation is presented in five distinct chapters which undertake a logical sequence in order to formulate and develop the dissertation to achieve the desired outcomes and objectives.

Chapter 1 introduces the dissertation topic, outlines background information including how and why the topic was investigated, its relevance to real life application and the topic motivation. The chapter also includes the aims and objectives of the dissertation.

The literature review forms the majority of the content of Chapter 2. This chapter includes review and collation of research regarding climate, air conditioning systems, energy recovery technology, previous studies of energy recovery applications and a review of the relevant Australian Standards and Building Code sections applicable to air conditioning and energy efficiency. The findings of this research were utilised throughout the dissertation and are highlighted in the dissertation justification section at the end of chapter 2.

Chapter 3 outlines the design methodology of the dissertation. The chapter includes all design parameters and design decisions which were included in the project. The design and documentation of the systems were undertaken through the chapter and are presented throughout. Some results are revealed in this section as proceeding parts of the design process rely on previous data. The chapter concludes with the detailed steps undertaken for the energy and cost analysis.

The results and discussion are presented in Chapter 4. The results are divided into three sections; heat load, energy & cost. The results are presented graphically with data relationships and findings discussed. The final chapter, Chapter 5, concludes and summarises the findings and outlines potential areas of future study.

2 Literature Review

2.1 Climate & Psychrometrics

The psychrometric condition of air comprises of a mixture of dry air and water vapour and is determined by the three psychrometric properties which are barometric pressure, dry-bulb temperature and wet-bulb temperature (Gatley 2013a). Dry-bulb temperature is the measurement of temperature undertaken by a normal thermometer. It is typically referred to as the temperature of air when a prefix is not used. Dry-bulb temperature is considered the mixture of the dry air component and the water-vapour component of the air temperature. Undertaking sensible heat transfer, by definition, involves changing the dry-bulb temperature without changing the associated water vapour of the air during the process (Gatley 2013b).

Cleveland and Morris (2009) describes the wet-bulb temperature as the temperature in which air will cool for the moisture content/water to be evaporated into unsaturated air. The wet-bulb temperature refers to the moisture content of the air, coupled with the dry-bulb temperature it can be used to calculate the relative humidity of air. The wet-bulb temperature is always lower than the dry-bulb temperature other than at the saturation point where they become equal. The wet-bulb temperature is determined by covering the bulb of a thermometer with a wet wick.

Wang (2000) describes dry-bulb temperature, wet-bulb temperature, solar radiation, wind speed and wind direction as the outdoor climate parameters which affect the performance of air conditioning systems and space load.

Outdoor climate parameters, referred to by Aktacir et al. (2008) as outdoor design conditions, are characteristic features of the climate for a particular location. This information is used for designing HVAC systems and if outdoor conditions are selected incorrectly in design it can have significant effects on the energy and comfort of a system. If inflated outdoor design conditions are used it can result in oversizing of system and uneconomical design where as if a system’s conditions are underestimated this will result in equipment and system deficiencies (Aktacir et al. 2008).

Legg (2017) outlines the resultant system effects when outdoor design conditions selections are overestimated as:

- oversized plant
- increased capital cost
- poor mechanical plant efficiency
- excessive operating costs

- limited plant control.

When strict outdoor design conditions are not used, the effects of this include undersized plant equipment and poor thermal conditions at peak load.

2.1.1 North Queensland Climate

The Bureau of Meteorology (2016) identifies six climate zones throughout Australia. The climate zones are illustrated on a map and are classified by temperature and humidity data collected from 1961 to 1990. The map illustrates the North Queensland (Townsville) climate being predominantly the 'hot humid summer' climate zone.

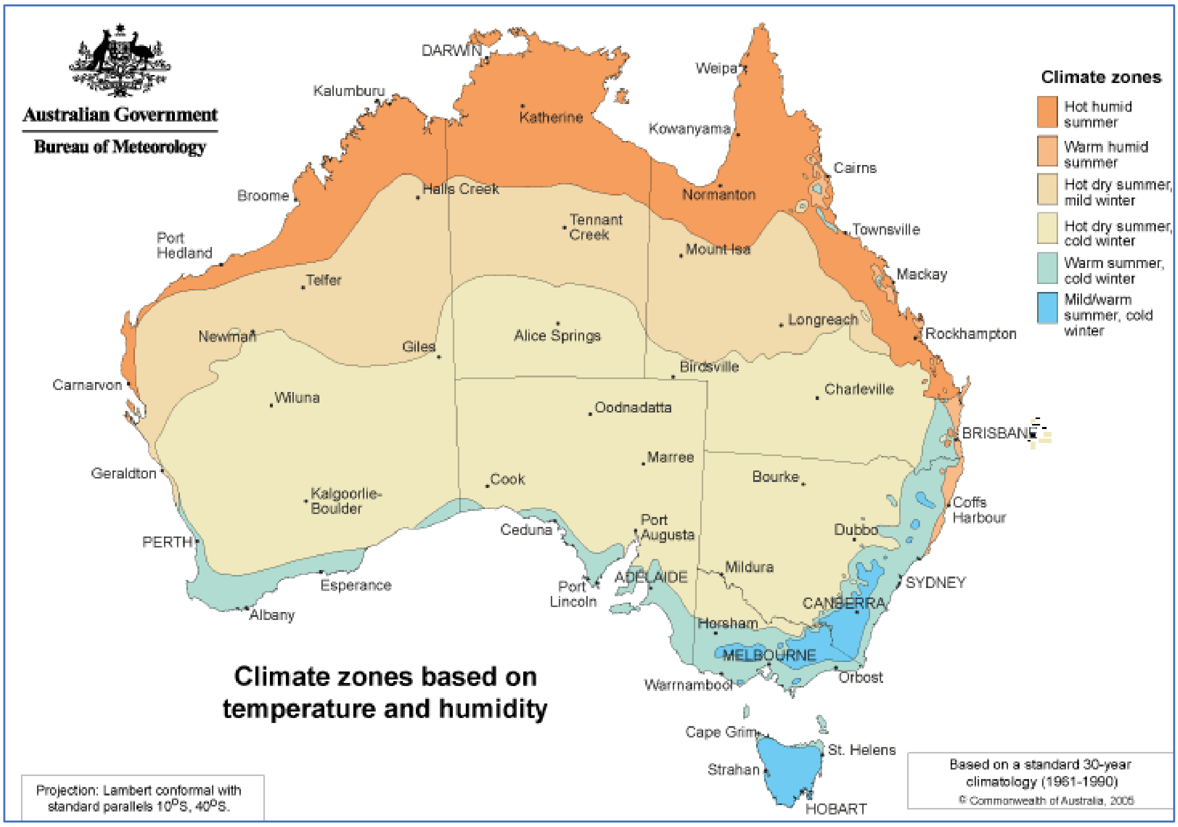


Figure 2-1: Climate Zones Australia (Bureau of Meteorology 2016)

The Townsville City Council (2018) describes Townsville's climate as dry and tropical. High temperatures and high humidity are common in the Townsville wet season which creates uncomfortable weather conditions including daily average temperatures often ranging between 29 and 32°C. High atmospheric water vapour content and reradiating nocturnal infrared radiative losses from the surface causes a regular occurrence of daily temperature averages exceeding 20°C and relative humidity higher than 80% at the same time (de Dear & Fountain 1994).

2.1.2 Outdoor Air – Air Conditioning

A typical air conditioning process comprises of outdoor air and return air from the room being mixed together and entering a conditioning apparatus which is then supplied to the room. The conditioning apparatus, also known as a cooling coil or evaporator, removes heat and moisture from the air stream to maintain desired room conditions. Sensible heat and latent heat are the thermal properties of air. In order to achieve comfort design conditions, the air conditioner must be of sufficient capacity to offset both sensible and latent loads in the room (AIRAH 1998).

The grand total heat is the total of the sensible and latent heat. Sensible heat is the heat energy that results in a rise or drop of the temperature of a substance when it is added to or removed the air without changing the state. The sensible energy load of air conditioning system is attributed by solar radiation, air infiltration, occupants, lighting and equipment from the building that is served by the system (Cleveland & Morris 2009).

Cleveland and Morris (2009) defines latent heat as the amount of thermal energy that is absorbed or released by air undergoing phase change whilst under constant temperature and pressure conditions. The latent energy load of an air conditioning system in a building is affected by the moisture content in the air and is attributed to by factors including air infiltration, outside air introduced to the building/air conditioning system, building occupants and heat due to cooking and steam.

Kang et al. (2010) reports the purpose of ventilation in buildings is for removal of heat and pollutants as a result of internal buildings materials and occupants and also providing clean outdoor air to building occupants. The main contributors to thermal loads on buildings are losses or gains through the building fabric and ventilation loads.

Outdoor air ventilation is a requirement in air conditioning systems for dilution of odours, dilution of toxic mixtures and to offset infiltration. However, outdoor air has significant effects on the total cooling capacity of an air conditioning system – increases in outdoor air increases the grand total heat (GTH). When the dew point of the outdoor air is greater than that of the room conditions the grand total heat increases which requires air conditioning plant to be of a larger capacity. Increases in outdoor air quantities requires a larger cooling coil and reduced by-pass factor which increases capital and operating costs of air conditioning plant (AIRAH 1998).

2.2 Air Conditioning Systems

Patrick et al. (2007) states that the second law of thermodynamics is the fundamental principle of air conditioning and refrigeration. The second law states that heat can pass only from a warm body to a colder body. The process of air conditioning involves heat transfer where warmer air becomes in contact with pipes or coils which have circulating gas or fluid inside. The heat is transferred from the air to the gas or fluid which results in a lower temperature in the air. The basic cooling methods include:

- Evaporative cooling
- Cold-water cooling
- Steam-jet cooling
- Gas compression refrigeration
- Absorption refrigeration
- Thermoelectric refrigeration

Each method is suitable for different applications and locations. The most common method of cooling is gas compression which is in operation in many residential and commercial systems. (Patrick et al. 2007)

Vedavarz et al. (2007) outlines four main components which when combined complete the gas compression air conditioning system. These components include:

- Evaporator
- Condenser
- Compressor
- Fan/blower

These components complete a closed network in which a refrigerant is mechanically circulated throughout. The refrigerant undertakes a cycle in which it is compressed, liquefied, expanded and evaporated. Figure 2-2 illustrates the gas compression cycle of an air conditioning system.

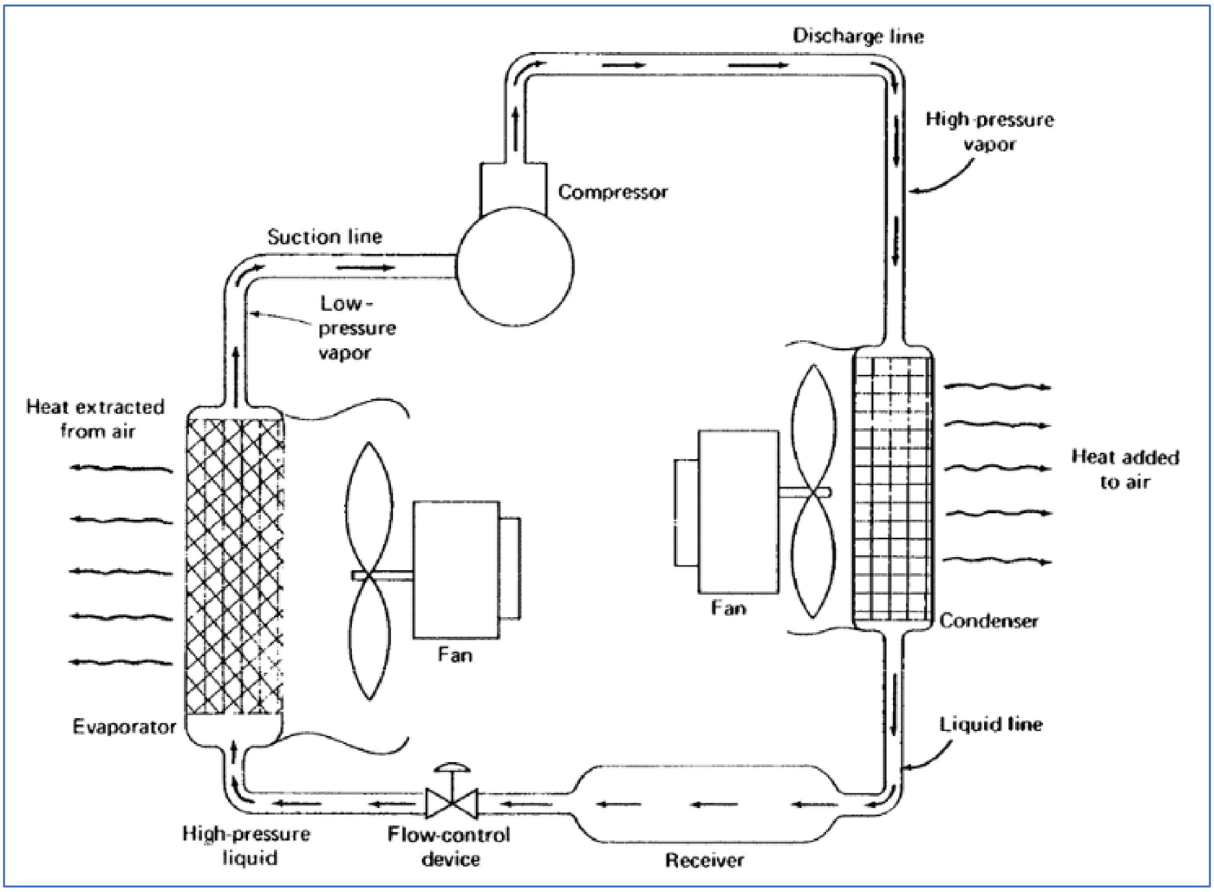


Figure 2-2: Components of a compression refrigeration system (Patrick et al. 2007)

Typically, the evaporator is located away from the remaining components of the system. The required capacity of the air conditioning system affects the design, shape and size of the evaporator coil. When in operation, refrigerant flows inside the evaporator coil where heat is transferred from the room air to the cooler fluid in the evaporator as the room air passes through the coil. As the evaporator absorbs heat, the refrigerant is boiled and is carried away as a gas or vapour (Patrick et al. 2007).

The compressor undergoes a suction stroke which typically occurs at low operating pressures. The suction stroke removes the refrigerant vapour from the evaporator to ensure the evaporator pressure is maintained and the evaporator coil temperature is kept low. The suction stroke draws the refrigerant vapour into the compressor where the compression stroke proceeds. The compression stroke superheats the gas through vapour compression to high temperatures to allow heat rejection at the condenser (Patrick et al. 2007).

The condenser coil carries superheated refrigerant vapour. The condenser fan blows lower temperature air over the condenser coil which cools the refrigerant vapour by absorbing the heat. At this point in the cycle the vapour condenses and changes phase into a warm liquid. The condenser coil is typically located external to the building (Patrick et al. 2007).

Hundy et al. (2016) identifies the numerous air conditioning system types and the choice of system is dependent on application and criteria. The system types include:

- Central air handling units
- Packaged air handling units
- Fan coil units
- Under floor systems
- Static cooling devices
- Split systems
- Dehumidifier systems

2.2.1 Packaged Air Handling Unit

Vedavarz et al. (2007) reports in packaged air handling units all components of an air conditioning system are housed within a single package. Package units are manufactured in two distinct configurations; horizontal and vertical. A horizontal package unit configuration is shown in Figure 2-3. Package air handlers are typically used in light-commercial and commercial applications, they are manufactured with supply and return connections integral to the unit. The thermodynamic processes in which these units can be used for include cooling, heating, humidification and filtration (ASHRAE 2012e).

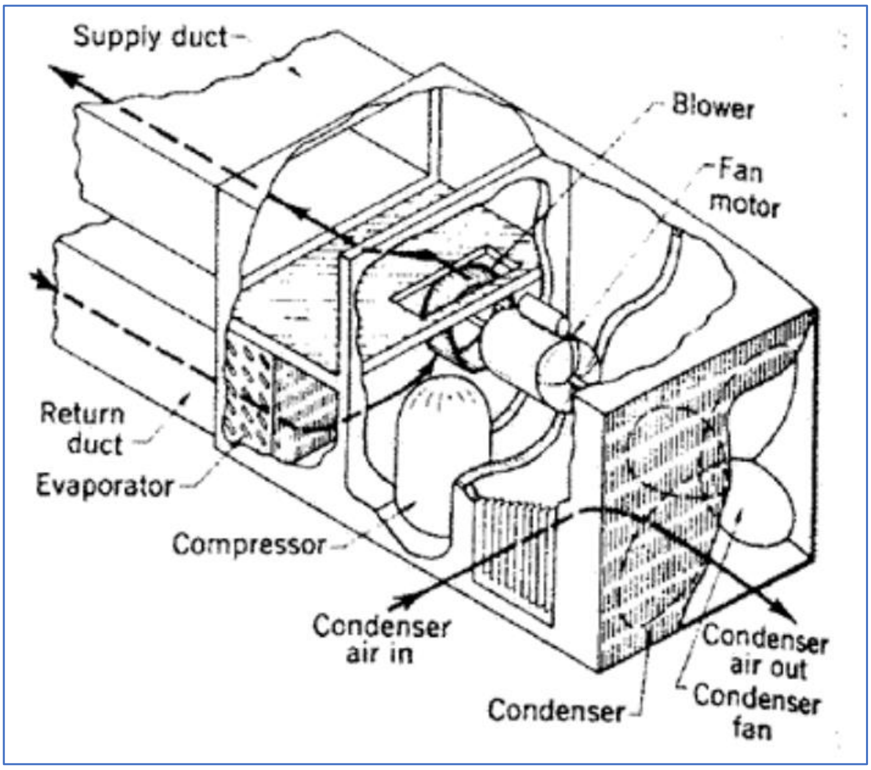


Figure 2-3: Horizontal Configuration Packaged Air Handling Unit (ASHRAE 2012e)

Hundy et al. (2016) outlines the advantages of packaged air handling units include:

- Low cost
- Space saving
- Heating & cooling capability

The disadvantages of packaged air handling units include:

- Large penetrations through building structures to accommodate this system type
- Elevated noise levels when systems are operating
- Limited humidity control

The capacities of the units can range from 6kW up to 200kW systems allowing for installation in small shops & single offices and sizable applications such as factories and warehouses.

2.3 Air-to-Air Energy Recovery

Air-to-air energy recovery involves the transfer of energy or heat recovery between two airstreams which are at different temperatures and humidity. The benefits of air-to-air energy recovery include acceptable indoor air quality, reduced energy costs and consumption. There are two types of air-to-air energy recovery devices or heat exchangers; these are heat recovery ventilators and energy recovery ventilators. The performance of an energy recovery device is called its effectiveness or efficiency. The effectiveness of a system is calculated by comparing the actual energy or moisture recovered with the maximum possible amount of energy or moisture able to be recovered. The effectiveness is dependent on the airflow direction and the configuration of the transferring airstreams. There are different orientations for exchangers, each have varying effectiveness and limitations. The three main configurations are (ASHRAE 2012f):

- Parallel flow
- Counterflow
- Crossflow

There are different types of energy recovery devices all which are suited to particular applications and design requirements. Energy recovery devices can be categorised into the following different types (ASHRAE 2012f):

- Fixed plate
- Membrane plate
- Energy wheel

- Heat pipe
- Run-around coil loop
- Thermosiphon
- Twin towers

Heat recovery ventilators, otherwise known as sensible heat exchange devices, can recover only sensible energy usually by means exhaust air from dryers, ovens and other heat sources. Heat recovery ventilators are ideal in conditions where outdoor air humidity is low and when the space has high latent loads (ASHRAE 2012f).

The amount of energy transferred by an energy recovery ventilator is referred to as the effectiveness or efficiency of the device. Energy recovery ventilators or enthalpy devices are used to recover both sensible (temperature) and latent (moisture) forms of energy. Latent energy transfer occurs when there is a difference in the pressure of the water vapour in the two air streams (ASHRAE 2012f).

2.3.1 Energy Recovery Configurations

2.3.1.1 Parallel Flow

A parallel flow heat exchanger configuration is comprised of supply and exhaust airstream surfaces flowing in the same direction. This configuration has a maximum effectiveness of 50% (ASHRAE 2012g). Cengel (2008) outlines the heat transfer process that results in the cold fluid temperature increasing and the hot fluid temperature decreasing. The cold fluid temperature will increase but will never exceed the hot fluid temperature. The parallel heat exchange configuration is illustrated in Figure 2-4.

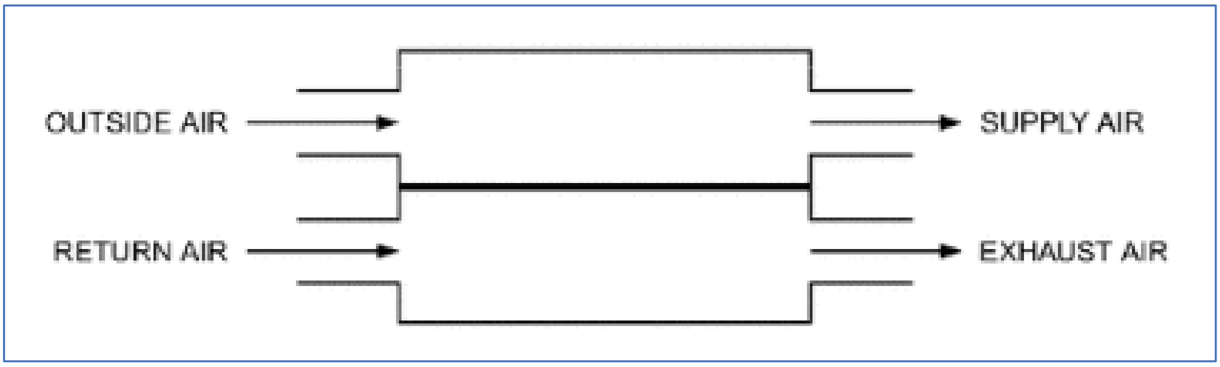


Figure 2-4: Parallel Flow Configuration (ASHRAE 2012g)

2.3.1.2 Counterflow

Cengel (2008) describes the counterflow heat exchanger process as hot and cold fluids entering the heat exchanger device from opposite ends. In this configuration the outlet temperature of the hot fluid can be exceeded by the outlet temperature of the cold fluid. ASHRAE (2012g) reports that counterflow heat exchangers theoretical effectiveness can be up to 100% however typical installed applications produce an effectiveness of 75 to 80%. Counter-flow heat exchangers are not as common as other configurations as construction of the separate air-streams results in design and manufacturing issues (Rabbia & Dowse 2000). The counterflow heat exchanger configuration is illustrated in Figure 2-5.

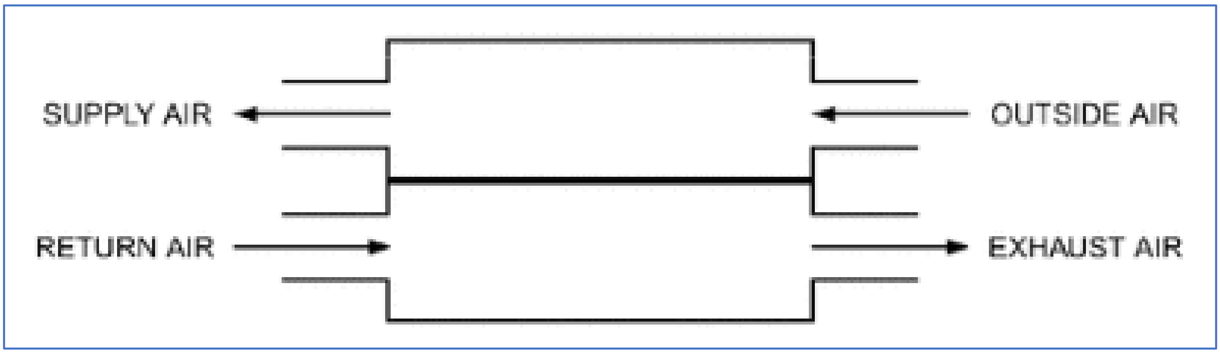


Figure 2-5: Counterflow Configuration (ASHRAE 2012g)

2.3.1.3 Crossflow

Rabbia and Dowse (2000) identifies crossflow heat exchanger orientation as the most common type of heat exchanger. Crossflow heat exchangers are orientated so that exhaust and supply air streams run perpendicular to each other. Crossflow exchangers theoretically have a lower effectiveness than counterflow, with units having an effectiveness of 50 – 70% (ASHRAE 2012g). Whilst crossflow heat exchangers are less effective than counterflow, crossflow configuration is favoured for air-to-air energy recovery due to the significant design and construction limitations of counterflow configurations .The crossflow heat exchanger configuration is illustrated in Figure 2-6.

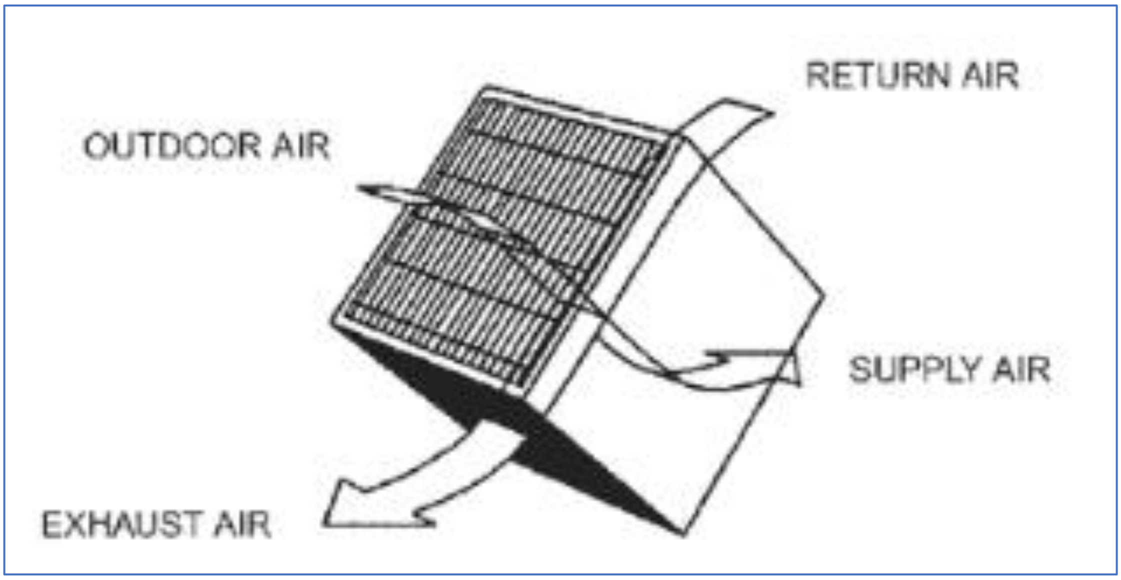


Figure 2-6: Crossflow Configuration (ASHRAE 2012g)

2.3.2 Energy Recovery Types

2.3.2.1 Fixed plate

Fixed plate energy recovery devices comprise of a heat transfer core which is made up of alternating layers of plates which are formed and sealed resulting in separate airpaths being adjacent to each other (Rabbia & Dowse 2000). Fixed plate devices achieve high sensible heat recovery and overall effectiveness, with no latent heat recovery. Typically, aluminium is the most popular material for fixed plate construction as it is not flammable and is highly durable. Other materials are also used. Fixed plate energy recovery devices are to be designed to suit a large number of sizes and performance requirements. They are made with no moving parts (other than fans) therefore maintenance is reduced on equipment (ASHRAE 2012d).

2.3.2.2 Membrane plate

A membrane plate energy recovery device employs the same system and construction as a fixed plate type system however the plates are made from a water vapour-permeable material. Membrane plate devices are able to transfer sensible and latent energy between two airstreams, latent energy is transferred via water-vapour diffusion. The devices are used in applications where sensible and latent energy are exchanged from a building's exhaust air and the introduced ambient fresh air (Woods 2014). The operating process of a membrane energy recovery device in summer conditions is shown in Figure 2-7.

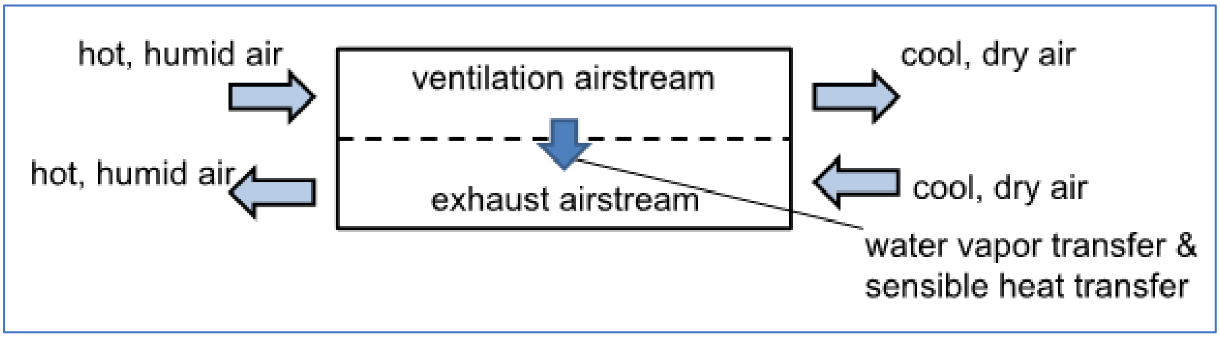


Figure 2-7: Summer membrane ERV process

The membrane, which allows for total enthalpy energy exchange, can be constructed from varied water-vapour permeable materials such as (ASHRAE 2012d):

- Treated paper
- Cellulose
- Polymers
- Hydrophilic electrolytes
- Other synthetic materials

Woods (2014) notes that membrane plate exchangers are typically crossflow orientation due to ease of construction. They typically yield sensible and latent effectiveness values of 60-80%. The membrane component requires regular maintenance as there can be issues with the durability of the material.

2.3.2.3 Energy wheel

Energy wheels or rotary enthalpy wheels transfer sensible and latent energy from adjacent supply and exhaust air paths. The energy wheel is a revolving cylinder filled with a permeable material which has a large surface area. The wheels operate using a counterflow orientation and can also be designed to transfer sensible heat only. The process for latent heat transfer involves the wheel media absorbing moisture from the outside air stream and transferring it to the airstream of low humidity. The typical effectiveness for energy wheel system can range from 50-85%. The disadvantages of energy wheels are that the devices require moving parts which require regular maintenance and there is a possibility that supply airstreams can be contaminated by exhaust air transfer (ASHRAE 2012a). The energy wheel transfer process is shown in Figure 2-8 below.

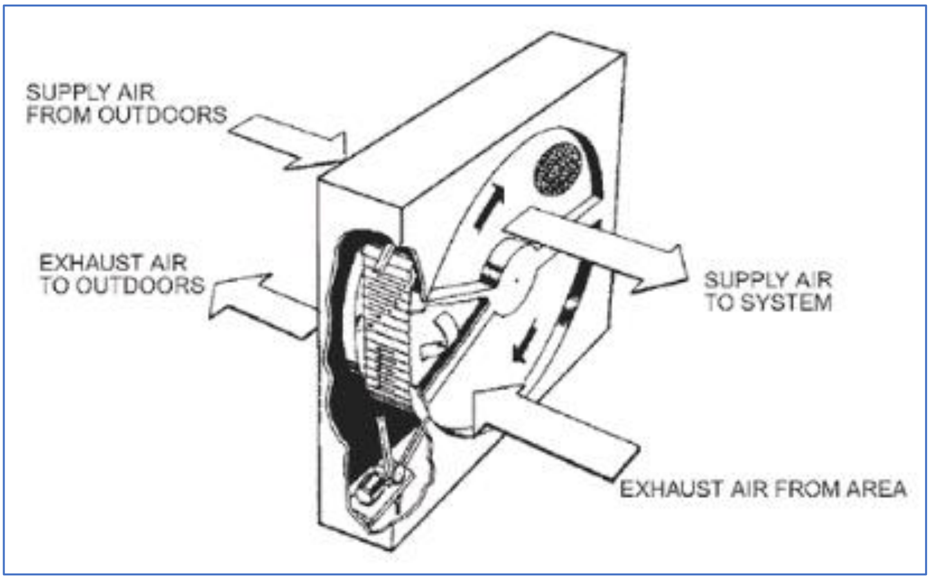


Figure 2-8: Energy Recovery Wheel system (ASHRAE 2012a)

2.3.2.4 Heat pipe

Rabbia and Dowse (2000) describe heat pipe air-to-air heat exchangers as a finned coil system where each tube is not connected. These tubes are usually filled with a refrigerant gas and sealed. One half of the heat exchanger acts as an evaporator and the other acts as a condenser, from here the high temperature air stream passes through evaporator and low temperature passes through the condenser. The refrigerant is then warmed and vaporizes, and due to the internal vapour pressure gradient, it passes to the condenser side where it warms the low-temperature air stream as shown in Figure 2-9. Heat pipes typically include copper tubes and aluminium fins which are connected by an internal wick. Heat pipes are suitable when only sensible heat transfer is required, they achieved only minimal latent transfer only under special conditions.

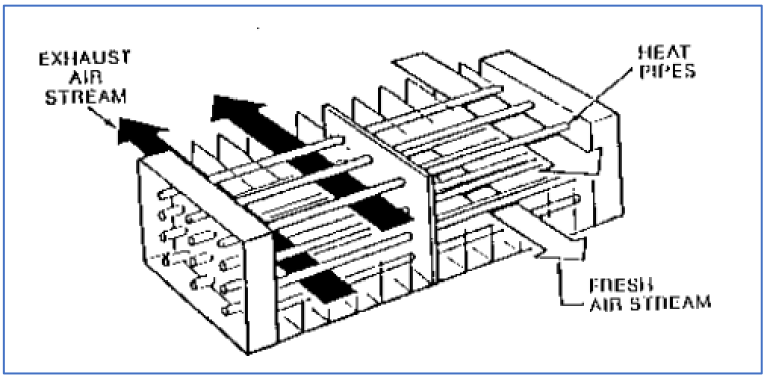


Figure 2-9: Heat pipe exchanger process (Rabbia & Dowse 2000)

Heat pipe systems typically produce a sensible effectiveness of 45%-65%. MGE (2019) detail the advantages of a heat pipe exchanger system which include no moving parts in the heat exchange process which results in zero energy required to operate the system and minimal maintenance required, only periodic cleaning. Heat pipe exchangers can also be manufactured with protective coating to protect the coils against corrosion. NortekAir (2017) describe heat pipe exchanger technologies as one of the most robust solutions including in applications such as high temperatures. Heat pipes are extremely advantageous where corrosive and/or contaminated air is current and is of high risk of fouling. The disadvantages of heat pipe systems include the low energy transfer and the requirement for refrigerant gas which can have detrimental effects to the environment and inhabitants if a leak is to occur, depending on the refrigerant gas type.

2.3.2.5 Run-around coil loop

A run around loop exchanger system is described by Rabbia and Dowse (2000) as using standard finned-tube coils to transfer heat to and from an intermediate working fluid such as water or glycol solution. The system then requires a pump, connected to a closed loop circuit, to move the fluid between two coils as seen in Figure 2-10. Run-around coil loop devices typically produce a sensible effectiveness of 55%-65% (ASHRAE 2012a).

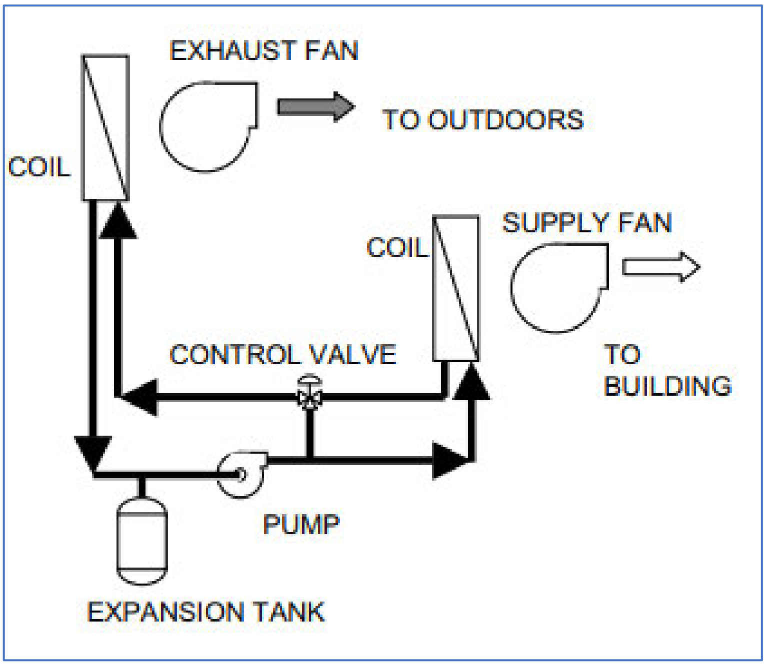


Figure 2-10: Run-around loop system schematic (Rabbia & Dowse 2000)

Rabbia and Dowse (2000) report the advantages of a run around loop system include high suitability when airpath separation is required, highly suited to industrial applications. MGE (2019) cited the advantage of run-around loop exchanger systems is that the system allows heat transfer between process air and ventilation without these elements being physically located nearby each other.

The disadvantages of a run-around loop systems range include the following (Rabbia & Dowse 2000):

- Electrical power, motor controls and temperature controls are required which results in higher operating and capital costs.
- Higher maintenance costs due to multiple components.
- Inability to transfer moisture (latent heat)
- The need for multiple fluid such as glycol and water.
- Potential risk of overheating or overcooling of supply are due to excess heat transfer.

2.3.2.6 Thermosiphon

There are two types of thermosiphon systems, these being sealed-tube thermosiphon and coil-type thermosiphon systems. The components that make a complete thermosiphon system consist of:

- Evaporator
- Condenser
- Interconnecting pipework
- A working fluid (vapour and liquid phase)

The working principle of a thermosiphon system is temperature differential and gravity force are used to circulate the working fluid between the condenser and evaporator. Thermosiphon systems can transfer heat in one or two directions. This system type has an approximate sensible effectiveness of 40 – 60% with no latent heat transfer achieved. The advantage of this system is there is no moving parts, so maintenance is kept to a minimum. The disadvantage is the effectiveness of the system is greatly dependent by overall and the pressure in the system (ASHRAE 2012b).

2.3.2.7 Twin Towers

A twin tower enthalpy recovery loop system comprises of two contactor towers which each house supply and exhaust airstreams. A sorbent solution is circulated between towers by pumps which transports water vapour and heat from exhaust to supply air streams. This system is shown schematically in Figure 2-11. To prevent air contamination, air is passed over demister pads which remove the sorbent from the airstream. A twin towers system is able to micro-biological clean the supply and exhaust airstreams. The disadvantages of this system include (ASHRAE 2012c):

- Highly intensive maintenance and adjustment required
- Limited manufacturers & supplies of system
- Whilst the calculated effectiveness of this system is 40-60%, the actual operating effectiveness is unknown.

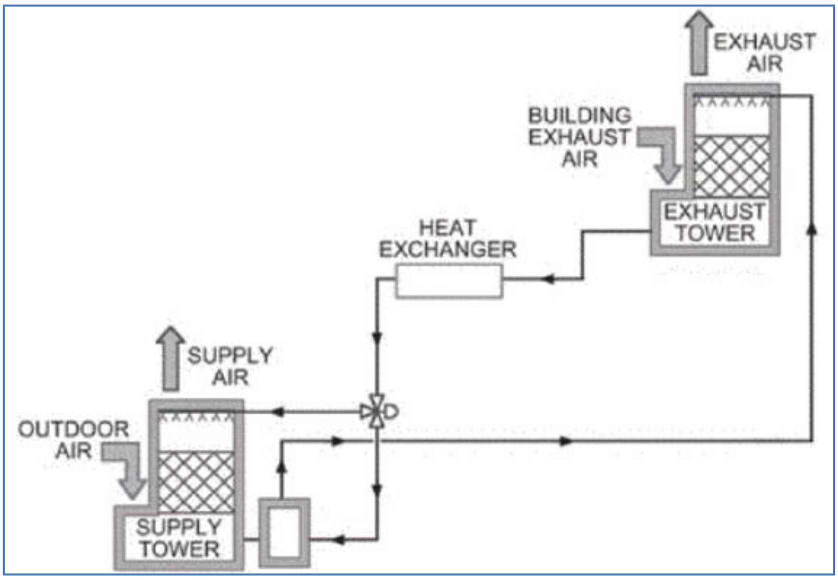


Figure 2-11: Twin Tower system schematic (ASHRAE 2012c)

2.4 Previous Studies

Abdel-Salam and Simonson (2014) completed simulations of a conventional air conditioning system with and without an ERV as part of a larger simulation project. The results revealed the following:

- 20% reduction in electricity usage per year when an ERV is installed.
- Reduction in initial cost of equipment due to a reduction in required plant size
- 20% reduction in life cycle cost when an ERV is installed.

Abdel-Salam and Simonson (2014) detailed significant energy savings, initial cost savings and life cycle cost savings from the study undertaken when ERV's were in use. Extracted from the literature was the following design parameters in regard to occupancy, outside air rates and application:

- Location: China
- Building Type: Office
- Building Area: 511m^2
- Occupancy: 5 m^2/person
- Outside Air Rate per person: 10L/s per person
- Total Outside air rate: 0.26m^3/s

Liu et al. (2010) outlines the effectiveness of ERV's in 5 different Chinese climatic zones. These 5 areas have vastly different climates. Table 2-1 outlines the ambient climatic conditions (dry bulb, wet bulb and humidity) of the 5 zones in which the study was undertaken as well numerous cities in these zones. The report had numerous findings, which included:

- A dramatic increase in energy savings when enthalpy efficiencies increased. In some months, saw a 15% increase in saved energy percentages when enthalpy was at 75%.
- Across the 5 Chinese cities studied, all of the cities yielded an energy savings increase over 15% at some point.
- An increase of 23% in energy consumption was recorded in January when no ERV was used.

Table 2-1: Outdoor Temperatures of Chinese Cities (Liu et al. 2010)

City	Outdoor Temp. Dry Bulb (°C)	Outdoor Temp. Wet Bulb (°C)	Humidity $(kg/kg_{dry\ air})$
Urumqi	34.1	18.5	0.0069
Harbin	30.3	23.4	0.0153
Beijing	33.2	26.4	0.019
Xi'an	35.2	26	0.0175
Shanghai	34	28.2	0.0219
Chongqing	36.5	27.3	0.0192
Guangzhou	33.5	27.7	0.0212
Hong Kong	32.4	27.3	0.0209
Kunming	25.8	19.9	0.0122
Guiyang	30	23	0.148

The study included simulations of the outdoor enthalpy in five cities in winter with the same indoor design enthalpy, the comparison of these are shown in Figure 2-12.

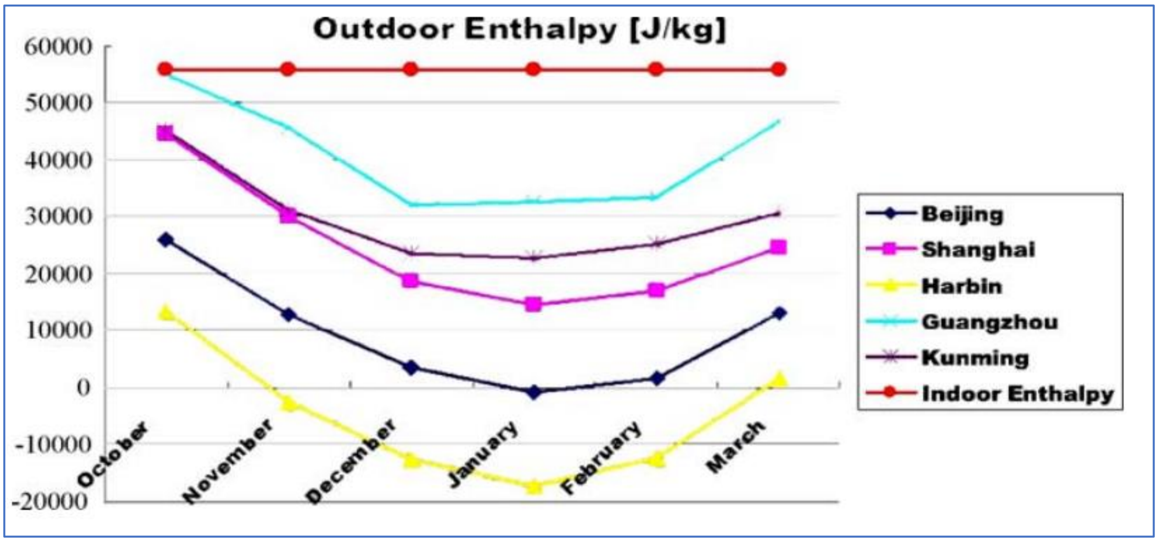


Figure 2-12: Indoor Design Enthalpy & Outdoor Enthalpy Five Cities (Liu et al. 2010)

Results produced diverse energy savings depending on city, however it revealed a general pattern that the greater the difference in outdoor enthalpy and indoor design enthalpy yields greater energy savings as seen in Figure 2-13.

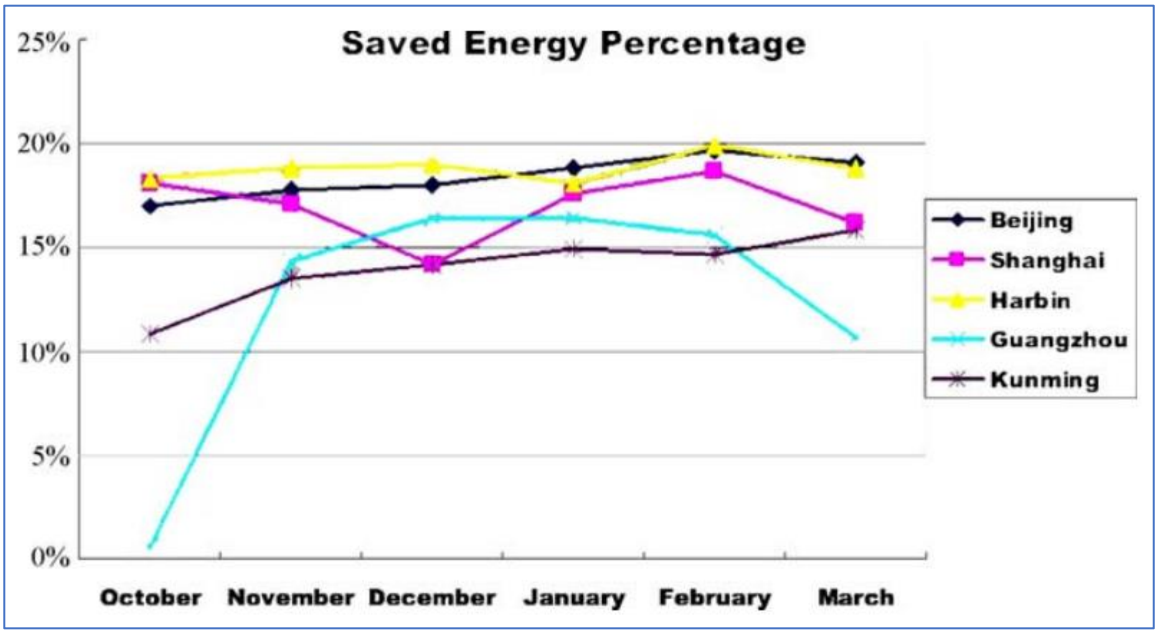


Figure 2-13: Energy Saved per city (Liu et al. 2010)

Pastor et al. (2010) documented the effectiveness of an energy recovery ventilator at varying air velocities. The study revealed firstly that counter-current formation is the optimal orientation for effectiveness in both latent and sensible energy transfer. The results showed when airspeed decreases, both latent and sensible effectiveness increase significantly in summer with efficiency values in excess of 0.6. It was revealed the effectiveness was increased when velocities were lower. The experiment was conducted under the climatic conditions shown in Table 2-2. This report produced large energy savings and effectiveness at a predominantly low relative humidity.

Table 2-2: Test Climate for ERV (Pastor et al. 2010)

	Summer	Winter
Inlet Temperature (TDB °C)	35	1.7
Inlet Temperature (TWB °C)	26	0.6
Relative Humidity (%)	49.34	82.02

2.5 Building Code of Australia/NCC

The Council of Australian Governments developed the National Construction Code (NCC) to incorporate all on-site construction requirements into a single code. The NCC provides the minimum necessary requirements for:

- Safety and health
- Amenity and accessibility
- Sustainability in design, construction, performance and liveability in new and upgraded existing buildings.

The NCC provides a consistent set of technical requirements for building, plumbing and drainage works. It allows for variations in climate and geographic conditions. The NCC is comprised of three parts: Building Code of Australia (BCA) Volume 1 & 2 and the Plumbing Code of Australia (PCA) Volume 3. BCA volumes 1 and 2 apply to classes of buildings.

The NCC encourages flexibility and innovation when complying with the code through a performance-based code. Another means to achieve code compliance is Deemed-to-Satisfy Provisions (ABCB 2016a).

2.5.1 Section J – BCA

The objective of Section J of the BCA is to reduce greenhouse gas emissions. The requirements of Section J are based on achieving an internal environment in which occupants find comfort sufficient and minimise the occupants' need for artificial heating, cooling or lighting. The Section's primary goal is not achieving optimal comfort (ABCB 2018). Section J contains requirements for building envelope (Parts J1, J2, J3) and for buildings services (Parts J5, J6, J7). Each part is titled as follows (ABCB 2016a):

- Part J1: Building Fabric
- Part J2: Glazing
- Part J3: Building Sealing
- Part J4: Not defined
- Part J5: Air Conditioning and Ventilation Systems
- Part J6: Artificial Lighting and Power
- Part J7: Heated Water Supply and Swimming Pool and Spa Pool Plant

2.5.1.1 Part J1: Building Fabric

The following items are requirements to achieve Section J Part 1 compliance (ABCB 2016c):

- Roof and ceiling construction require a minimum R-value. The R-value is the thermal resistance rating of a material, which is describe as the ability to resist heat transfer. This is dependent on the climate zone, roof colour and building classification.
- Both internal and external walls require insulating properties with a minimum R-value. Factors affecting this are wall colour, climate zone, building classification, wall materials and shading.

2.5.1.2 Part J2: Glazing

The intention of Part J2 is to reduce the air conditioning energy consumption as a result of glazing. The following items are requirements to achieve Section J Part 2 compliance (ABCB 2016c):

- Section J2.4 requires a calculation process which compares the U-values and solar heat gain coefficient to a worst-case glazing performance value depending on window framing type and glass description.
- The thermal performance required can be reduced by using shading. Shading devices must restrict a significant proportion of solar radiation. Shading can be provided by permanent projections such as verandas, balconies, canopies, eaves or hoods.

2.5.1.3 Part J3: Building Sealing

The intention of Part J3 is to ensure air-conditioned buildings are adequately sealed for conservation of energy. Sealing is required for roof lights, windows, doors and exhaust fans (ABCB 2016c).

2.5.1.4 Part J5: Air Conditioning and Ventilation Systems

Part J5 sets minimum energy efficiency requirements for air conditioning systems, components and ventilation systems. Compliance with Part J5 requires control of air conditioners, pumps, chillers and fans to reduce energy consumption. Control over items such as temperatures and plant operation are required. Furthermore, energy consumption is reduced by compliance with insulation for ductwork, pipework & vessels (ABCB 2016c).

2.6 AS1668.2

AS1668.2 is the Australian Standard for the use of ventilation and air in buildings. Part 2 of this standard is in reference to mechanical ventilation in buildings. The Standard details the ventilation rates required for health and ventilation amenity. The Standard eliminates the risk of causing adverse health effects to occupants by maintaining contaminants (including body odours, volatile compounds etc) below exposure levels. The Standard outlines calculation methods for ventilation rates which vary for building/room use, occupancy and contaminants (Standards Australia 2012).

2.7 Justification

The review of literature undertaken demonstrates there is a significant amount of energy recovery technology available all with varying levels of effectiveness and outlines the suitability of each type of energy recovery technique when transferring sensible and latent energy. The literature also reveals numerous cases where the effectiveness of energy recovery ventilators is highly beneficial when incorporated into air conditioning systems. The literature details cases where energy recovery ventilators have been used in different scenarios of varying geographic location, climate, building use, building occupancy and outside air rates. This literature was able to be compared to that of the Australian Standards requirement.

From research, there appears to be some gaps in literature pertaining to a number of criteria. There is no literature displaying implementation and energy savings of energy recovery ventilation in multi-purpose hall applications, where occupancies are significantly high. Also, the is a significant gap in research of the effects the North Queensland climate, particularly

Townsville, has on the energy efficiency and overall effect on mechanical services construction and operation.

The dissertation will descend upon prior literature and pre-existing technologies to tailor a solution for efficient air conditioning design for multi-purpose halls in North Queensland. The intent is to prove the performance and cost effectiveness of energy recovery ventilators in air conditioning system for multi-purpose halls in North Queensland climates.

3 Design Methodology

3.1 Design Parameters

In order to develop the design for the dissertation, several parameters were required to be established. These parameters are consistent with industry practices and are suitable design and construction methods. The parameters were derived and calculated from a number of sources including Australian Standards, the Building Code of Australia, Industry design guidelines & handbooks and equipment manufacturer's recommendations.

3.1.1 BCA Compliant Building

The design of the two types of air conditioning system are based on a reference building. The building was designed to minimum compliance under Section J - Energy Efficiency of the Building Code of Australia (BCA) in order to ensure consistency across the two systems in comparison and align with industry standard construction and design practices. The project was designed using the Deemed To Satisfy provision of the BCA 2016. For the purpose of the dissertation, the building and the mechanical services design are compliant with the following parts of the BCA Section J:

- Part 1 – Building Fabric
- Part 2 – Glazing
- Part 3 – Building Sealing

It must be noted the NCC BCA 2019 had not come into effect at the time of commencement of this project therefore the 2016 publication was referenced.

3.1.1.1 Building Classification

A building's classification is determined by its use. The BCA outlines the intent of building classification is to categorise buildings with comparable risk levels in terms of the building's use, hazards and occupancy (ABCB 2016c). There are 9 classifications of buildings with some of these having sub classifications. Commercial buildings are classed 3 – 9 and vary upon definition. The reference building is a multi-purpose hall which is a Class 9b building and will be designed to this classification according to BCA 2016 (ABCB 2016a).

3.1.1.2 Building Location

The BCA has eight climatic zones in which energy efficiency measures vary depending on zone. These zones, shown in Figure 3-1, are based upon the Bureau of Meteorology's climate map of 6 distinct climate zones.

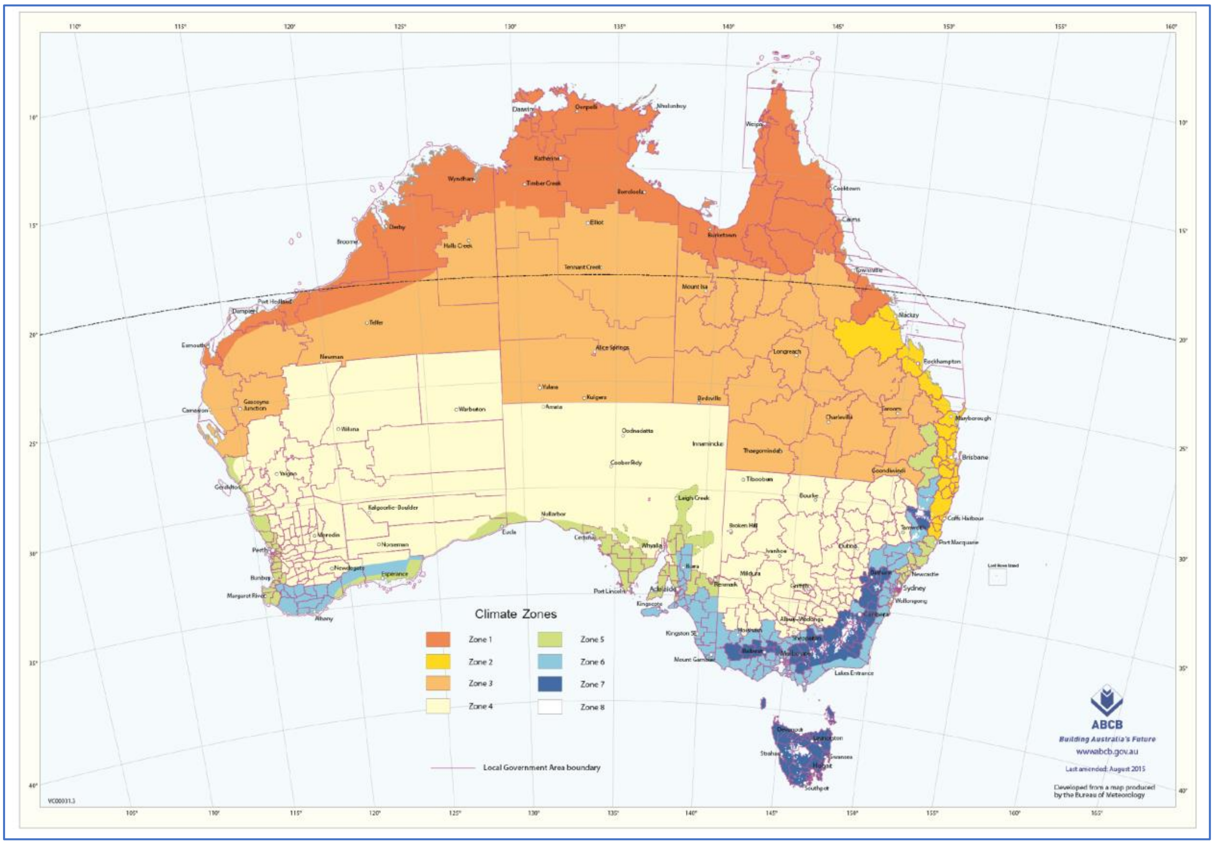


Figure 3-1: Climate Map for Thermal Design (ABCB 2016a)

The multi-purpose hall design will be based Townsville, North Queensland climatic zone. According to the BCA climate map for thermal design, Townsville lies within climate zone 1 which can be described as high humidity summer and warm winter conditions (ABCB 2016a).

3.1.1.3 Part J1 – Building Fabric

3.1.1.3.1 Solar Absorptance

The Building Code of Australia (BCA) classifies the colour of surfaces based on their solar absorptance. The solar absorptance is the inverse of solar reflectance and is expressed as a value between 0 and 1. A solar absorptance value of 1 indicates that 100% of the received solar radiation is absorbed by the surface, where a value of 0 indicates no solar radiation is absorbed by the surface. (Colorbond Steel 2013)

The BCA outlines typical absorptance values for varying colours as shown in Table 3-1.

Table 3-1: Typical Absorptance Values (ABCB 2016a)

Colour	Value
Slate (dark grey)	0.90
Red, green	0.75
Yellow, buff	0.60
Zinc aluminium – dull	0.55
Galvanised steel – dull	0.55
Light grey	0.45
Off white	0.35
Light cream	0.30

The roof structure of the multi-purpose hall is zinc aluminium type which is based on common industry construction practices and has a solar absorptance value of 0.55. The wall colour is considered a light grey and has a solar absorptance of 0.45.

3.1.1.4 Roof and Ceiling

Under BCA requirements, a roof and ceiling construction must achieve a minimum Total R-Value depending on building classification, roof surface solar absorptance and climate zone. The BCA describes the Total R-Value as the sum of the R-Values of individual components in a building structure layer including, material, insulation, airspace and related surface resistances. Cengel and Ghajar (2015) describe the R-value as the overall thermal resistance of a structure or material and the equation is as follows:

$$R = \frac{L}{k} \; (m^2 \cdot {}^\circ\mathrm{C}/W)$$

Where,

$L = thickness\ of\ material\ (m)$

$k = thermal\ conductivity\ of\ the\ material\ (W/m \cdot {}^\circ\mathrm{C})$

The overall heat transfer coefficient of a material, known as the U-factor, is the inverse of the R-value.

$$U = \frac{1}{R} \, (W/m^2 \cdot {}^\circ\mathrm{C})$$

Table 3-2 outlines the minimum requirements for the R-value of roof and ceilings for each climate zone, as provided in Section J1.3 of the BCA 2016.

Table 3-2: Roofs and Ceilings - Minimum Total R-Value for Each Climate Zone – Table J1.3a (ABCB 2016a)

Climate Zone	**1,2,3,4,5**	**6**	**7**	**8**
Direction of Heat Flow	Downwards		Upwards	
Minimum Total R-Value for a roof or ceiling with a roof upper surface solar absorptance value of not more than 0.4	3.2	3.2	3.7	4.8
Minimum Total R-Value for a roof or ceiling with a roof upper surface solar absorptance value of more than 0.4 but not more than 0.6	3.7	3.2	3.7	4.8
Minimum Total R-Value for a roof or ceiling with a roof upper surface solar absorptance value of more than 0.6	4.2	3.2	3.7	4.8

As the building is located in climate zone 1 and has a solar absorptance of 0.55, the required minimum R-value of the roof structure is 3.7.

3.1.1.5 Walls

ABCB (2016a) notes that the Deemed-to-satisfy provisions for external walls that form the envelope of a building in climate zone 1 must achieve a minimum total R-value of 3.3. The minimum R-value can be reduced by 0.5 if the solar absorptance value is less than 0.6. The minimum required R-value for the wall structure for the reference building is therefore 2.8.

3.1.1.6 Part J2 - Glazing

In order to achieve BCA compliance for the glazing requirements, the aggregate air conditioning energy value attributable to the glazing of a building must not exceed the allowance obtained by multiplying the energy index found in Table J2.4a of the BCA 2016 by the façade area exposed to air conditioned space for that orientation (ABCB 2016a). A Class 9b building in climate zone 1 has an energy index of 0.13. The aggregate air conditioning energy value is calculated by adding the air conditioning energy of each glazing element by using the following equation:

$$A_1[\, SHGC_1\, (C_A \times S_{H1} \times C_B \times S_{C1}) + C_C \times U_1] + A_2[\, SHGC_2\, (C_A \times S_{H2} \times C_B \times S_{C2}) + C_C \times U_2] + ..$$

Where;

$A_{1,2,etc} = the\ area\ of\ each\ glazing\ element$

$C_{A,B\ and\ C} = the\ energy\ constants\ A, B\ and\ C\ for\ the\ specific\ orientation$

$SHGC_{1,2,etc} = the\ Total\ System\ SHGC\ of\ each\ glazing\ element$

$S_{H1,2,etc} = the\ heating\ shading\ multiplier\ for\ each\ glazing\ element$

$S_{C1,2,etc} = the\ cooling\ shading\ multiplier\ for\ each\ glazing\ element$

$U_{1,2,etc} = the\ Total\ System\ U - Value\ of\ each\ glazing\ element$

ABCB (2016a)

The Australian Building Codes Board provides a glazing calculator which incorporates the above calculation into a spreadsheet which is used to calculate compliance for a building's glazing elements. The calculator requires inputs such as façade orientation, glazing size, window shading and glass performance characteristics. The glass performance characteristics are the U-value (mentioned in the previous section) and the Solar Heat Gain Coefficient (SHGC). Memari (2013) describes the SHGC as the fraction of solar radiation heat gained through the window. The glazing selected for the multi-purpose hall is a Viridian manufactured product with a U-value of 3.6 and a SHGC of 0.54. These values were entered into the glazing calculator as shown in Appendix D and the building's glazing elements were calculated to be compliant with NCC standards.

3.1.1.7 Building Structure

The building is single storey multi-purpose hall incorporating standard constructions methods for the North Queensland environment. The building is a portal-frame type construction with light steel roof purlins supporting the roof sheeting. The building's plant decks are located on low level roofs. The building's fabric and glazing comprise of the minimum BCA/NCC requirements mentioned in previous sections. The internals include a 1600m^2 double sports court area/performance area and connecting subsidiary areas, which have not been included in the heat load simulation of this project. Refer to Appendix B for building layout plans.

3.1.2 Building Occupancy

The multi-purpose hall is considered an assembly room type enclosure as per AS 1668.2. In Table A1 of this standard, it notes that when the number of occupants of the building is not known, the occupancy can be determined by the using a net floor area per person depending on enclosure type. The net floor area per person for a large assembly room is 1m^2 per person. Therefore, for the 1600m^2 multi-purpose hall the building occupancy is 1600 people.

3.1.3 Heat Load Simulation

The heat load simulation software used to calculate the heat load on the building is CAMEL. CAMEL is abbreviated from Carrier Air conditioning Method of Estimating Loads. CAMEL undertakes a psychrometric analysis of a building to calculate the heating and cooling load estimation. The program performs calculations for peak load only, part load is not considered. The program can model a multitude of system types with numerous variables. The calculations inherit the principles outlined in the AIRAH/RHACE Application Manual DA9 Air Conditioning Systems and in accordance with the Federal Government Construction Authority (ACADS BSG 2013).

3.1.3.1 Camel Inputs

3.1.3.1.1 Location/Ambient Design Conditions

The program has climatic data for several locations, including Townsville. The data has been extracted from weather recordings since 1990. The location of the building was selected which contains the geographical data for Townsville as shown in Table 3-3.

Table 3-3: Townsville Geographical Data

Hemisphere	South
Latitude	19.3°
Winter Design °CDB	12.9
Winter Design %RH	80
Daily Range	6.2

Comfort and critical conditions are the two sets of climatic data that can be used to calculate the heat load of the building. Comfort conditions are the 3.00pm dry-bulb and wet-bulb temperatures which are exceeded on 10 days per year. The critical conditions are the dry-bulb and wet-bulb temperatures which are exceeded 0.25% of the operating time of the system (AIRAH 1998). Comfort conditions were chosen for the heat load calculation and the design conditions for each month for 3pm are shown in Table 3-4.

Table 3-4: Townsville Design Conditions Based on Climatic Data

	Jan	Feb	Mar	Apr	May	Jun	Jun	Aug	Sep	Oct	Nov	Dec
3pm °CDB	33.4	33.4	33.4	31.8	29.7	28.1	27.5	28.8	30.7	32.1	33.4	33.4
3pm °CWB	26.8	26..8	26.8	25.8	23.8	22.2	21.7	22.0	23.7	24.9	25.8	26.8

The relationship between dry bulb temperature, wet bulb temperature and moisture content for Townsville is plotted in Figure 3-2.

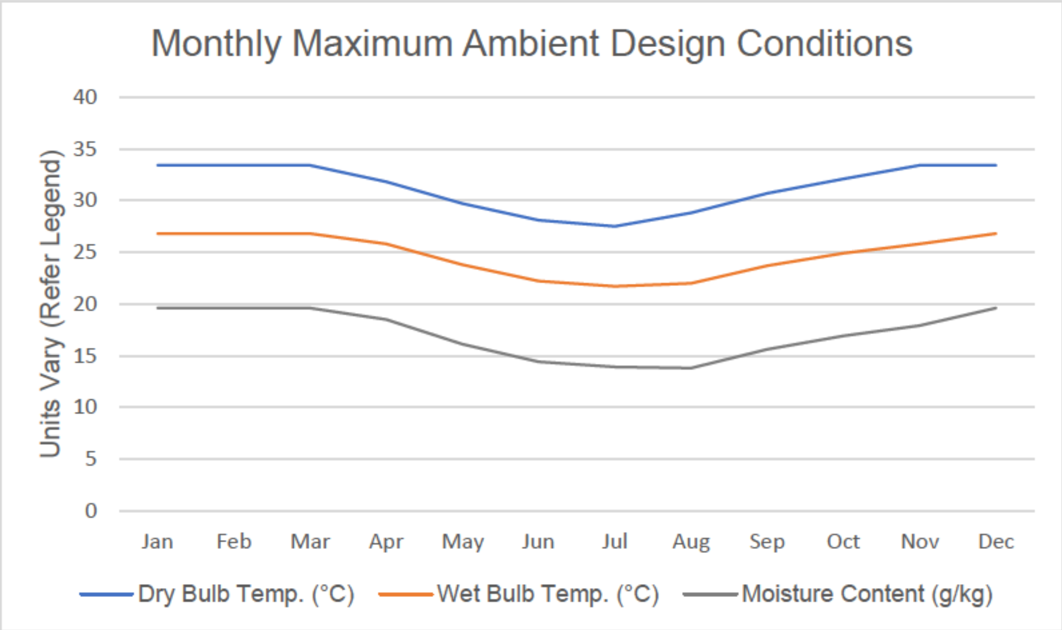


Figure 3-2: Monthly Maximum Design Conditions

3.1.3.1.2 System Type

As the system serves a single zone using a central cooling coil(s), the system type 'Single Zone Heating & Cooling' was selected in CAMEL.

3.1.3.1.3 Room Design Conditions

Optimal room comfort air conditioning parameters vary across time and people. This can be dependent on many factors including activity level, locations, adaptation, air velocity and many more. AIRAH (2007) believes the ideal design conditions are when greenhouse gas emissions are reduced, and indoor comfort is achieved. Figure 3-3 shows the historically acceptable comfort conditions.

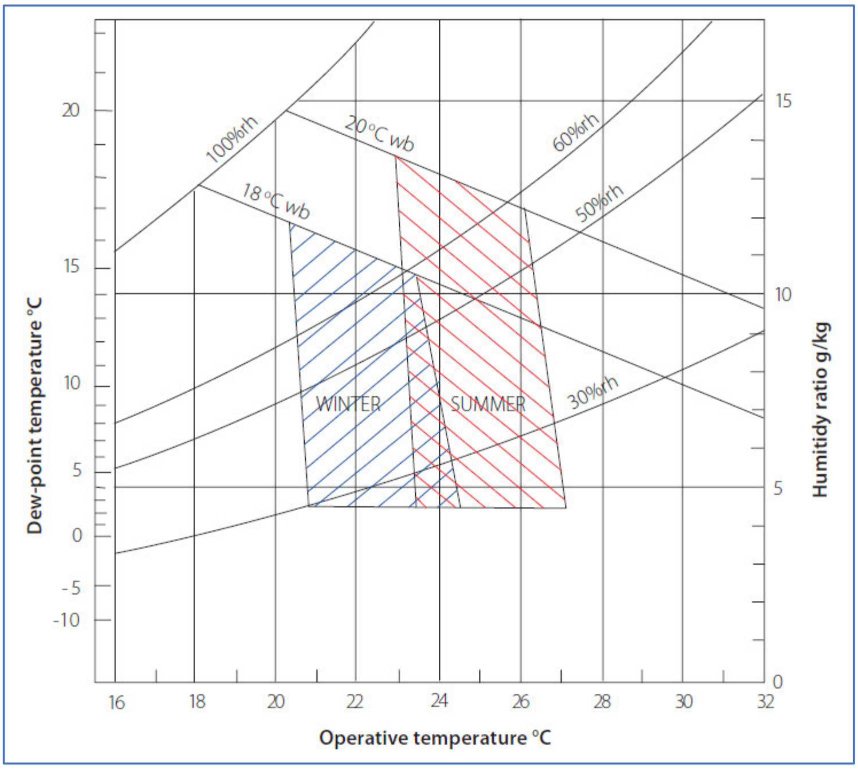


Figure 3-3: Summer & Winter Comfort Zones (AIRAH 2007)

As per the design guidelines in AIRAH (1998), the room design conditions selected are 24°C, 50% RH for summer shown in Table 3-5.

Table 3-5: Design Conditions

Condition	Summer	Winter
Outside Conditions	33.4°C DB/26.8°C WB	12.9°C
Internal Room Design Conditions	24°C DB ± 1°C 50% RH	22°± 1°C

3.1.3.1.4 Bypass Factor

AIRAH (1998) describes the bypass factor as the representation of the portion of air which passes through the air conditioning coil and its thermal properties remain un-altered. Table 3-6 outlines typical coil bypass factors for different applications.

Table 3-6: Typical Bypass Factors AIRAH (1998)

Coil Bypass Factor	Type of Application	Example
0.30 – 0.50	A small total load or a load that is somewhat larger with a low sensible heat factor (high latent load)	Residence
0.20 – 0.30	Typical comfort application with a relatively small total load or a low sensible load factor with a somewhat larger load	Residence, small retail shop, factory
0.10 – 0.20	Typical comfort application	Department store, Bank, Factory
0.05 – 0.10	Applications with high internal sensible loads or requiring a large amount of outdoor air ventilation	Office Block, Department Store, Restaurant, Factory
0 – 0.10	All outdoor air applications	Hospital, Operating Room

Due to the multi-purpose hall requiring typical comfort air conditioning and large amounts of outdoor required, the bypass factor for the design is 0.10.

AIRAH (1998) reports for heat load calculations where high latent loads are occurring, like a multi-purpose hall, the grand total heat line (GTH) ,when plotted on a psychrometric chart, does not intersect the saturation curve or yield an apparatus dew point (ADP), therefore the evaporator coil is deemed impractical and unable to achieve the desired conditions. The apparatus dew point is the effective surface temperature of the cooling coil and the temperature where complete removal of latent and sensible gains occurs (Simha 2012). In order to achieve practical coil conditions, an ADP can be fixed for the heat load calculation. The ramifications of setting a fixed ADP is the relative humidity within the room can fluctuate, however it will remain within the acceptable values of human comfort. The apparatus dew point (ADP) for the heat load calculation is 12°C.

3.1.3.1.5 Supply Fan Heat Gain

Heat is gained by the air conditioning system due to the supply air fan. The system is a draw-through fan which adds heat to the supply air path and increases room sensible heat through:

- Temperature rise due to fan inefficiencies

- Pressure/velocity rise causing energy gain in the air path
- The fan is in the airpath, which motor and drives increase hat gain in the system.

To calculate the supply fan heat gain for a packaged type air conditioning system, the difference in supply air and room air temperature is required as well as the fan total pressure.

AIRAH (1998) notes for a fan serving a system with considerable ductwork and a low velocity system, the fan pressure is approximately 0.3 to 0.5 kPa. The off-coil supply air design temperature will be 12°C and the design room temperature is 24°C, making the difference in temperature 12°C.

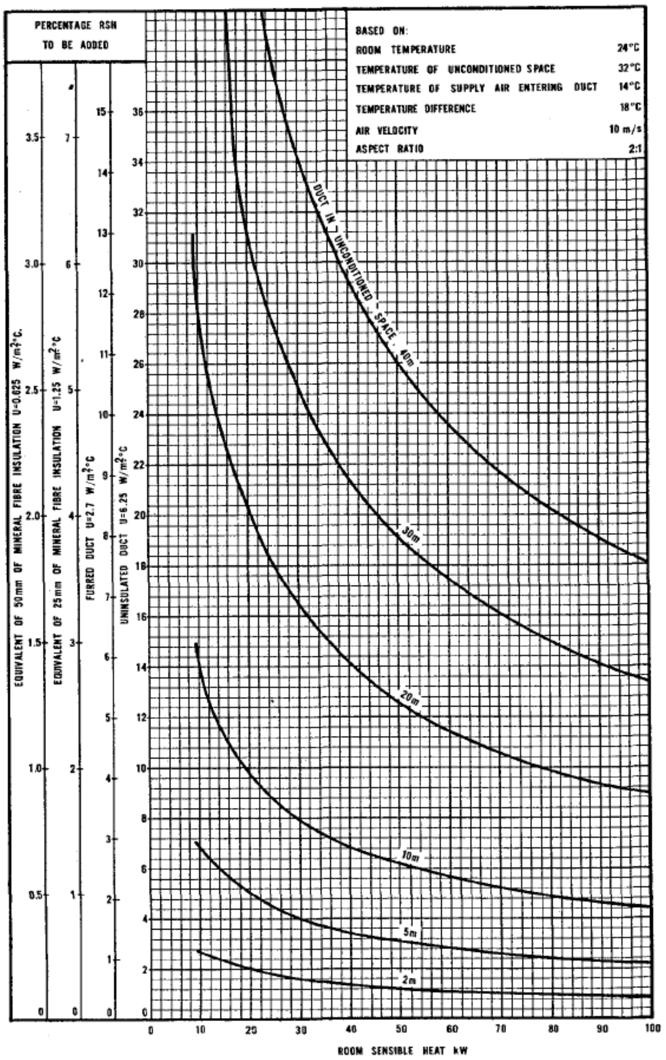
For the above parameters, Table 53 in AIRAH (1998) notes the supply fan heat gains are 5%.

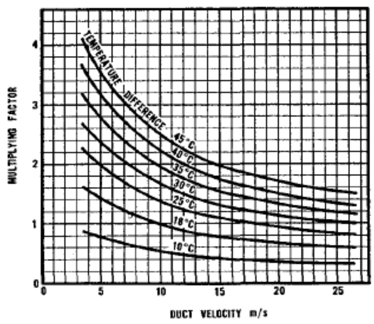
3.1.3.1.6 Duct Gains & Leakage

Return air duct heat gains result from the inward gain of hot moist air into the return air path. To calculate the return air duct gains percentage, the room sensible heat (RSH) must be estimated. An initial estimate of 30kW is used, which will be refined once final heat loads are calculated. The following are estimations of parameters in order to define a value for RSH using Figure 3-4:

- Length of insulated ductwork within un-conditioned space: 30m
- Un-conditioned space temperature: 36°C
- Return air temperature: 24°C
- Duct velocity: 5m/s

From Figure 3-4, the percentage addition to room sensible heat due to return air duct gains are 2.5%.





MULTIPLYING FACTORS FOR OTHER ROOM TEMPERATURES

Room Temperature	Multiplying Factor
24.0	1.00
24.5	0.95
25.0	0.91
25.5	0.88
26.0	0.86
26.5	0.84
27.0	0.82

Figure 3-4: Return Air Duct Heat Gain (AIRAH 1998)

Return air duct leakage for ductwork outside of a conditioned space is dependent on the length of exposed ductwork. As it is anticipated there will be limited external return air ductwork, it is estimated 2% of air leakage will occur and was added to the heat load calculation. (AIRAH 1998).

AIRAH (1998) notes supply air ductwork located in conditioned spaces will inherit no supply air duct gains or leakage.

3.1.3.1.7 Safety Factor

To allow for probable error or estimate, a safety factor of 5% was added to the building's sensible heat total (AIRAH 1998).

3.1.3.1.8 Storage Mass

The storage mass is the mass per unit area of floor (kg/m^2). It is used to determine the storage load factors of a rooms materials in order to calculate the thermal capacity of the materials enclosing the building or room (AIRAH 1998).

The storage mass is calculated by summing the total mass of the external walls, roofs, partitions, floors and ceiling. The CAMEL software automatically calculates the storage mass using building fabric inputs which was found to be 291 kg/m^2 (ACADS-BSG 2013).

3.1.3.1.9 Outside Air Rates

Under the requirements of AS1668.2 – Mechanical Ventilation in Buildings, the minimum effective outside air requirements shall be provided to an enclosure by means of mechanical ventilation. The minimum effective outdoor air rate based on building occupancy with the use of particulate filtration is calculated using Clause 2.8.4.2 as follows;

$Q_f = n \times 7.5\ L/s$ where n = the number of occupants (1600 people)

Therefore;

$Q_f = 1600 \times 7.5\ L/s$

$Q_f = 12000\ L/s$

3.1.3.1.10 Infiltration Rates

Infiltration air is the outdoor air that infiltrates a building through cracks in door and windows due to wind and pressure differences. Infiltration air causes increased sensible and latent heat gains to the building and in turn the air conditioning system (Howell 2017a).

In order to calculator the infiltration of the building the number of air changes was determined using the following equation;

$N = 3600\ {}^{q}/_{V}$ where;

$N = air\ changes\ per\ hour$

$q = outside\ air\ (m^3/s)$

$V = volume\ of\ room\ (m^3)$

$$N = 3600\ \times \frac{12}{(1600 \times 7.4)}$$

$N = 3.65 \quad Ch/h$

AIRAH (1998) reports the amount of infiltration air into a building is dependent on wind pressure and temperature differences from the internal and external of the building. These factors are considered as forces. The infiltration for the building was calculated by summing values for parameters from Table 3-7. As the outdoor air changes exceeds half an air change, the difference in these were deducted from the total calculated from Table 3-7.

Table 3-7: Infiltration Due To Wind Forces (AIRAH 1998)

Parameter	Condition	Ch/h	Condition	Ch/h
Exposure	Sheltered	0	Exposed	$+\frac{1}{2}$
Construction	Wet	0	Dry	$+\frac{1}{2}$
Location of Windows	1 wall or 2 adjacent walls	0	2 opposite walls, 3 or 4 walls	$+\frac{1}{2}$
Type of Window	Gasketed	0	Not gasketed	$+\frac{1}{2}$
Openable window area per wall area	Less 25%	0	50%	$+\frac{1}{4}$
Partitioning	Nil	0	Heavy	$-\frac{1}{2}$

The summation of the parameter values is shown below:

Exposure $= +\frac{1}{2}$

Construction $= +\frac{1}{2}$

Location of Windows $= +\frac{1}{2}$

Type of Window $= +\frac{1}{2}$

Total $= 2\ Ch/h$

Outside Air Changes $\approx 3.5\ Ch/h$

$\approx 3.5 - 0.5 = 3$

$3 - 2 = 1\ Ch/h$

Total infiltration for the room $= 1\ Ch/h$

3.1.3.1.11 External Loads

3.1.3.1.11.1 Walls

The input parameters are for the external walls to distinguish wall exposure, shading, glazing and thermal properties for inclusion in the heat load calculation. Refer Appendix C for external wall surface modelling. The typical external wall input parameters are outlined in Table 3-8.

Table 3-8: Typical Wall Parameter Inputs

Parameter	Input
Exposure	Wall orientation (Nth, Sth, etc)
Height of Wall	Dependent on Surface
Length of Wall	Dependent on Surface
Shading Scheme	Dependent on Surface
Wall U-factor	0.357 $W/m^2°C$ (Refer section 3.1.1.5)
Wall Surface Density	219 kg/m^2
Wall Absorptivity	0.45 (Refer section 3.1.1.3.1)

3.1.3.1.11.2 Roof

The typical roof input parameters are shown in Table 3-9.

Table 3-9: Typical Roof Parameter Inputs

Parameter	Input
Exposure	Sun
Area of Roof	1600m^2
Roof U-factor	0.27 $W/m^2°C$ (Refer section 3.1.1.4)
Roof Density	21 kg/m^2
Wall Absorptivity	0.55 (Refer section 3.1.1.3.1)

3.1.3.1.11.3 Shading

The shading elements were inputted for the different building facades using the parameters shown in Figure 3-5. The parameters are measurements from different datum points on the external wall surface. Refer Appendix C for Shading Schemes.

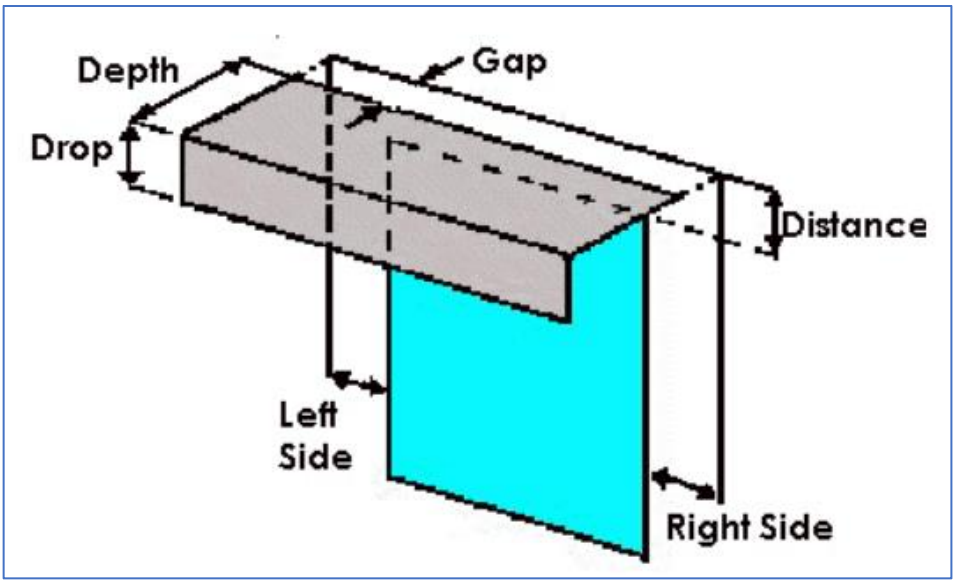


Figure 3-5: Shading Parameter Inputs

3.1.3.1.11.4 Glazing

Table 3-10 outlines the typical glazing inputs used for the heat load calculation.

Table 3-10: Typical Glazing Parameter Inputs

Parameter	Input
Window Type	Dependent on Window
Number of Windows	Dependent on Surface
Direction of Windows	Horizontal
Distance Between Window	Dependent on Surface & Window
Vertical Offset of Window	Dependent on Surface & Window
Horizontal Offset of Window	Dependent on Surface & Window
Window Height	Dependent on Window
Window Width	Dependent on Window
Glass U-Factor	3.6 $W/m^2°C$ (Refer section 3.1.1.6)
SHGC	0.54 (Refer section 3.1.1.6)
Window Frame Shade Factor Correction	1.1
Internal Shading	No

Refer Appendix C for Glazing elements.

3.1.3.1.12 Internal Building Loads

Occupants, occupant activity, lighting, appliances all produce sensible and latent heat which contribute to the total air conditioning load of a building. Humans dissipate a combination of sensible and latent heat dependent on the activity being undertaken, size of the person, the person's gender and the room temperature. Typically, humans undertaking exercise of a higher intensity will produce more latent heat. An activity of seated was selected for the full occupancy however an additional sensible load was added to allow for heat produced by appliances/equipment AIRAH (1998).

Lights produce sensible heat which is attributable to the air conditioning load of a building. The maximum illumination density for the building use was extracted Table J6.2a in ABCB (2016a) and included in the heat load calculation.

The internal building load inputs are outlined in Table 3-11.

Table 3-11: Internal Building Heat Load Input Parameters

Parameter	Input
Occupant Activity	Seated at rest
Occupancy	1600 people
Lighting Load	15 W/m^2
Light Type	Exposed Fluorescent
Additional Sensible Load	5 W/m^2

3.1.3.1.13 Pre-Conditioner

The pre-conditioner tab within the Camel program was used to apply the energy recovery ventilator to the selected system. As noted in Section 2.3.2.2, membrane plate heat energy recovery ventilators typically yield sensible and latent efficiency values of 60- 80%. The values of the energy recovery ventilator efficiency were entered and are shown in Table 3-12.

Table 3-12: ERV Efficiency Inputs

Efficiency Type	Efficiency Input
Sensible Efficiency	0.6
Latent Efficiency	0.6

3.2 Design & Documentation of Systems

Upon completion of the heat load calculation, the air distribution system and overall system layout were designed. These systems were designed using industry standards and to equipment manufacturer specifications to ensure relevance to real-world applications.

3.2.1 Heat Load Calculation Output

Table 3-13 outlines the results from the heat load calculation for systems with and without an ERV. The results are used to calculate the air distribution system, air handling unit and ERV to adequately meet the performance parameters from the heat load calculation.

Table 3-13: Heat load Calculation Results

System	S/A (L/s)	O/A		GTH (kW)	GTSH (kW)	Coil Entering Conditions		Coil Leaving Conditions	
		Quantity (L/s)	% S/A			T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)
System 1 - ERV	17487	12000	69	531	287	27.1	21.6	13.5	13.1
System 2 – No ERV	18108	12000	66	771	369	30.7	24.6	13.9	13.6

Where;
$S/A = Supply\ Air\ Quantity\ (L/s)$
$O/A = Outside\ Air\ Quantity\ (L/s)$
$GTH = Grand\ Total\ Heat\ (kW)$
$GTSH = Grand\ Total\ Sensible\ Heat\ (kW)$
$T_{DB} = Dry\ Bulb\ Temperature\ (°C)$
$T_{WB} = Wet\ Bulb\ Temperature\ (°C)$

After review of the heat load calculation results in conjunction with industry consultation, it was determined that due to the low sensible heat factor (SHF) of System 2, Air Change Australia (air handling unit manufacturer) are unable to manufacture a standard package air handling unit to meet the performance criteria in Table 3-13. The low sensible heat factor is a result of the high amounts of outside air passing through the coil without pre-conditioning. This resulted in the design conditions of the building being altered to 24°C and 70% RH by increasing the supply air quantity which reduces comfort levels within the building. This yielded a reduction in the Grand Total Heat of the system. The results of the revised heat load calculation are shown in Table 3-14, the design of system 2 (No ERV) will be based upon these results and closely reflects an industry application. An air handling unit and ERV manufactured by Air Change Australia were able to meet the performance criteria outlined in Table 3-13 and remained for the revised heat load calculation.

Table 3-14: Revised Heat Load Calculation Results

System	S/A (L/s)	O/A		GTH (kW)	GTSH (kW)	Coil Entering Conditions		Coil Leaving Conditions	
		Quantity (L/s)	% S/A			T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)
System 1 - ERV	17487	12000	69	531	287	27.1	21.6	13.5	13.1
System 2 – No ERV	32000	12000	37	723	369	27.8	22.9	18.3	17.2

Table 3-15: ERV Performance Criteria

System	S/A (L/s)	O/A		Air Entering Conditions		Air Leaving Conditions		Notes
		Quantity (L/s)	% S/A	T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)	
ERV	12000	12000	100	33.4	26.6	28.3	22.6	ERV supplies 100% of outside air to System 1

For complete heat load calculation results refer Appendix E.

3.2.1.1 Unit Selections

As previously mentioned, the air handling units were selected based on manufacturers specifications. As the required cooling capacity for both systems were significantly high, the building is served by four (4) air handling units of equal capacity in both cases. The systems comprise of two (2) air handling units located at both the Eastern and Western ends of the building, mounted upon roof top plant decks.

3.2.1.1.1 System 1 – ERV

The performance criteria for the system 1 air handling units and energy recovery ventilators are shown in Table 3-16 and Table 3-17.

Table 3-16: System 1 Air Handling Unit Schedule

Unit No.	**S/A (L/s)**	**O/A (L/s)**	**GTH (kW)**	**GTSH (kW)**	**Coil Entering Conditions**		**Coil Leaving Conditions**	
					T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)
AHU-1	4372	3000	133	72	27.1	21.6	13.5	13.1
AHU-2	4372	3000	133	72	27.1	21.6	13.5	13.1
AHU-3	4372	3000	133	72	27.1	21.6	13.5	13.1
AHU-4	4372	3000	133	72	27.1	21.6	13.5	13.1

Table 3-17: System 1 ERV Schedule

Unit No.	**S/A (L/s)**	**O/A (L/s)**	**Air Entering Conditions**		**Air Leaving Conditions**		**Notes**
			T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)	
ERV-1	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-1
ERV-2	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-2
ERV-3	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-3
ERV-4	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-4

Air Change manufacture a combined air handling unit & energy recovery ventilator system which reduces installation time and physical footprint. The selected packaged ERV dimensions for AHU/ERV 1-4 are shown in Figure 3-6.

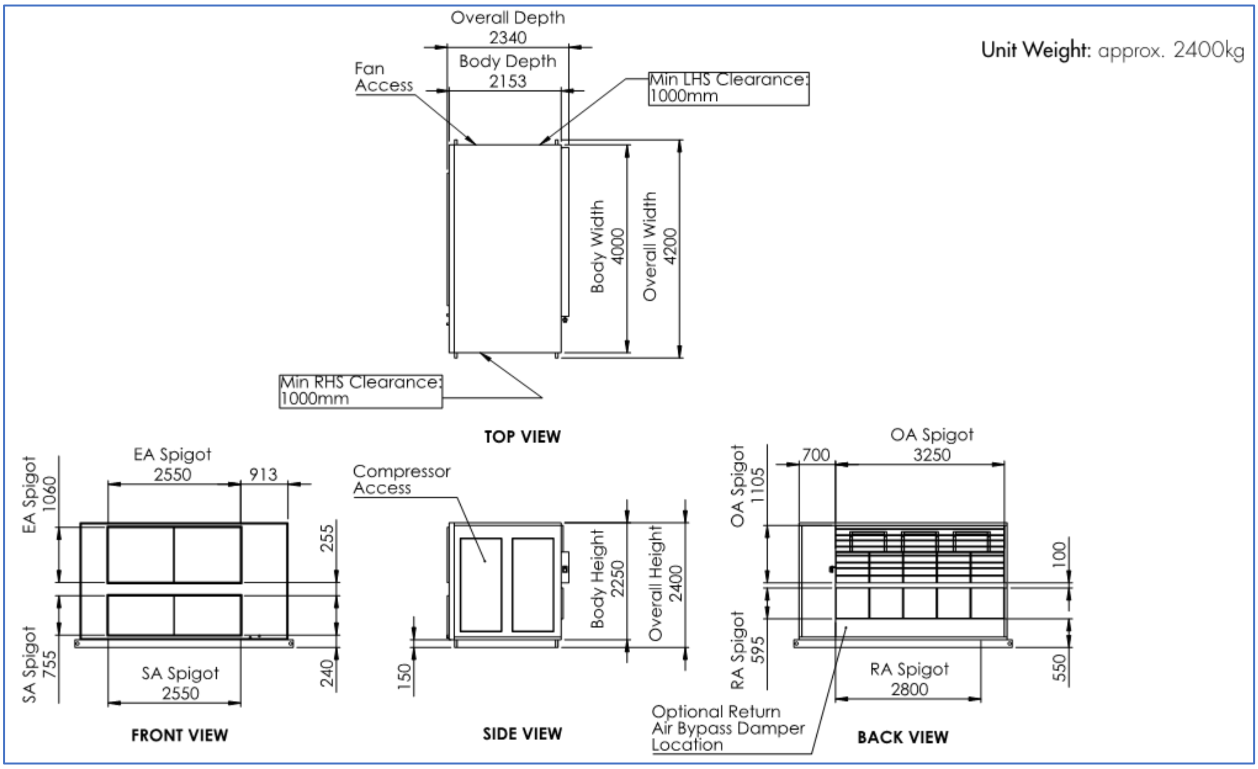


Figure 3-6: Packaged ERV AHU Dimensions (Air Change Australia 2018)

For complete equipment specifications, refer Appendix F.

3.2.1.1.2 System 2 – No ERV

The performance criteria for the system 1 air handling units are shown in Table 3-18.

Table 3-18: System 2 Air Handling Unit Schedule

Unit No.	S/A (L/s)	O/A (L/s)	GTH (kW)	GTSH (kW)	Coil Entering Conditions		Coil Leaving Conditions	
					T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)
AHU-1	8000	3000	181	92.25	27.8	22.9	18.3	17.2
AHU-2	8000	3000	181	92.25	27.8	22.9	18.3	17.2
AHU-3	8000	3000	181	92.25	27.8	22.9	18.3	17.2
AHU-4	8000	3000	181	92.25	27.8	22.9	18.3	17.2

The dimensions for the selected package air handling unit manufactured by Air Change/Dunn Air are shown in Figure 3-7.

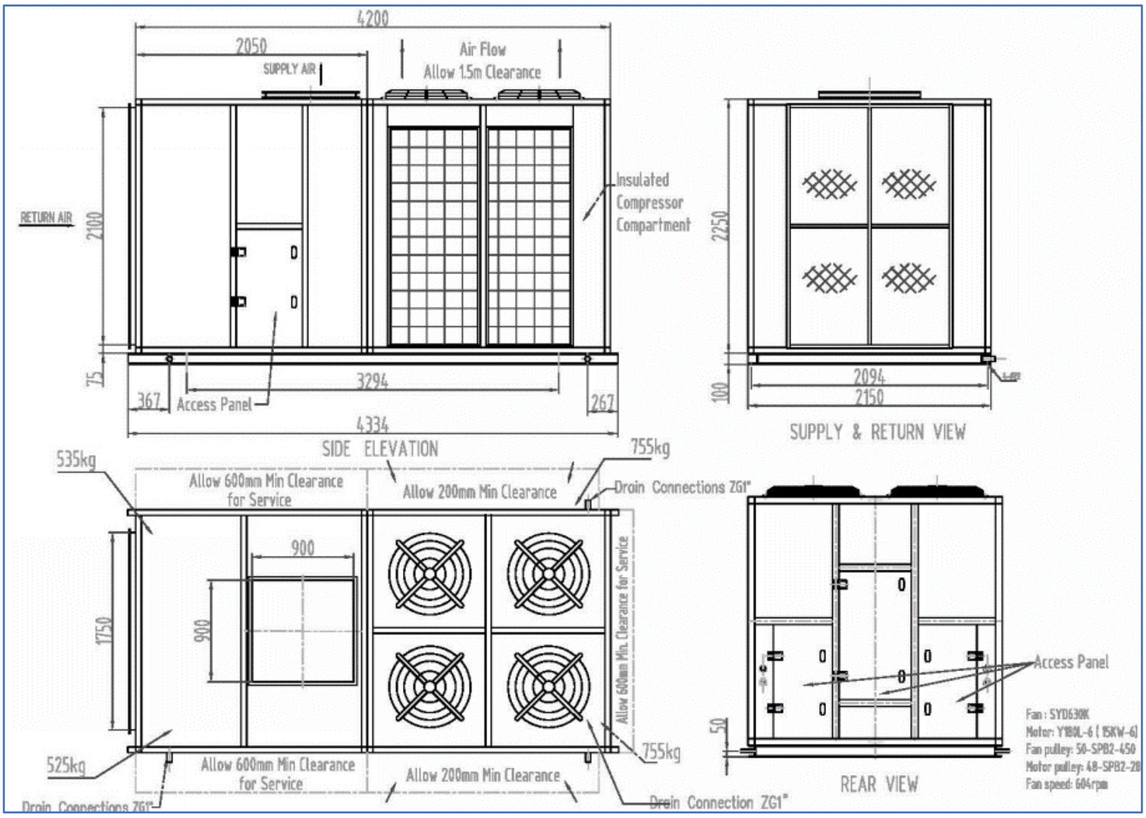


Figure 3-7: Package AHU Dimensions (Dunnair Australia 2015)

For complete equipment specifications, refer Appendix F.

3.2.2 HVAC System Design

3.2.2.1 Ductwork

The air distribution systems were designed using the Equal Friction Loss Method (EFLM). Howell (2017b) outlines the method uses a constant pressure loss per unit length to size ductwork based on airflow as well as incorporating acceptable parameters for duct velocity depending on application. The ductwork can be sized using friction charts published in numerous texts including ASHRAE (2009) and AIRAH (2007). For the project, the ductwork was sized using a dynamic duct calculator which incorporates these charts and converts to equivalent square duct sizes. AIRAH (2007) state to use a maximum pressure loss of 1 Pa/m when sizing ductwork using the Equal Friction Loss Method. Butcher (2004) notes that when noise generation is a controlling factor, the duct velocities shall be kept to a minimum depending on the building use. The ductwork was sized using the parameters in Table 3-19.

Table 3-19: Duct Sizing Parameters

Parameter	Value
Pressure Loss	1 Pa/m
Duct Air Velocity	6 m/s

In order to achieve compliance with BCA Section J – Part 5 (Air conditioning and Ventilation) ductwork insulation in an air conditioning system must have a minimum R-value of not less than the values shown in Table 3-20 for climate zone 1.

Table 3-20: Minimum Insulation R-value for Location (ABCB 2016a)

Location of Ductwork & Fittings	R-Value	Nominal Insulation Thickness[1]
Within a conditioned space	1.2	38mm
Exposed to direct sunlight	3.0	100mm
All other locations	2.0	75mm

[1] denotes the minimum insulation thickness to achieve required R-value as nominated by Insulation manufacturer Fletcher Insulation (Fletcher Insulation 2019).

It is to be noted the duct work sizes typically given on design drawings are noted as airpath size (mm), the insulation thickness and type is noted on the design drawing legend but is not included in the size noted. In fabrication or workshop drawings, the size noted on drawings is typically the 'sheet metal' size or outer dimensions which includes the airpath size and insulation thickness. The drawings presented in this dissertation are considered design drawings, therefore sizes will be noted as airpath size (mm). The duct sizes were determined through coordination with the building structure, air handling unit connections and industry practices & guides.

3.2.2.1.1 System 1 – Duct Sizing

As previously mentioned, the building is to be served by 4 air handling units for both system options. Two units each serve both the Eastern and Western ends of the building. The air distribution systems for system 1 serving the building comprise of individual supply air rectangular ductwork connecting to the supply air outlet of the air handling units, the two supply air ducts from each unit connect to a central supply air rectangular duct and rise to penetrate the external wall. The internal circular ductwork is exposed at high level within the building where supply air is distributed.

Return air ductwork is by means of a single rectangular duct serving each air handling unit which is located external to the building, this connects the return air grille to the air handling unit. System 1 (ERV) requires exhaust and outside air rectangular ductwork. The exhaust ductwork is connected to the exhaust outlet of the energy recovery ventilator and discharges the air to the atmosphere. The outside air ductwork intakes fresh air from external and supplies it to the ERV by connecting to the inlet of the unit. Duct sizing is shown in Table 3-21.

Table 3-21: System 1 - Duct Sizes

Duct System	Airflow (L/s)	Duct Velocity (m/s)	Air Path Size (mm)	R-Value	Insulation Thickness (mm)	Sheet Metal Size (mm)
Supply External (1 unit)	4372	6	1400x600	3.0	100	1600x800
Supply External (2 units combined)	8744	6	1200x1200	3.0	100	1400x1400
Supply Internal (2 units combined)	8744	6	Ø1400	1.2	50	Ø1500
Return External	4372	6	1200x650	3.0	100	1400x850

Outside Air External	3000	6	3250x1100 (to suit unit connection)	N/A	N/A	3250x1100
Exhaust Air External	3000	6	2550x1050 (to suit unit connection)	N/A	N/A	2550x1050

3.2.2.1.2 System 2 – Duct Sizing

The air distribution systems for system 2 serving the building comprise of individual supply air rectangular ductwork connecting to the supply air outlet of the air handling units, the two supply air ducts from each unit connect to a central supply air rectangular duct and rise to penetrate the external wall. The internal circular ductwork is exposed at high level within the building where supply air is distributed.

Return air ductwork is by means of a single rectangular duct serving each air handling unit which is located external to the building, this connects the return air grille to the air handling unit. System 2 requires an outside air duct intake which is connected to the return air plenum. Duct sizing for system 2 is shown in Table 3-22.

Table 3-22: System 2 - Duct Sizes

Duct System	Airflow (L/s)	Duct Velocity (m/s)	Air Path Size (mm)	R-Value	Insulation Thickness (mm)	Sheet Metal Size (mm)
Supply External (1 unit)	8000	6	1400x1000	3.0	100	1600x1200
Supply External (2 units combined)	16000	6	1650x1650	3.0	100	1850x1850
Supply Internal (2 units combined)	16000	6	Ø1800	1.2	50	Ø1900
Return External	5000	6	1400x1000	3.0	100	1600x1200
Outside Air External	3000	6	750x750	N/A	N/A	750x750

3.2.2.2 Air Grilles

The air grille types are based upon information provided in the Holyoake component manual which outlines the most suitable grille type depending on application.

3.2.2.2.1 Supply Air Grille Type

Holyoake (2011b) notes the supply air grille suitable for a duct mounted application is the DDL-20 type grille. As seen in Figure 3-8 the grille type was selected with double deflection blades which are individually adjustable for directing air in horizontal and vertical planes.

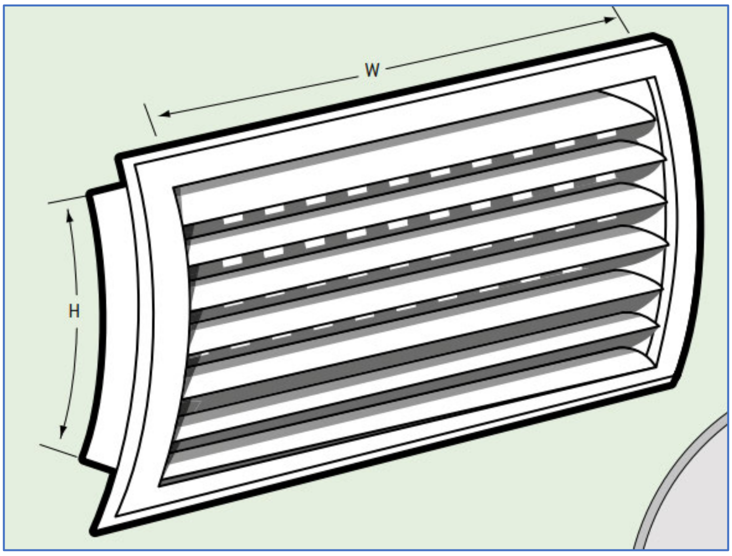


Figure 3-8: Double deflection supply air grille (Holyoake 2011b)

3.2.2.2.2 Return Air Grille Type

An eggcrate type grille was selected for the return air grille for both systems. Eggcrate grilles can be used in a wall application and provide a significant amount of free area (Holyoake 2011a).

3.2.2.3 Grille Selection Criteria

In order to correctly size the air grilles for the project, several parameters were used to select the grille size from the manufacturer's literature.

The supply air grilles were selected using the following parameters:

- Airflow per grille (L/s)
- Noise Criteria (NC)
- Required distance of throw (m)

The return air grilles were selected using the following parameters:

- Airflow per grille (L/s)
- Noise Criteria (NC)

As reported by Gorse et al. (2012) noise criteria (NC) is a single number used to represent equal hearing perception across all frequency bands at different sound levels. Noise criteria curves represent equal loudness levels heard by the human ear and are plotted on a graph of frequency against decibels. In order to achieve a noise rating, the noise must be less than the curve at every frequency. Price Industries (2011) guidelines recommend the system noise to be NC 40 – 50 for indoor stadiums and gymnasiums. To accommodate for possible direct and reverberant noise within the space, the grilles were selected at NC 20 -30.

The required throw for the supply air grilles in both systems was determined by measuring the distance from the ductwork to the outer wall on the hall which is approximately 18m.

3.2.2.3.1 Supply

The grilles were selected using the above parameters in accordance with the manufacturer's specifications shown in Appendix G. The grille sizes for each system are shown in Table 3-23.

Table 3-23: Supply Air Grille Selections

	System 1	System 2
Total Airflow (Western End)	8744	16000
Number of Grilles	8	8
Airflow per grille	1093 L/s	2000 L/s
Selected Grille Size	900x400mm	1200x500mm
Throw	19m	21m
NC	24	29

Note: Supply air grille sizes for the Eastern end are as per Table 3-23.

3.2.2.3.2 Return

The return air grilles were selected using air flow and noise criteria in accordance with manufacturers specifications shown in Appendix G.

Table 3-24: Return Air Grille Selections

	System 1	System 2
Total Airflow (AHU-1)	4372 L/s	5000 L/s
Number of Grilles	1	1
Airflow per grille	4372 L/s	5000 L/s
Selected Grille Size	2400x750mm	2600x800mm
NC	23	20

Note: Return air grille sizes for AHU 2-4 are as per Table 3-24

3.2.2.3.3 Grille Schedule

Table 3-25 outlines the grille type, sizes and number off for each system.

Table 3-25: Grille Schedule

Grille Reference	Grille Type	Size	No. Off
System 1			
S1	Duct Mounted Double Deflection Louvre	900x400	16
R1	Wall Mounted Aluminium Eggcrate Grille	2400x750	4
System 2			
S1	Duct Mounted Double Deflection Louvre	1200x500	16
R1	Wall Mounted Aluminium Eggcrate Grille	2600x800	4

3.2.2.4 Design & Documentation

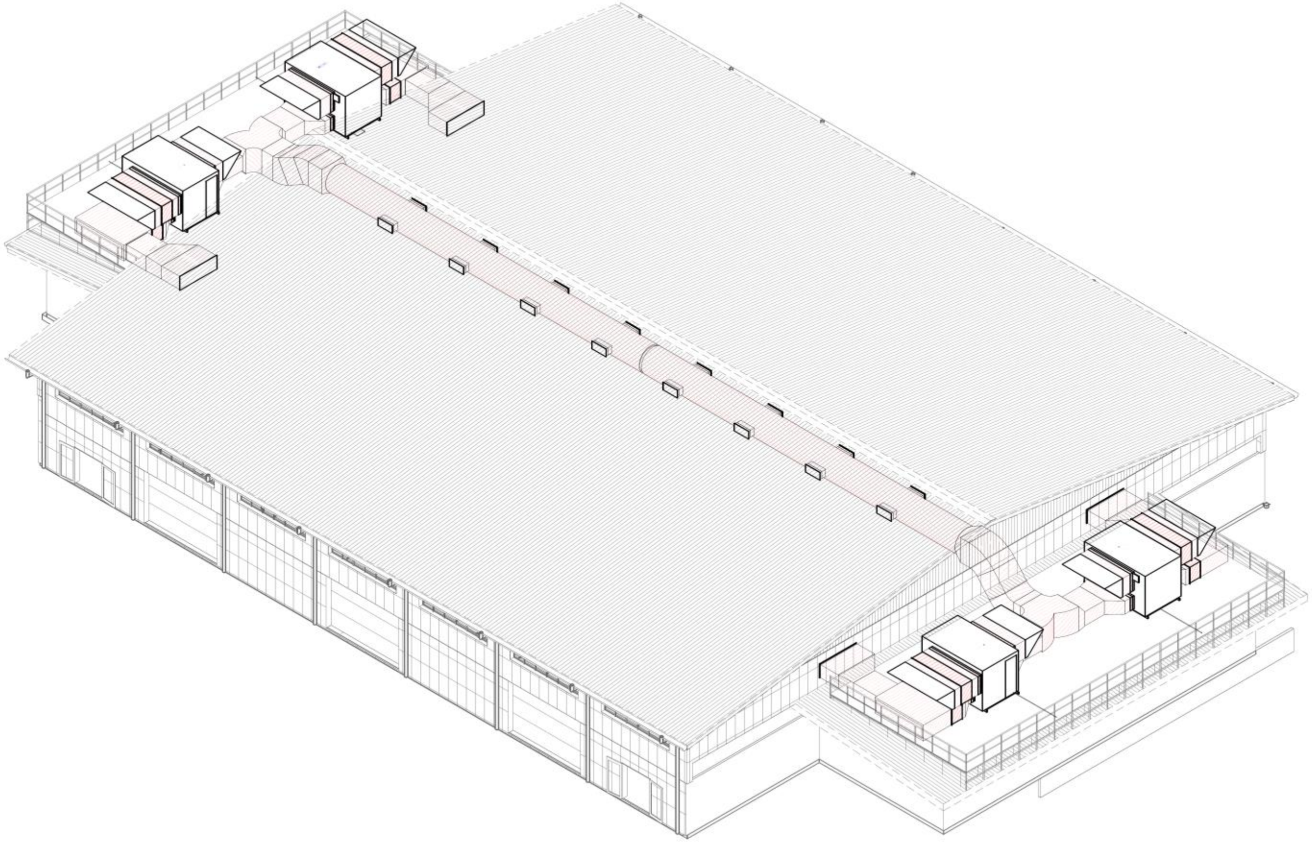
The beforementioned design parameters were used to develop mechanical services documentation for both systems using the 3-D building and services modelling software Revit.

3.2.2.4.1 System 1 – ERV Mechanical Plans

The following mechanical services plans entail the design and documentation of System 1 – ERV. The cover page, M101, illustrates the 3-D perspective of the building and system 1. M102 includes the details, legend, notes and equipment schedules. M103 shows the mechanical services floor plan which illustrates the four packaged ERV units serving the building, with two units at each end of the building located upon the mechanical services plant decks. The two systems at each end include a single supply air ductwork route in the centre of the building from each end and individual return air ductwork serving each unit. Drawings M104 and M105 include section views, elevations and 3-D perspectives of the plant area. This shows the supply, return, exhaust and intake ductwork required to serve each packaged ERV unit.

SYSTEM 1 ERV

MECHANICAL DRAWING LIST	
SHEET No.	SHEET NAME
M101	COVER PAGE
M102	LEGEND, NOTES, SCHEDULES & DETAILS
M103	MECHANICAL SERVICES FLOOR PLAN
M104	SECTIONS
M105	3D PERSPECTIVES



Rev	Description	By	Appd	Date
A	FINAL ISSUE	GM	GM	27.08.19

UNIVERSITY OF SOUTHERN QUEENSLAND
Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND
Title: COVER PAGE

Design	GM
Drawn	GM
Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	27.08.19

1:100 PLANS at A1 0 1000 2000 3000 4000 5000
1:20 DETAILS 0 200 400 600 800 1000

MECHANICAL

ENG4111/4112 - RESEARCH PROJECT

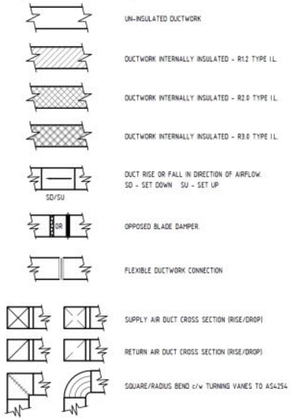
SEMESTER 2, 2019

Drawing No. M101 Revision A

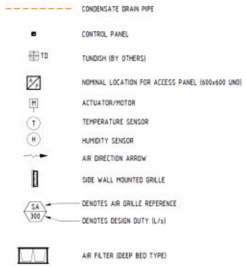
GENERAL NOTES

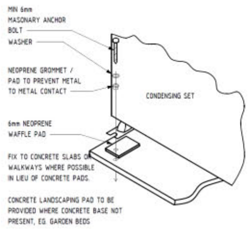
1. ALL DIMENSIONS ARE IN MILLIMETERS WITH THE SEEN DIMENSION FIRST. DUCT SIZES SHOWN ARE CLEAR AIR PATH SIZES.
2. ALL EQUIPMENT, DUCT AND FLEXIBLE DUCT SHALL BE SUPPORTED FROM THE BUILDING STRUCTURE. REFER TO STRUCTURAL DRAWINGS FOR SUPPORTS. COORDINATE WITH BUILDER FOR FINAL LOCATION OF STRUCTURAL SUPPORTS.
3. COORDINATE ACCESS PANELS, ELECTRICAL SUPPLIES AND TUNDISH LOCATIONS WITH ASSOCIATED TRADES.
4. ALL EXPOSED REFRIGERATION PIPEWORK, CONDENSATE AND ELECTRICAL WORK OUTSIDE THE BUILDING SHALL BE INSULATED WITH ARMAFLEX INSULATED TO THICKNESSES REQUIRED BY NCC AND PROTECTED WITH TOP HAT SECTION.
5. PROVIDE SEPARATE INSULATED DRAIN PIPE TO EACH FAN COIL UNIT. DRAIN INSULATION SHALL BE INSTALLED OVER THE FULL LENGTH OF THE PIPE. LABEL EACH DRAIN WITH THE FAN COIL UNIT REFERENCE AT THE ENTRY TO THE TUNDISH. PROVIDE 'S' TRAP ON EACH DRAIN AT ENTRY TO TUNDISH.
6. TAPE INSULATION JOINTS WITH PROPRIETARY PRODUCT, DUCT TAPE IS NOT ACCEPTABLE.
7. ALL RIGID DUCTWORK SHALL BE SUPPORTED FROM UNISTRUTS ON M10 THREADED ROD OR APPROVED EQUAL HUNG FROM STRUCTURAL MEMBERS.
8. ALL FLEXIBLE DUCT WORK SHALL BE SUPPLIED IN CONTINUOUS LENGTHS AND SHALL NOT BE JOINED. MAXIMUM LENGTH SHALL BE 6 METERS. SIZE IN ACCORDANCE WITH THE FLEXIBLE DUCT SCHEDULE ON THE DRAWING.
9. ALL WALL MOUNTED SENSORS AND CONTROLLERS SHALL BE HARD WIRED, MOUNTED AT 1600 AFL AND HAVE FACE PLATES OF THE TYPE THAT CANNOT BE REMOVED WITHOUT THE USE OF A TOOL.
10. LABEL ALL EQUIPMENT, SENSORS, CONTROLLERS AND CONTROL PANELS.
11. LABEL ALL INDIVIDUAL CONDENSATE DRAIN LINES AT EQUIPMENT AND TUNDISHES.
12. SCREW FIX WHITE ENGRAVED TRAFFOLYTE LABELS TO ALL AIR CONDITIONING PLANT AND ANCILLARY EQUIPMENT FOR IDENTIFICATION PURPOSES INCLUDING BUT NOT LIMITED TO AIR CONDITIONING PLANT, FANS, ASSOCIATED CONTROLS AND THE LIKE. PROVIDE LABELS FOR ISOLATING SWITCHES, CONTROL PANELS, SWITCHBOARDS AND THE LIKE AS FURTHER SPECIFIED. ALL LABELS ARE TO BE ENGRAVED WITH BLACK LETTERING A MINIMUM OF 5 MM HIGH.
13. WHERE ANY MECHANICAL EQUIPMENT IS TO BE SUPPORTED FROM STRUCTURAL MEMBERS OF THE BUILDING THEY SHALL BE SECURED TO THE WEB SECTION OF THE STRUCTURAL MEMBERS ONLY.
14. THE MECHANICAL CONTRACTOR IS TO COORDINATE THE FINAL DESIGN WITH THE TRUSS MANUFACTURER TO ENSURE SUFFICIENT SPACE FOR DUCTWORK, FAN COIL UNITS AND DUCTWORK.

DUCTWORK LEGEND

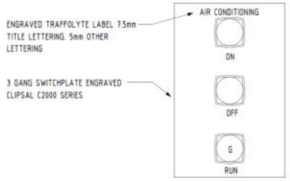


LEGEND

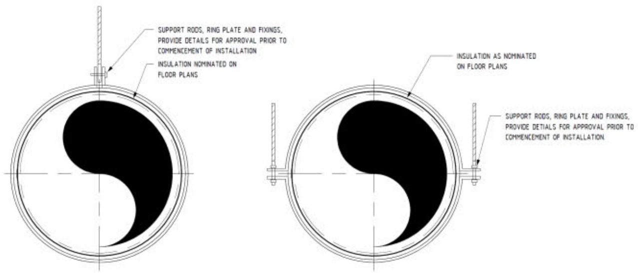




CONDENSING SET MOUNTING DETAILS



CONTROL STATION



DUCTS UP TO 900mm OVERALL DIAMETER

DUCTS OVER 900mm DIAMETER

CIRCULAR DUCT SUPPORT METHODS

PACKAGED ERV AHU SCHEDULE

Ref	Supply Air	Return Air	Exhaust Air	Outside Air	Total Cooling	Sensible Cooling	Air On DB	Air On WB	Air Off DB	Air Off WB	Serving	Type
AHU-1	4370 L/s	4370 L/s	3000 L/s	3000 L/s	133.0 kW	72.0 kW	27.1 °C	21.6 °C	13.5 °C	13.1 °C	WESTERN PLANTDECK	PACKAGED ERV AHU
AHU-2	4370 L/s	4370 L/s	3000 L/s	3000 L/s	133.0 kW	72.0 kW	27.1 °C	21.6 °C	13.5 °C	13.1 °C	WESTERN PLANTDECK	PACKAGED ERV AHU
AHU-3	4370 L/s	4370 L/s	3000 L/s	3000 L/s	133.0 kW	72.0 kW	27.1 °C	21.6 °C	13.5 °C	13.1 °C	EASTERN PLANTDECK	PACKAGED ERV AHU
AHU-4	4370 L/s	4370 L/s	3000 L/s	3000 L/s	133.0 kW	72.0 kW	27.1 °C	21.6 °C	13.5 °C	13.1 °C	EASTERN PLANTDECK	PACKAGED ERV AHU

AMBIENT CONDITIONS 33.9°C DB / 28.7°C WB. UNITS TO GIVE CAPACITIES AS NOTED ABOVE AT 38°C AIR ON CONDENSERS AND CONTINUE TO OPERATE UP TO 40°C

SUPPLY AIR GRILLE

Ref.	Face Size	Description	Comments
S1	900x400	DOUBLE DEFLECTION SIDE BLOW	OBD BEHIND, DUCT MOUNTED

RETURN AIR GRILLE

Ref.	Face Size	Description	Comments
R1	2400x750	ALUMINIUM EGG CRATE GRILLE	WALL MOUNTED C/W PLENUM BEHIND

Rev	Description	By	Appd	Date
A	FINAL ISSUE	GM	GM	27.08.19

UNIVERSITY OF SOUTHERN QUEENSLAND

Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND

Title: LEGEND, NOTES, SCHEDULES & DETAILS

Design	GM
Drawn	GM
Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	27.08.19

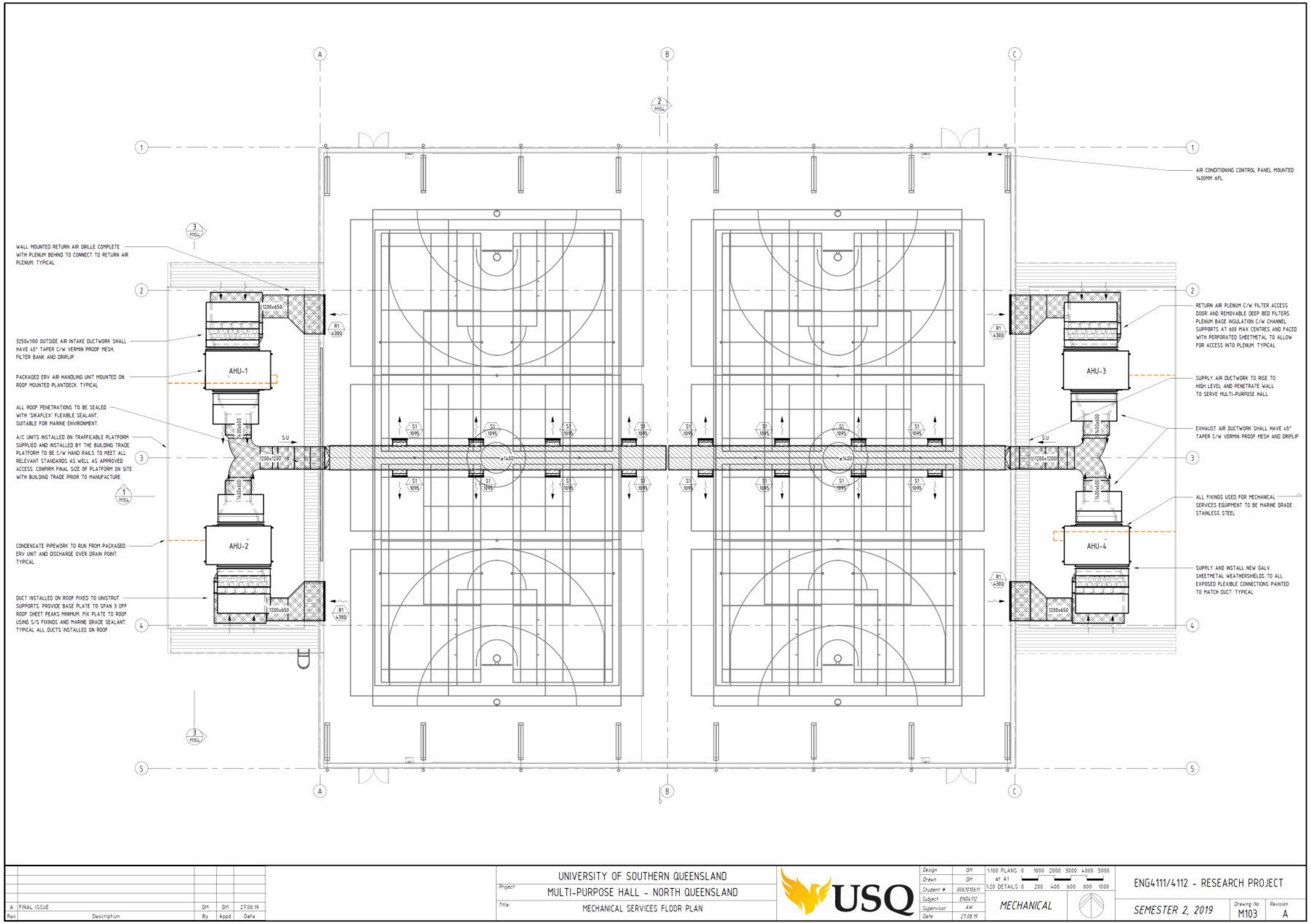
1:100 PLANS 0 1000 2000 3000 4000 5000 at A1
1:20 DETAILS 0 200 400 600 800 1000

MECHANICAL

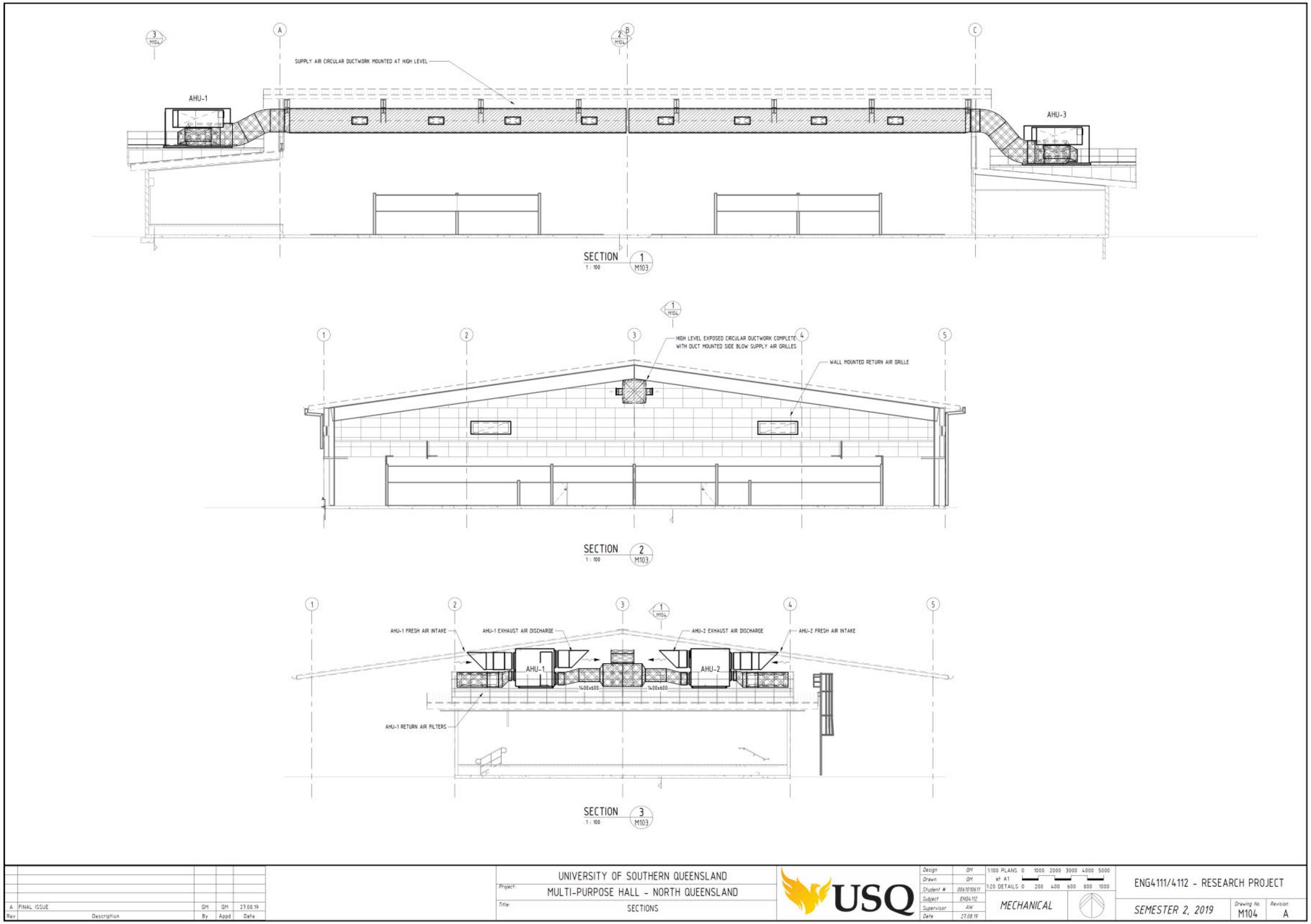
ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

Drawing No. M102 | Revision A



WALL MOUNTED RETURN AIR GRILLE COMPLETE WITH PLENUM BEHIND TO CONNECT TO RETURN AIR PLENUM. TYPICAL
3250x1100 OUTSIDE AIR INTAKE DUCTWORK SHALL HAVE 45° TAPER C/W VERMIN PROOF MESH, FILTER BANK AND DRIPLIP
PACKAGED ERV AIR HANDLING UNIT MOUNTED ON ROOF MOUNTED PLANTDECK. TYPICAL
ALL ROOF PENETRATIONS TO BE SEALED WITH 'SIKAFLEX' FLEXIBLE SEALANT, SUITABLE FOR MARINE ENVIRONMENT.
A/C UNITS INSTALLED ON TRAFFICABLE PLATFORM SUPPLIED AND INSTALLED BY THE BUILDING TRADE. PLATFORM TO BE C/W HAND RAILS TO MEET ALL RELEVANT STANDARDS AS WELL AS APPROVED ACCESS. CONFIRM FINAL SIZE OF PLATFORM ON SITE WITH BUILDING TRADE PRIOR TO MANUFACTURE.
CONDENSATE PIPEWORK TO RUN FROM PACKAGED ERV UNIT AND DISCHARGE OVER DRAIN POINT. TYPICAL
DUCT INSTALLED ON ROOF FIXED TO UNISTRUT SUPPORTS. PROVIDE BASE PLATE TO SPAN 3 OFF ROOF SHEET PEAKS MINIMUM. FIX PLATE TO ROOF USING S/S FIXINGS AND MARINE GRADE SEALANT. TYPICAL ALL DUCTS INSTALLED ON ROOF
AHU-1
AHU-2
AHU-3
AHU-4
AIR CONDITIONING CONTROL PANEL MOUNTED 1400MM AFL.
RETURN AIR PLENUM C/W FILTER ACCESS DOOR AND REMOVABLE DEEP BED FILTERS. PLENUM BASE INSULATION C/W CHANNEL SUPPORTS AT 600 MAX CENTRES AND FACED WITH PERFORATED SHEETMETAL TO ALLOW FOR ACCESS INTO PLENUM. TYPICAL
SUPPLY AIR DUCTWORK TO RISE TO HIGH LEVEL AND PENETRATE WALL TO SERVE MULTI-PURPOSE HALL
EXHAUST AIR DUCTWORK SHALL HAVE 45° TAPER C/W VERMIN PROOF MESH AND DRIPLIP
ALL FIXINGS USED FOR MECHANICAL SERVICES EQUIPMENT TO BE MARINE GRADE STAINLESS STEEL
SUPPLY AND INSTALL NEW GALV. SHEETMETAL WEATHERSHIELDS TO ALL EXPOSED FLEXIBLE CONNECTIONS PAINTED TO MATCH DUCT. TYPICAL
A FINAL ISSUE GM GM 27.08.19
Rev Description By Appd Date
UNIVERSITY OF SOUTHERN QUEENSLAND
Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND
Title: MECHANICAL SERVICES FLOOR PLAN
USQ
Design GM
Drawn GM
Student # 0061010611
Subject ENG4112
Supervisor AW
Date 27.08.19
1:100 PLANS 0 1000 2000 3000 4000 5000 at A1
1:20 DETAILS 0 200 400 600 800 1000
MECHANICAL
ENG4111/4112 - RESEARCH PROJECT
SEMESTER 2, 2019
Drawing No. M103
Revision A


SUPPLY AIR CIRCULAR DUCTWORK MOUNTED AT HIGH LEVEL
AHU-1
AHU-3
SECTION 1
1 : 100
M103
HIGH LEVEL EXPOSED CIRCULAR DUCTWORK COMPLETE WITH DUCT MOUNTED SIDE BLOW SUPPLY AIR GRILLES
WALL MOUNTED RETURN AIR GRILLE
SECTION 2
1 : 100
M103
AHU-1 FRESH AIR INTAKE
AHU-1 EXHAUST AIR DISCHARGE
AHU-2 EXHAUST AIR DISCHARGE
AHU-2 FRESH AIR INTAKE
AHU-1
AHU-2
1400x600
1400x600
AHU-1 RETURN AIR FILTERS
SECTION 3
1 : 100
M103
A FINAL ISSUE GM GM 27.08.19
Rev Description By Appd Date
Project:
Title:
UNIVERSITY OF SOUTHERN QUEENSLAND
MULTI-PURPOSE HALL - NORTH QUEENSLAND
SECTIONS
USQ
Design GM
Drawn GM
Student # 0061010611
Subject ENG4112
Supervisor AW
Date 27.08.19
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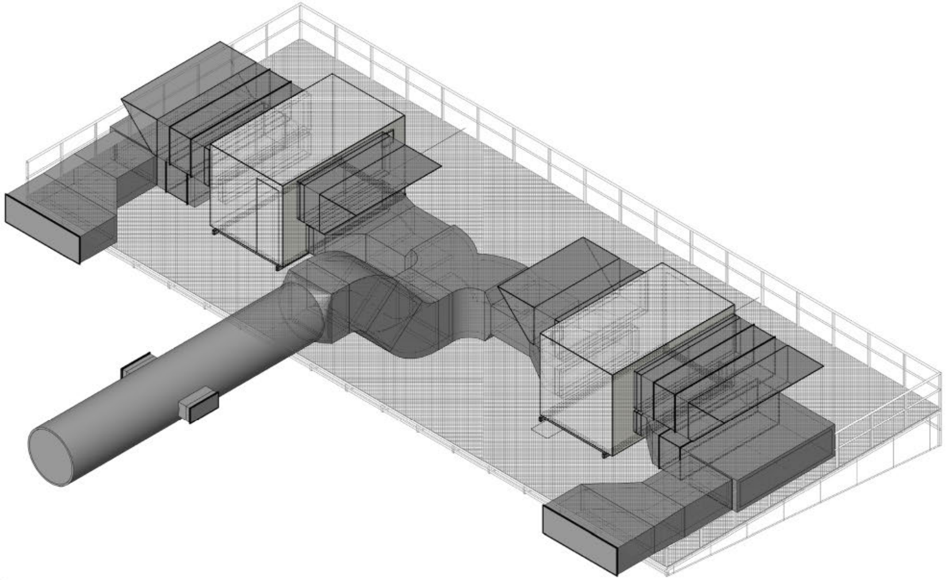
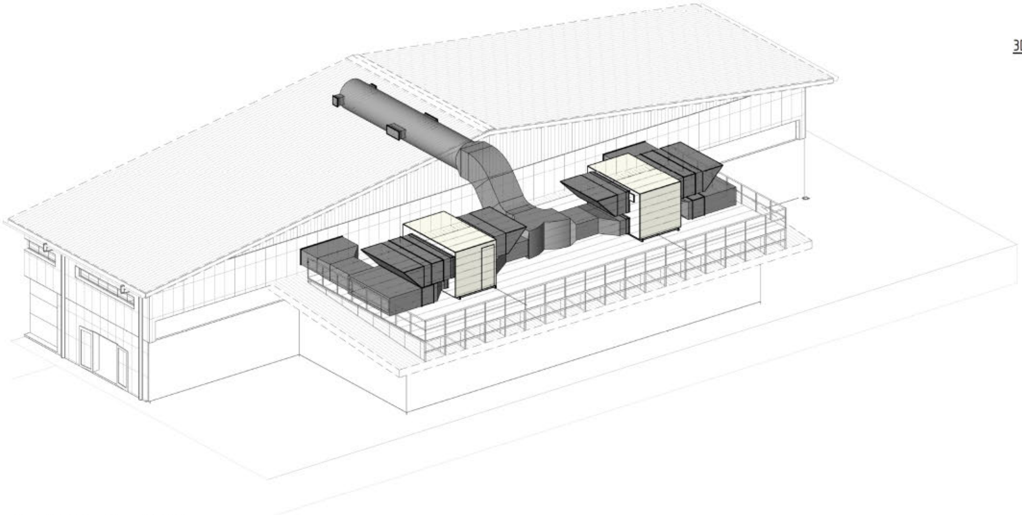
MECHANICAL
ENG4111/4112 - RESEARCH PROJECT
SEMESTER 2, 2019
Drawing No. M104
Revision A



3D PLANTROOM PERSPECTIVE



3D SOUTH-EAST PERSPECTIVE

Rev	Description	By	Appd	Date
A	FINAL ISSUE	GM	GM	27.08.19

	UNIVERSITY OF SOUTHERN QUEENSLAND
Project:	MULTI-PURPOSE HALL - NORTH QUEENSLAND
Title:	3D PERSPECTIVES

USQ

Design	GM
Drawn	GM
Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	27.08.19

1:100 PLANS at A1 0 1000 2000 3000 4000 5000
1:20 DETAILS 0 200 400 600 800 1000

MECHANICAL

ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

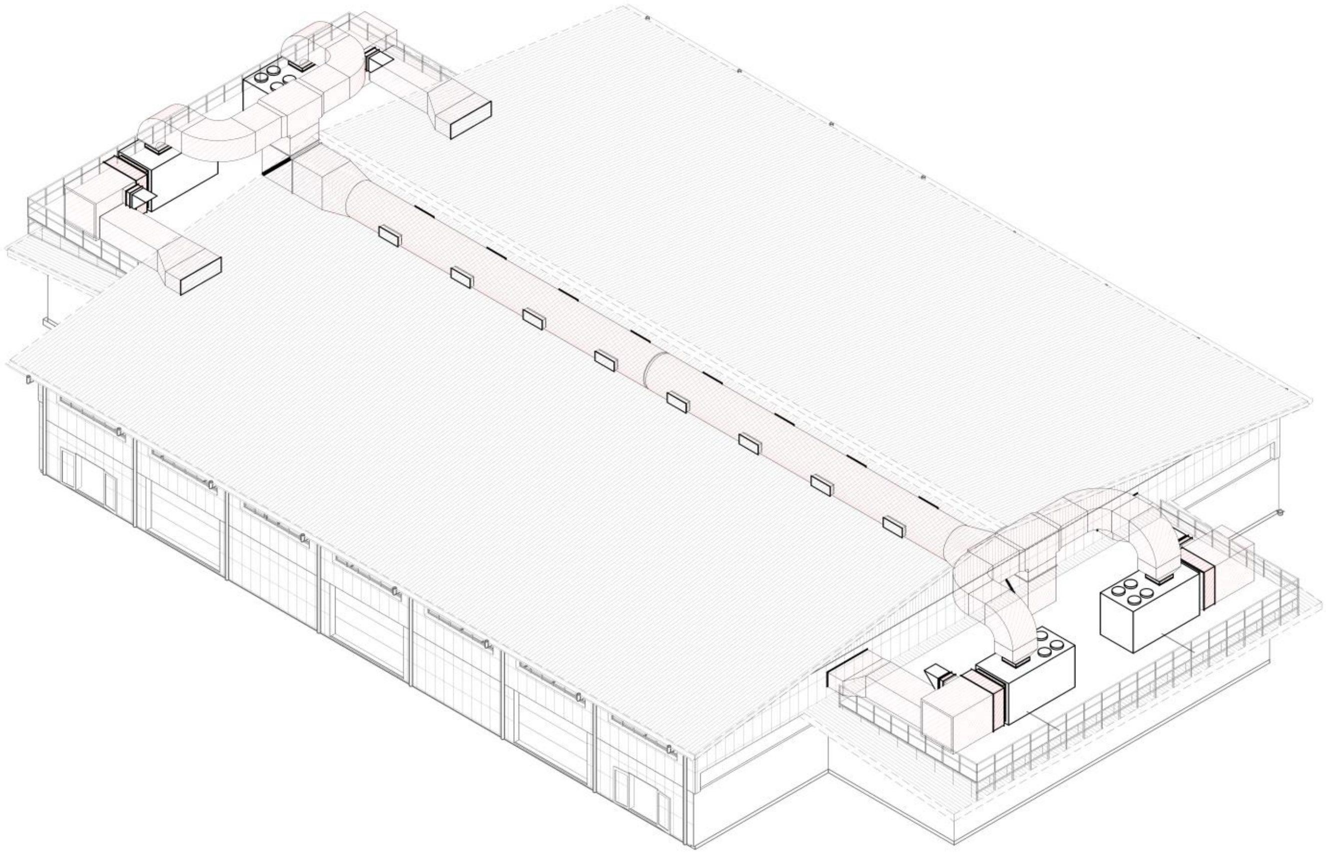
Drawing No.	Revision
M105	A

3.2.2.4.2 System 2 – No ERV Mechanical Plans

The following mechanical services plans entail the design and documentation of System 2 – No ERV. The cover page illustrates the 3-D perspective of the building and system 2. M002 includes the details, legend, notes and equipment schedules. M003 shows the mechanical services floor plan which illustrate the packaged air handling units serving the building, with two units at each end of the building located upon the mechanical services plant decks. The two systems at each end include a single supply air ductwork route running down the centre of the building from each end and individual return air ductwork serving each unit. Drawings M004 and M005 include section views, elevations and 3-D perspectives of the plant area. This shows the supply, return and outside air ductwork for the packaged air handling units and also shows the excessive duct sizes and significantly larger plant size when compared to the ERV system. This is further outlined in the floor plan shown in M003 shows the central exposed ductwork being significantly larger for the non-ERV option and supply air grilles sizes also increasing in size across the two systems this is a result of the requirement of a significantly larger airflow and required cooling capacity for the non-ERV system.

SYSTEM 2 NO ERV

MECHANICAL DRAWING LIST	
SHEET No.	SHEET NAME
M201	COVER PAGE
M202	LEGEND, NOTES, SCHEDULES & DETAILS
M203	MECHANICAL SERVICES FLOOR PLAN
M204	SECTIONS
M205	3D PERSPECTIVES



Rev	Description	By	Appd	Date
A	FINAL ISSUE	GM	GM	27.08.19

UNIVERSITY OF SOUTHERN QUEENSLAND

Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND

Title: COVER PAGE

USQ

Design	GM
Drawn	GM
Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	27.08.19

1:100 PLANS 0 1000 2000 3000 4000 5000
at A1
1:20 DETAILS 0 200 400 600 800 1000

MECHANICAL

ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

Drawing No. M201

Revision A

GENERAL NOTES

1. ALL DIMENSIONS ARE IN MILLIMETERS WITH THE SEEN DIMENSION FIRST. DUCT SIZES SHOWN ARE CLEAR AIR PATH SIZES.
2. ALL EQUIPMENT, DUCT AND FLEXIBLE DUCT SHALL BE SUPPORTED FROM THE BUILDING STRUCTURE. REFER TO STRUCTURAL DRAWINGS FOR SUPPORTS. COORDINATE WITH BUILDER FOR FINAL LOCATION OF STRUCTURAL SUPPORTS.
3. COORDINATE ACCESS PANELS, ELECTRICAL SUPPLIES AND TUNDISH LOCATIONS WITH ASSOCIATED TRADES.
4. ALL EXPOSED REFRIGERATION PIPEWORK, CONDENSATE AND ELECTRICAL WORK OUTSIDE THE BUILDING SHALL BE INSULATED WITH ARMAFLEX INSULATED TO THICKNESSES REQUIRED BY NCC AND PROTECTED WITH TOP HAT SECTION.
5. PROVIDE SEPARATE INSULATED DRAIN PIPE TO EACH FAN COIL UNIT. DRAIN INSULATION SHALL BE INSTALLED OVER THE FULL LENGTH OF THE PIPE. LABEL EACH DRAIN WITH THE FAN COIL UNIT REFERENCE AT THE ENTRY TO THE TUNDISH. PROVIDE 'S' TRAP ON EACH DRAIN AT ENTRY TO TUNDISH.
6. TAPE INSULATION JOINTS WITH PROPRIETARY PRODUCT, DUCT TAPE IS NOT ACCEPTABLE.
7. ALL RIGID DUCTWORK SHALL BE SUPPORTED FROM UNISTRUTS ON M10 THREADED ROD OR APPROVED EQUAL HUNG FROM STRUCTURAL MEMBERS.
8. ALL FLEXIBLE DUCT WORK SHALL BE SUPPLIED IN CONTINUOUS LENGTHS AND SHALL NOT BE JOINED. MAXIMUM LENGTH SHALL BE 6 METERS. SIZE IN ACCORDANCE WITH THE FLEXIBLE DUCT SCHEDULE ON THE DRAWING.
9. ALL WALL MOUNTED SENSORS AND CONTROLLERS SHALL BE HARD WIRED, MOUNTED AT 1600 AFL AND HAVE FACE PLATES OF THE TYPE THAT CANNOT BE REMOVED WITHOUT THE USE OF A TOOL.
10. LABEL ALL EQUIPMENT, SENSORS, CONTROLLERS AND CONTROL PANELS.
11. LABEL ALL INDIVIDUAL CONDENSATE DRAIN LINES AT EQUIPMENT AND TUNDISHES.
12. SCREW FIX WHITE ENGRAVED TRAFFOLYTE LABELS TO ALL AIR CONDITIONING PLANT AND ANCILLARY EQUIPMENT FOR IDENTIFICATION PURPOSES INCLUDING BUT NOT LIMITED TO AIR CONDITIONING PLANT, FANS, ASSOCIATED CONTROLS AND THE LIKE. PROVIDE LABELS FOR ISOLATING SWITCHES, CONTROL PANELS, SWITCHBOARDS AND THE LIKE AS FURTHER SPECIFIED. ALL LABELS ARE TO BE ENGRAVED WITH BLACK LETTERING A MINIMUM OF 5 MM HIGH.
13. WHERE ANY MECHANICAL EQUIPMENT IS TO BE SUPPORTED FROM STRUCTURAL MEMBERS OF THE BUILDING THEY SHALL BE SECURED TO THE WEB SECTION OF THE STRUCTURAL MEMBERS ONLY.
14. THE MECHANICAL CONTRACTOR IS TO COORDINATE THE FINAL DESIGN WITH THE TRUSS MANUFACTURER TO ENSURE SUFFICIENT SPACE FOR DUCTWORK, FAN COIL UNITS AND DUCTWORK.

DUCTWORK LEGEND

UN-INSULATED DUCTWORK

DUCTWORK INTERNALLY INSULATED - R1.2 TYPE I.L.

DUCTWORK INTERNALLY INSULATED - R2.0 TYPE I.L.

DUCTWORK INTERNALLY INSULATED - R3.0 TYPE I.L.

SD/SU — DUCT RISE OR FALL IN DIRECTION OF AIRFLOW. SD - SET DOWN SU - SET UP

OPPOSED BLADE DAMPER.

FLEXIBLE DUCTWORK CONNECTION

SUPPLY AIR DUCT CROSS SECTION (RISE/DROP)

RETURN AIR DUCT CROSS SECTION (RISE/DROP)

SQUARE/RADIUS BEND c/w TURNING VANES TO AS4254

LEGEND

CONDENSATE DRAIN PIPE

CONTROL PANEL

TD — TUNDISH (BY OTHERS)

NOMINAL LOCATION FOR ACCESS PANEL (600x600 UNO)

ACTUATOR/MOTOR

T — TEMPERATURE SENSOR

H — HUMIDITY SENSOR

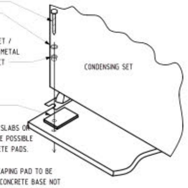
AIR DIRECTION ARROW

SIDE WALL MOUNTED GRILLE

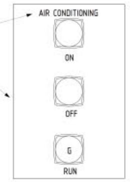
SA — DENOTES AIR GRILLE REFERENCE

300 — DENOTES DESIGN DUTY (L/s)

AIR FILTER (DEEP BED TYPE)



CONDENSING SET MOUNTING DETAILS



CONTROL STATION

AHU SCHEDULE

Ref	Supply Air	Return Air	Outside Air	Total Cooling	Sensible Cooling	Air On DB	Air On WB	Air Off DB	Air Off WB	Serving	Type
AHU-1	8000 L/s	5000 L/s	3000 L/s	181.0 kW	92.3 kW	27.8 °C	22.9 °C	18.3 °C	17.2 °C	WESTERN PLANTDECK	PACKAGED AHU
AHU-2	8000 L/s	5000 L/s	3000 L/s	181.0 kW	92.3 kW	27.8 °C	22.9 °C	18.3 °C	17.2 °C	WESTERN PLANTDECK	PACKAGED AHU
AHU-3	8000 L/s	5000 L/s	3000 L/s	181.0 kW	92.3 kW	27.8 °C	22.9 °C	18.3 °C	17.2 °C	EASTERN PLANTDECK	PACKAGED AHU
AHU-4	8000 L/s	5000 L/s	3000 L/s	181.0 kW	92.3 kW	27.8 °C	22.9 °C	18.3 °C	17.2 °C	EASTERN PLANTDECK	PACKAGED AHU

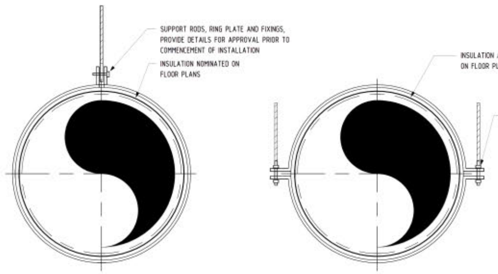
AMBIENT CONDITIONS 33.9°C DB / 28.7°C WB. UNITS TO GIVE CAPACITIES AS NOTED ABOVE AT 38°C AIR ON CONDENSERS AND CONTINUE TO OPERATE UP TO 40°C

SUPPLY AIR GRILLE

Ref.	Face Size	Description	Comments
S1	1200x500	DOUBLE DEFLECTION SIDE BLOW	OBD BEHIND, DUCT MOUNTED

RETURN AIR GRILLE

Ref.	Face Size	Description	Comments
R1	2600x800	ALUMINIUM MESH GRILLE	WALL MOUNTED C/W PLENUM BEHIND



DUCTS UP TO 900mm OVERALL DIAMETER

DUCTS OVER 900mm DIAMETER

CIRCULAR DUCT SUPPORT METHODS

Rev	Description	By	Appd	Date
A	FINAL ISSUE	GM	GM	27.08.19

UNIVERSITY OF SOUTHERN QUEENSLAND

Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND

Title: LEGEND, NOTES, SCHEDULES & DETAILS

USQ

Design	GM
Drawn	GM
Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	27.08.19

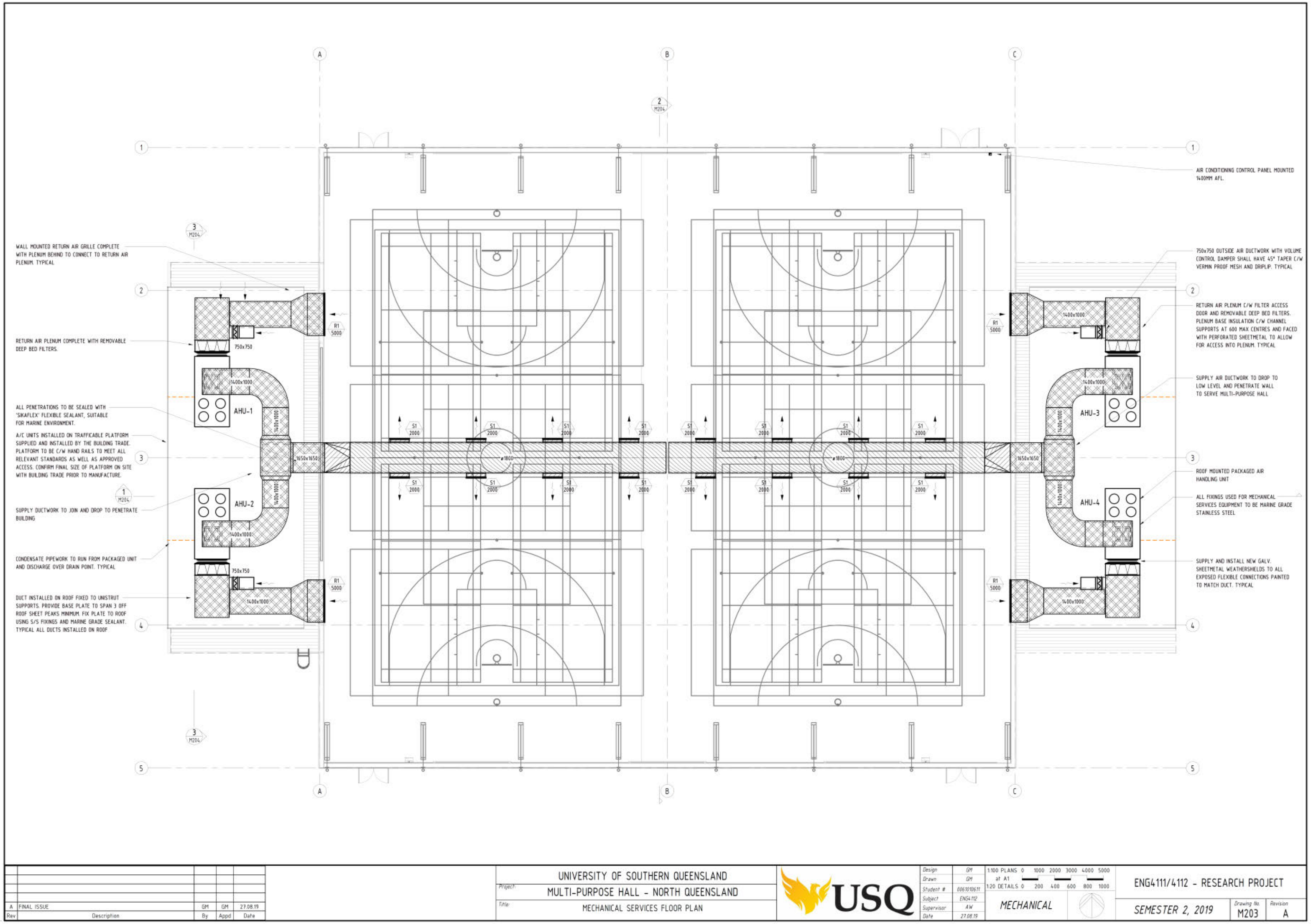
1:100 PLANS 0 1000 2000 3000 4000 5000 at A1
1:20 DETAILS 0 200 400 600 800 1000

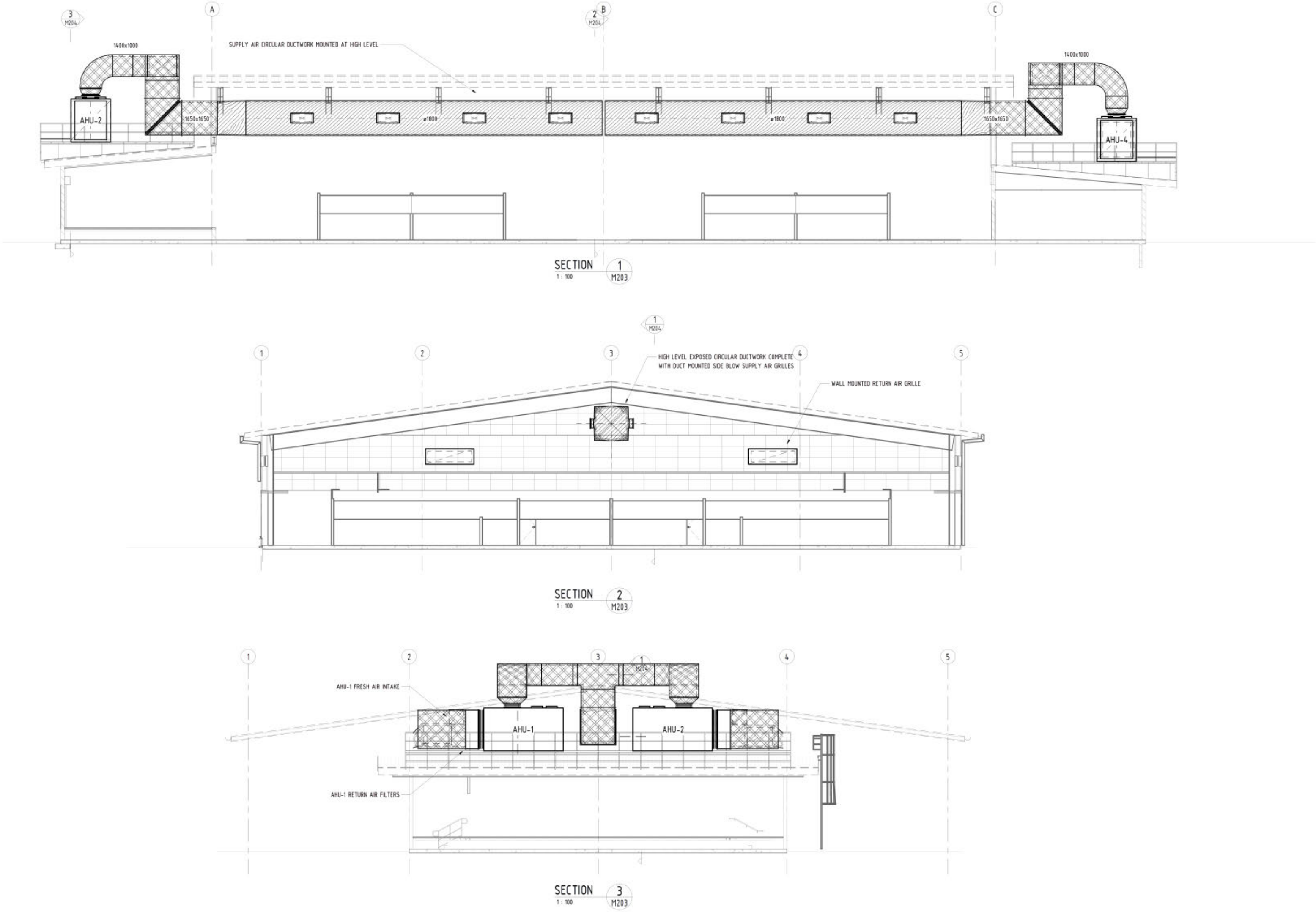
MECHANICAL

ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

Drawing No. M202 Revision A


WALL MOUNTED RETURN AIR GRILLE COMPLETE WITH PLENUM BEHIND TO CONNECT TO RETURN AIR PLENUM. TYPICAL
RETURN AIR PLENUM COMPLETE WITH REMOVABLE DEEP BED FILTERS.
ALL PENETRATIONS TO BE SEALED WITH 'SIKAFLEX' FLEXIBLE SEALANT, SUITABLE FOR MARINE ENVIRONMENT.
A/C UNITS INSTALLED ON TRAFFICABLE PLATFORM SUPPLIED AND INSTALLED BY THE BUILDING TRADE. PLATFORM TO BE C/W HAND RAILS TO MEET ALL RELEVANT STANDARDS AS WELL AS APPROVED ACCESS. CONFIRM FINAL SIZE OF PLATFORM ON SITE WITH BUILDING TRADE PRIOR TO MANUFACTURE.
SUPPLY DUCTWORK TO JOIN AND DROP TO PENETRATE BUILDING
CONDENSATE PIPEWORK TO RUN FROM PACKAGED UNIT AND DISCHARGE OVER DRAIN POINT. TYPICAL
DUCT INSTALLED ON ROOF FIXED TO UNISTRUT SUPPORTS. PROVIDE BASE PLATE TO SPAN 3 OFF ROOF SHEET PEAKS MINIMUM. FIX PLATE TO ROOF USING S/S FIXINGS AND MARINE GRADE SEALANT. TYPICAL ALL DUCTS INSTALLED ON ROOF
AIR CONDITIONING CONTROL PANEL MOUNTED 1400MM AFL.
750x750 OUTSIDE AIR DUCTWORK WITH VOLUME CONTROL DAMPER SHALL HAVE 45° TAPER C/W VERMIN PROOF MESH AND DRIPLIP. TYPICAL
RETURN AIR PLENUM C/W FILTER ACCESS DOOR AND REMOVABLE DEEP BED FILTERS. PLENUM BASE INSULATION C/W CHANNEL SUPPORTS AT 600 MAX CENTRES AND FACED WITH PERFORATED SHEETMETAL TO ALLOW FOR ACCESS INTO PLENUM. TYPICAL
SUPPLY AIR DUCTWORK TO DROP TO LOW LEVEL AND PENETRATE WALL TO SERVE MULTI-PURPOSE HALL
ROOF MOUNTED PACKAGED AIR HANDLING UNIT
ALL FIXINGS USED FOR MECHANICAL SERVICES EQUIPMENT TO BE MARINE GRADE STAINLESS STEEL
SUPPLY AND INSTALL NEW GALV. SHEETMETAL WEATHERSHIELDS TO ALL EXPOSED FLEXIBLE CONNECTIONS PAINTED TO MATCH DUCT. TYPICAL
AHU-1
AHU-2
AHU-3
AHU-4
R1 5000
S1 2000
1400x1000
750x750
1650x1650
A FINAL ISSUE GM GM 27.08.19
Rev Description By Appd Date
UNIVERSITY OF SOUTHERN QUEENSLAND
Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND
Title: MECHANICAL SERVICES FLOOR PLAN
Design GM
Drawn GM
Student # 0061010611
Subject ENG4112
Supervisor AW
Date 27.08.19
1:100 PLANS 0 1000 2000 3000 4000 5000
at A1
1:20 DETAILS 0 200 400 600 800 1000
MECHANICAL
ENG4111/4112 - RESEARCH PROJECT
SEMESTER 2, 2019
Drawing No. M203
Revision A



Rev	Description	By	Appd	Date
A	FINAL ISSUE	GM	GM	27.08.19

UNIVERSITY OF SOUTHERN QUEENSLAND

Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND

Title: SECTIONS

USQ

Design	GM
Drawn	GM
Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	27.08.19

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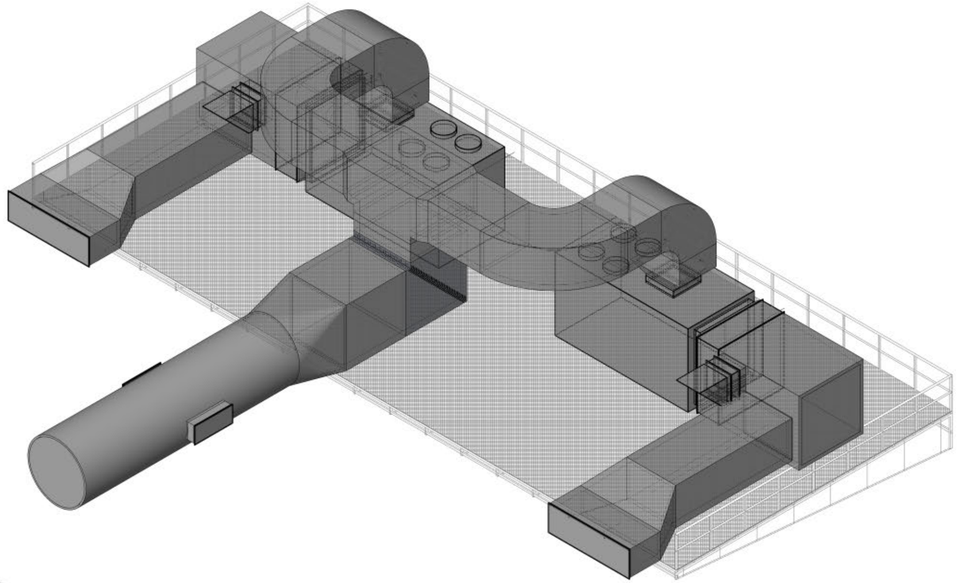
MECHANICAL

ENG4111/4112 - RESEARCH PROJECT

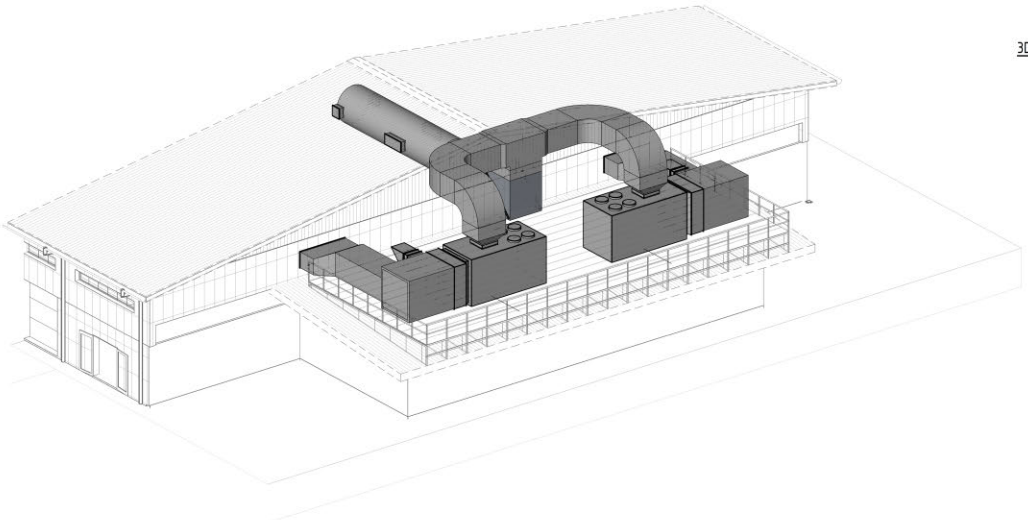
SEMESTER 2, 2019

Drawing No: M204

Revision: A



3D PLANTROOM PERSPECTIVE



3D SOUTH-EAST PERSPECTIVE

Rev	Description	By	Appd	Date
A	FINAL ISSUE	GM	GM	27.08.19

Project: UNIVERSITY OF SOUTHERN QUEENSLAND
MULTI-PURPOSE HALL - NORTH QUEENSLAND

Title: 3D PERSPECTIVES

USQ

Design	GM
Drawn	GM
Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	27.08.19

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at A1
1:20 DETAILS 0 200 400 600 800 1000

MECHANICAL

ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

Drawing No. M205

Revision A

3.3 Energy Analysis

The Beaver software incorporates a building's geographical location, services and structure to estimate the energy consumption of the building. The program also estimates temperature profiling throughout the building, energy consumption and peak demand for varying fuel types (ACADS BSG 2016).

3.3.1 Beaver Inputs

Beaver utilises all system parameters entered from the heat load simulation in CAMEL. The program allows for direct input of values outlined in Section 3.1.3. Further input parameters were required to complete the building energy analysis.

3.3.1.1 Plant Operating Schedule

Specification JV of the BCA 2014 states that the annual energy consumption of an air conditioning system is to be calculated using the following:

- Daily occupancy and operation profiles shown in Table 3-26
- Internal heat gains from appliances of 5 W/m^2 for a Class 9B building (ABCB 2016b)
- Internal heat gains from artificial lighting shown in Table 3-26

Table 3-26: Occupancy & Operation Profiles of a Class 9b School Table 2g (ABCB 2016b)

Time Period (Local Standard Time)	Occupancy (Monday to Friday)	Artificial Lighting (Monday to Friday)	Appliances & Equipment (Monday to Friday)	Air Conditioning (Monday to Friday)
12:00am to 1:00am	0%	5%	5%	Off
1:00am to 2:00am	0%	5%	5%	Off
2:00am to 3:00am	0%	5%	5%	Off
3:00am to 4:00am	0%	5%	5%	Off
4:00am to 5:00am	0%	5%	5%	Off
5:00am to 6:00am	0%	5%	5%	Off
6:00am to 7:00am	0%	5%	5%	Off
7:00am to 8:00am	5%	30%	30%	On
8:00am to 9:00am	75%	85%	85%	On
9:00am to 10:00am	90%	95%	95%	On
10:00am to 11:00am	90%	95%	95%	On
11:00am to 12:00pm	90%	95%	95%	On
12:00pm to 1:00pm	50%	80%	70%	On

1:00pm to 2:00pm	50%	80%	70%	On
2:00pm to 3:00pm	90%	95%	95%	On
3:00pm to 4:00pm	70%	90%	80%	On
4:00pm to 5:00pm	50%	70%	60%	On
5:00pm to 6:00pm	20%	20%	20%	Off
6:00pm to 7:00pm	20%	20%	20%	Off
7:00pm to 8:00pm	20%	20%	20%	Off
8:00pm to 9:00pm	10%	10%	10%	Off
9:00pm to 10:00pm	5%	5%	5%	Off
10:00pm to 11:00pm	5%	5%	5%	Off
11:00pm to 12:00am	5%	5%	5%	Off

Notes:

1. The occupancy profile is expressed as a percentage of the maximum number of people that can be accommodated in the building. The artificial lighting profile is expressed as a percentage of the maximum illumination power density permitted under Part J6. The appliances and equipment profile are expressed as a percentage of the maximum internal heat gain. The air conditioning profile is expressed as the plant status.
2. Saturday and Sunday profiles are 5% continuous artificial lighting and 5% continuous appliances and equipment. There is no occupancy and the air conditioning is "off".

Beaver has in-built occupancy and operational profiling which are in accordance with BCA guidelines. A Class 9b profiling schedule was selected in Beaver. The BCA profiling schedules include the following parameters for the energy analysis:

- Monday to Friday
- 7:00am – 5:00pm (10 Hours)
- Analysis period 1st January – 31st December
- 2600 hours per year of operation.

3.3.1.2 Air Handling Unit Fans

The supply air input power was automatically calculated by Beaver and used in the energy analysis. An energy recovery ventilator system includes an exhaust fan for extraction of exhaust air within the building as previously mentioned. The exhaust fans require power input and operates in conjunction with supply air fan of the air handling unit. The power input for the exhaust was given in the manufacturers technical data as 3 fans at 3.4kW power input each. The total power input for the exhaust fan is 12.2kW for system 1.

System 2 only required a power input for the supply air fan of the air handling unit which was calculated by Beaver. System 2 does not have an exhaust fan, so no power input was required.

3.4 Cost Analysis

3.4.1 Capital Cost

The capital cost is the total value of the air handling equipment, ductwork and air grilles. The cost comparison was simplified to exclude items of negligible cost difference across the systems such as switchboards, wiring, controls and associated ancillaries. The capital cost excludes many items such as builders' costs, haulage and installation/labour costs. The capital cost is for the supply of the mechanical systems only. These values were calculated using industry guidelines using quantities derived from the mechanical services documentation and pricing information provided by equipment manufacturers.

3.4.2 Energy Cost

The energy analysis calculated the total annual energy consumption for both systems. The energy consumption includes lights and equipment load which are consistent across both systems to accurately review the energy consumption due to air conditioning. A flat rate of $0.27 per kWh is the supply rate for small businesses under Tariff 20 from Ergon Energy (Ergon Energy 2019) which was used to the determine the estimated energy costs of operating the system.

3.4.3 Maintenance Cost

ASHRAE (2015) reports of a research project which was undertaken which collected data on HVAC system maintenance costs. In 2004, the mean HVAC maintenance cost was USD$0.47/ft^2. Conversion to current rate using inflation rates to 2019 values, metric numbers and Australian Dollar was completed to calculate maintenance costs which are shown in Table 3-27. It is assumed that the maintenance cost for both systems are equal as the Non-ERV option has significantly larger components whereas the ERV option requires maintenance of the ERV component.

Table 3-27: Maintenance Cost Rates

	System 1 & 2
Cost (m^2 /annum)	$10.20
Cost ($/annum)	$16,320

3.4.4 Life Cycle Cost

Kubba (2010) outlines that capital, energy/operating, maintenance and repair costs are included when evaluating the costs over the time of a system's life, which determines the life cycle cost. In order to calculate the life cycle cost of each system, the inflation rate and rate of increase of electricity are required to predict maintenance and energy costs in the future. The following rates were used to calculate the lifecycle cost and are an average of the historical increase over the past 10 years:

- Inflation Rate – 2% (Rate Inflation 2019)
- Electricity Price Increase – 5% (Queensland Competition Authority 2019)

The life cycle cost analysis was undertaken over a 25 year period, as this is the typical economic life of a packaged air handling unit (AIRAH 2007). The life cycle cost was calculated using the spreadsheet shown in Appendix I.

4 Results & Discussion

The detailed methodology yielded significant amounts of data sets and quantitative results. Limited results tables have been presented throughout the methodology due to the progressive nature of the analytical process and the reliance on data from preceding sections of the methodology in order to formulate a design. The presentation of results will reflect the methodology and will be presented in three sections: heat load calculation, energy analysis and cost analysis. The results are presented in the following sections including detailed analysis and interpretation of the findings.

4.1 Heat Load

As described, initial heat load calculations were required to determine the overall heat load on the building in order to accurately design a system adequate to meet the heat load requirements of the building. Table 4-1 details the results of the heat load calculation for each system in order adequately condition the building at the desired design conditions. The table outlines the required airflow, Grand Total & Sensible heat required as well as the coil conditions required. The results show that there is a significant reduction in Grand Total Heat of a system when an ERV is used with required coil conditions being quite similar.

However, when air handling unit selections were undertaken in accordance with manufacturer's technical specifications it was determined that the manufacturer's equipment was unable to meet the performance criteria of 'System 2 – No ERV' shown in Table 4-1 with the evaporator coil unable to achieve the Grand Total Heat, with the desired room conditions and the prescribed supply air flow. As previously mentioned, the room conditions and airflow were altered in order to meet the criteria with a manufactured product. The analysis was completed through comparison of 'System 1 – ERV' and 'System 2 – No ERV (Practical)'. The results showed a reduction of 192kW GTH and an 82kW reduction in GTSH. Altering the relative humidity within the space to 70%RH, resulted in the coil leaving conditions of System 2 to change which results in less than desirable room conditions.

Table 4-1: Heat Load Calculation Results

System	S/A (L/s)	O/A		GTH (kW)	GTSH (kW)	Coil Entering Conditions		Coil Leaving Conditions	
		Quantity (L/s)	% S/A			T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)
System 1 - ERV	17487	12000	69	531	287	27.1	21.6	13.5	13.1
System 2 – No ERV	18108	12000	66	771	369	30.7	24.6	13.9	13.6
System 2 – No ERV (Practical)	32000	12000	37	723	369	27.8	22.9	18.3	17.2

The psychrometric chart shown in Figure 4-1 outlines the psychrometric process required to be undertaken for System 2 – No ERV (Not practical) as a result of the heat load calculation. The chart shows the significantly high moisture and enthalpy content of the outside air. Table 4-2 details the exact condition of the data points shown in the psychrometric process. The evaporator coil is required to remove 7.46 g/kg of moisture and 36.26 kJ/Kg of enthalpy from the combined return and outside air path to achieve the design conditions of the room.

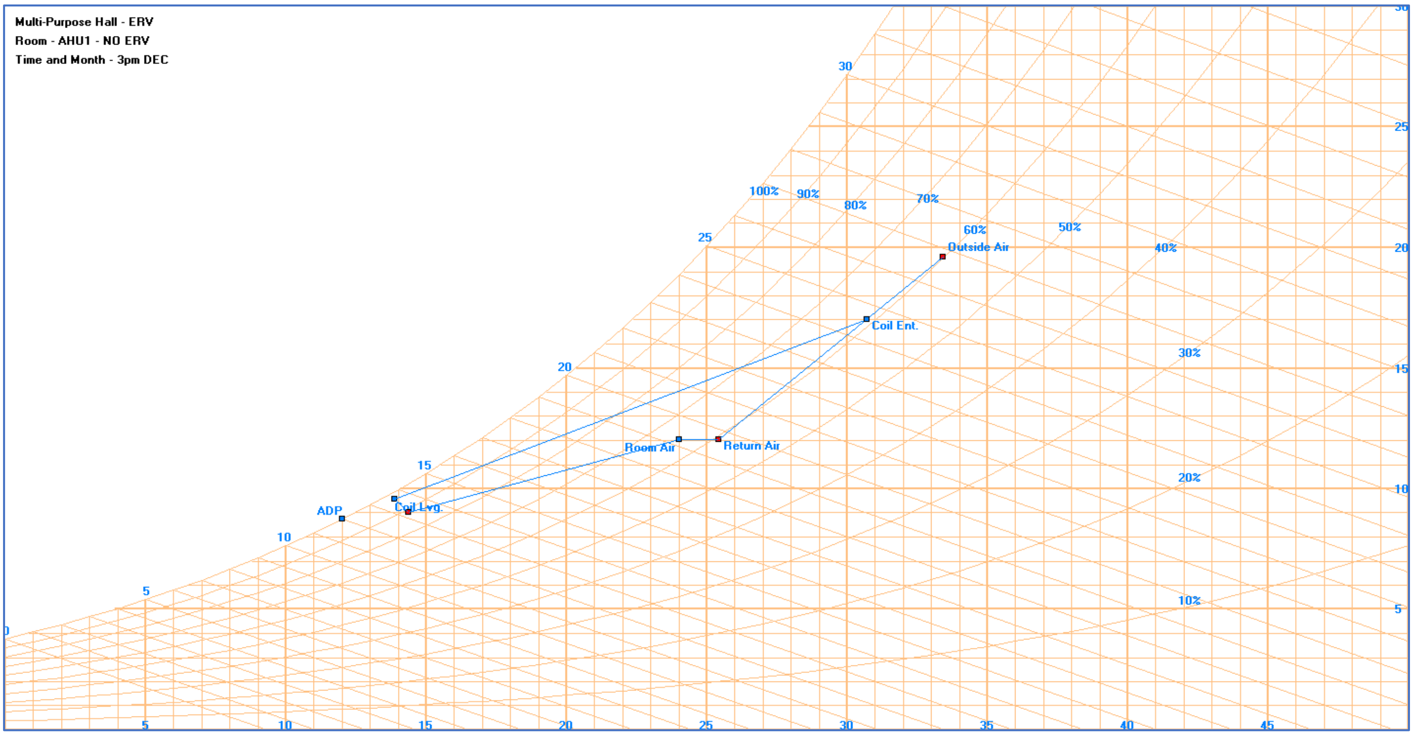


Figure 4-1: System 2 (No ERV - Not Practical) Psychrometric Process

Table 4-2: System 2 (No ERV – Not Practical) Psychrometric Data

Air Conditions	T_{DB} (°C)	T_{WB} (°C)	RH (%)	Moisture Content (g/kg)	Enthalpy (kJ/Kg)
Outside Air	33.4	26.8	60.2	19.7	84.05
Room Air	24.0	19.25	64.4	12.08	54.7
Coil Entering Air	30.7	24.6	61.1	17.09	74.56
Coil Leaving Air	13.9	13.6	96.8	9.63	38.3
Room Entering Air	14.4	13.3	88.7	9.1	37.49
Return Air	25.4	19.7	59.3	12.09	53.35
Apparatus Dew Point	12				
Mix R/A + O/A	30.7	24.6	61.1	17.09	74.56

Figure 4-2 shows the psychrometric process of system 2 with room conditions altered. The air handling unit is required to remove 3.76 g/kg of moisture and 19.36 kJ/Kg of enthalpy from the combined return and outside air path to achieve the design conditions of the room. Only minimal removal of moisture content is required by the coil due higher than usual relative humidity set for the design conditions. In Figure 4-2, the altered design conditions point has moved up the chart in comparison to Figure 4-1 as a result of changing the wet bulb temperature which increases the relative humidity.

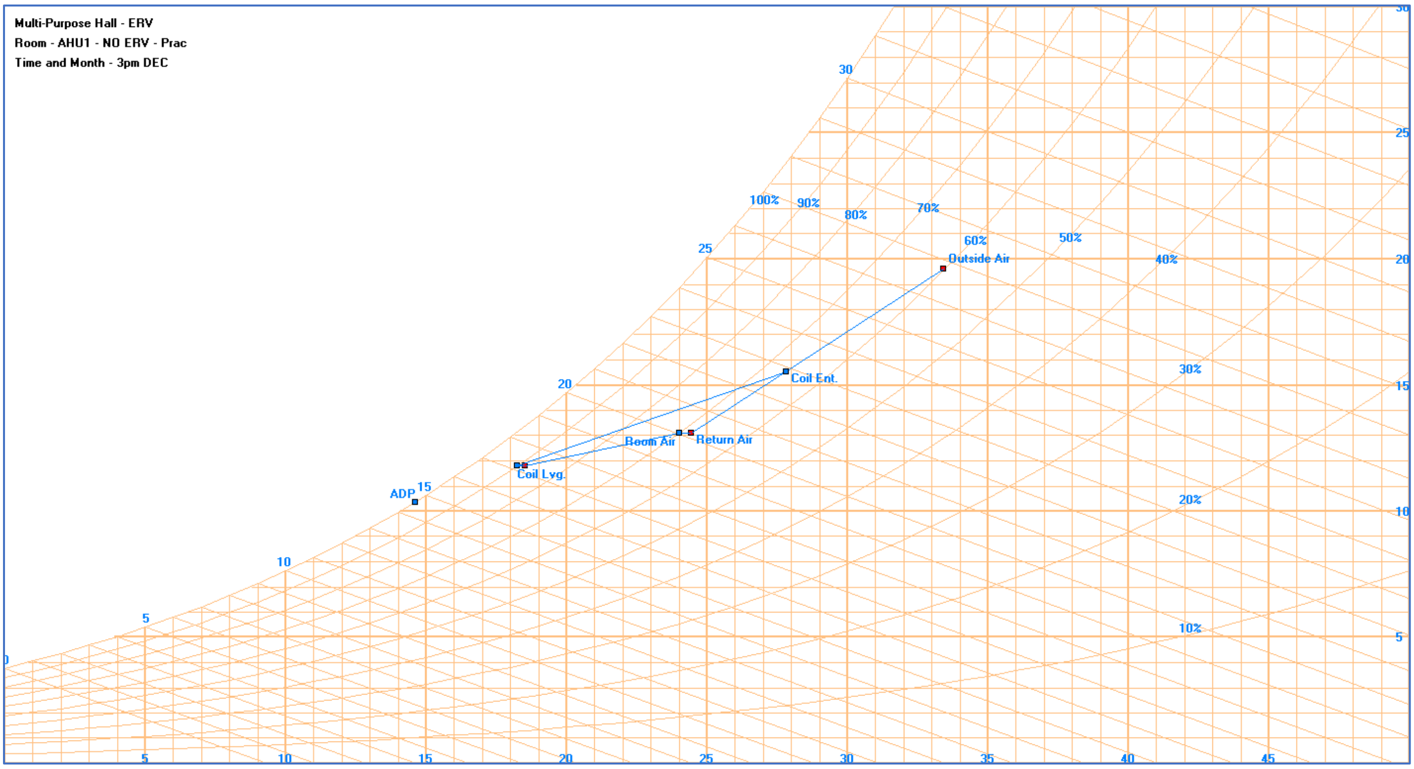


Figure 4-2: System 2 (No ERV) Psychrometric Process

Table 4-3: System 2 (No ERV) Psychrometric Data

Air Conditions	T_{DB} (°C)	T_{WB} (°C)	RH (%)	Moisture Content (g/kg)	Enthalpy (kJ/Kg)
Outside Air	33.4	26.8	60.2	19.7	84.05
Room Air	24.0	20.05	70	13.15	57.6
Coil Entering Air	27.8	22.9	66.21	15.64	67.86
Coil Leaving Air	18.3	17.2	89.9	11.88	48.5
Room Entering Air	18.5	17.3	89.05	11.91	48.8
Return Air	24.4	20.2	68.5	13.182	58.09
Apparatus Dew Point	14.6				
Mix R/A + O/A	27.8	22.9	66.2	15.64	67.86

Figure 4-3 displays the psychrometric results from the heat load simulation of the system with an energy recovery ventilator. The data line from the outside air point to the Air Off ERV (H.E Lvg) show the work undertaken by the ERV. The ERV removes 4.72 g/kg of moisture and 17.37kJ/Kg of enthalpy from the outside air, with a total heat content removal of over 240kW. The benefit of the ERV is that it utilises exhaust tempered air from the room to pre-condition the outside air, which essentially acts as 'free cooling'. Whilst the rates of enthalpy and moisture removal from the coil appear less than the values in Table 4-3, the total required cooling is significantly less due to the lower supply air flow.

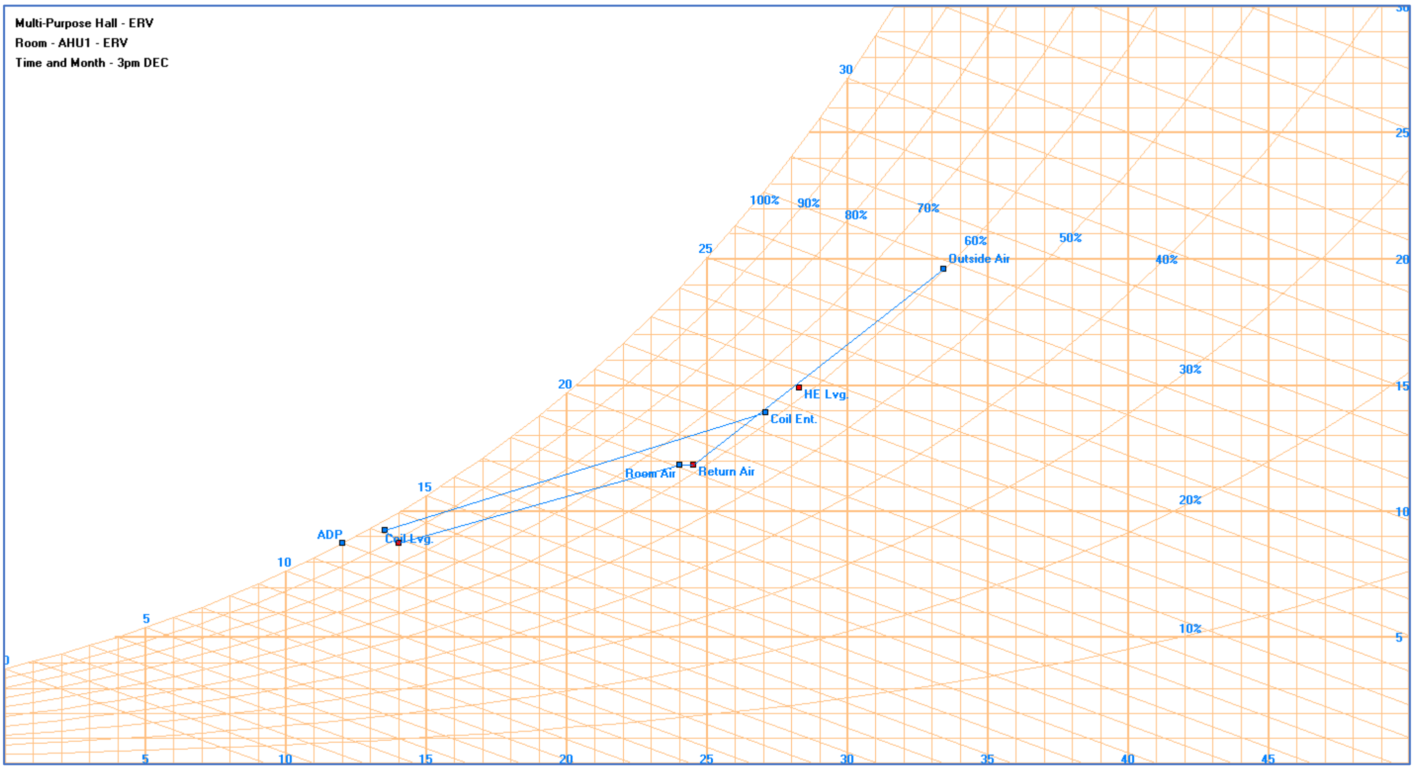


Figure 4-3: System 1 (ERV) Psychrometric Process

Table 4-4: System 1 (ERV) Psychrometric Data

Air Conditions	T_{DB} (°C)	T_{WB} (°C)	RH (%)	Moisture Content (g/kg)	Enthalpy (kJ/Kg)
Outside Air	33.4	26.8	60.2	19.7	84.05
Air Off ERV	28.3	22.6	61.65	14.98	66.68
Room Air	24.0	19.1	63.4	11.89	54.38
Coil Entering Air	27.1	21.6	62	14.01	62.98
Coil Leaving Air	13.5	13.1	95.7	9.27	36.98
Room Entering Air	14.0	12.8	87.6	8.75	36.19
Return Air	24.5	19.3	61.78	11.94	55.03
Apparatus Dew Point	12.0				
Mix R/A + O/A	27.1	21.6	61.96	14.01	62.98

As previously mentioned, the CAMEL software estimates the peak grand total heat of a system using the 3pm peak monthly comfort conditions. Comfort conditions mean the peak conditions are exceeded 10 times per year, which explains the fluctuation above the room design conditions seen in Table 4-4.

The result of the peak loading on the building is seen in Figure 4-4, which displays the grand total heat of a system over its operational hours for each month for System 1. January, February and March have a GTH of over 550kW from initial operation of plant at 7am. GTH in these months increases to over 650kW by 11am and remains above this until operation of plant ceases.

Figure 4-4 also illustrates the significant difference between hourly profiles from summer to winter months for System 2 – No ERV. The hourly profiling across months remains consistent throughout the year, with the GTH in winter months tapering off more rapidly after after peak daily loading has occurred at 3pm.

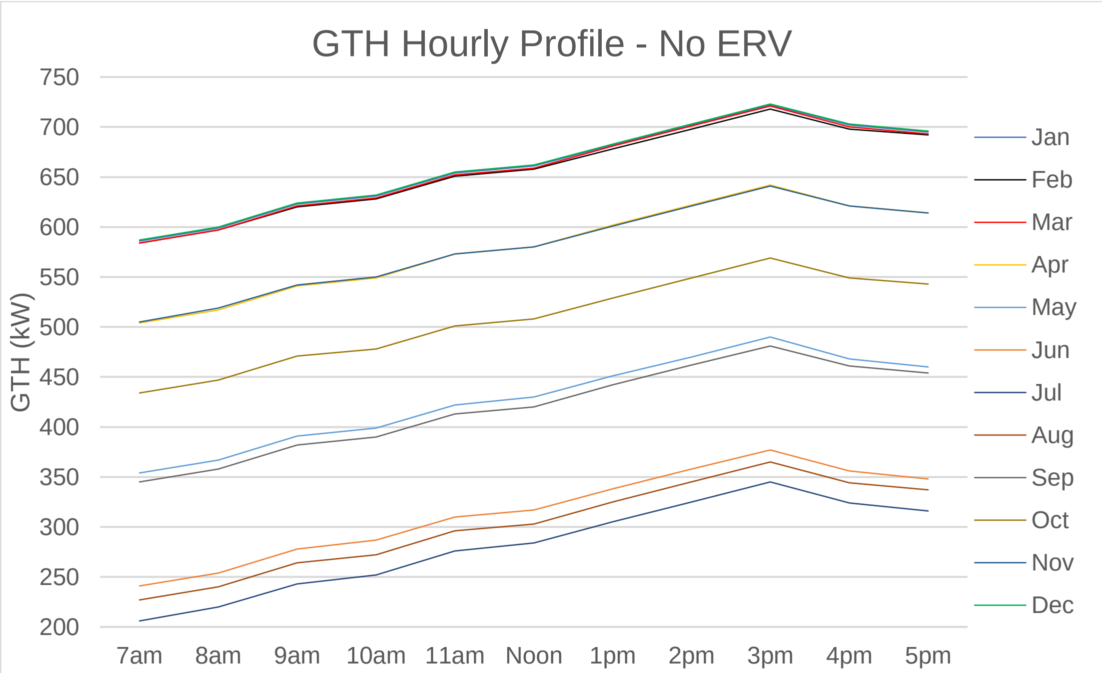


Figure 4-4: GTH Hourly Profile - No ERV

When comparing the above data with the GTH hourly profiles for Figure 4-5, other than the obvious difference in total GTH, it can be seen that system 1 (ERV) experiences a higher rate of increase of GTH from the from 7am to 3pm than system 2. This indicates that when solar loads on the building are less at 7am, the system requires less GTH as the ERV is pre-conditioning the outside air and offsetting the cooling capacity required to handle the high outside air loads. As the operating hours continue, the GTH increases more rapidly as the solar load on the building increases to its peak loading condition at 3pm. When comparing this to Figure 4-4 , it is evident that from the initial system operation at 7am, the required cooling capacity is significantly higher as the outside air at ambient conditions increases the required Grand Total Heat of the system significantly.

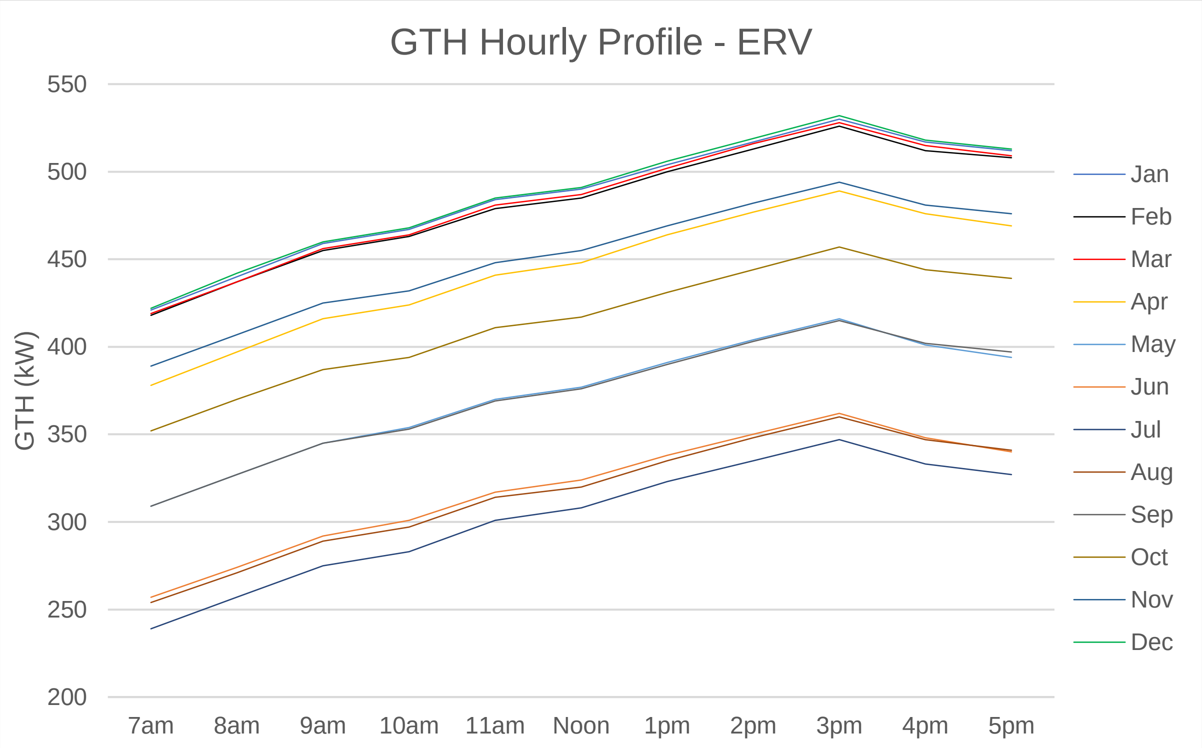
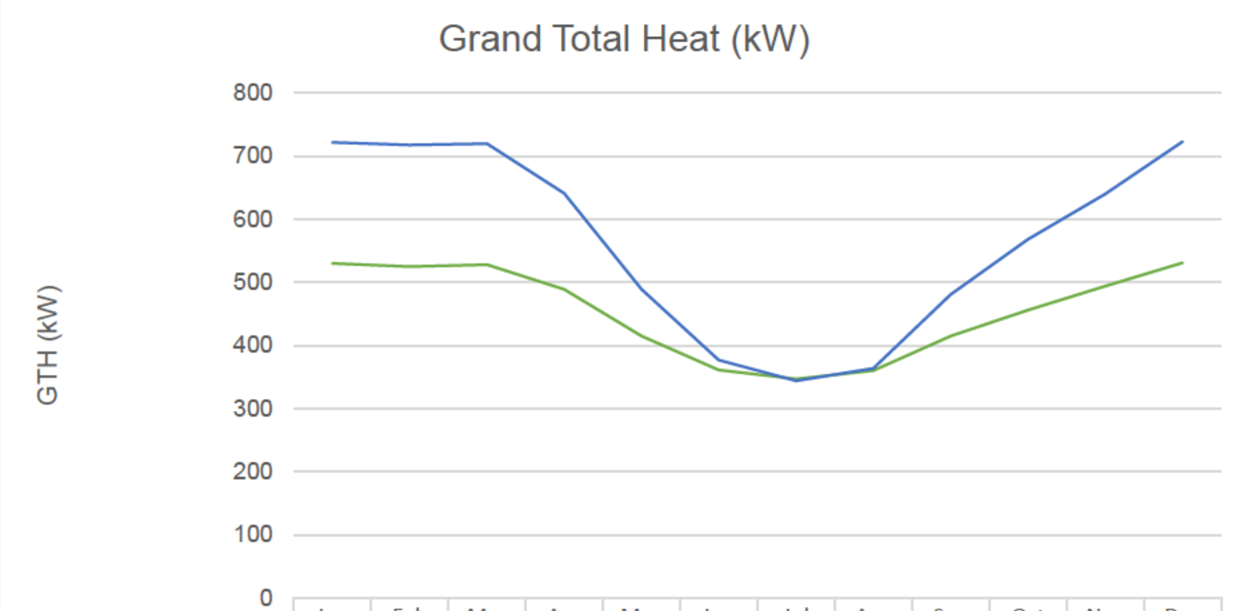


Figure 4-5: GTH Hourly Profile – ERV

Figure 4-6 compares the monthly grand total heat of both systems. The figure compares the 3pm monthly GTH for both systems as seen in Figure 4-4 & Figure 4-5. It is evident that implementation of an ERV reduces the grand total heat of the system by 27% in the summer months. Savings are reduced as the ambient temperatures become lower into the winter months. In July & August, the required grand total heat is roughly equal for both systems. This is due to ambient air conditions being equal to the air conditions produced by the energy recovery ventilator. Therefore, there is no increase in grand total heat when an ERV is not used through winter months.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
System 1 - ERV	530	525	528	489	415	361	347	360	415	456	494	531
System 2 - No ERV	722	718	720	641	489	377	344	364	481	568	640	723

Figure 4-6: Grand Total Heat per System

With the required air handling unit capacities and coil conditions calculated, the air handling unit schedule was determined. In order to align with manufacturers specifications and to suit the building layout, the systems will comprise of four units of equal capacity to serve the buildings as seen in the layout plans. Table 4-5 contains the performance specifications for the air handling units for system 1.Table 4-6 is the energy recovery ventilator equipment schedule for the energy recovery ventilators which are included with the air handling units.

The performance specifications required by the air handling units for system 2 are shown in Table 4-7.

Table 4-5: System 1 Air Handling Unit Schedule

Unit No.	S/A (L/s)	O/A (L/s)	GTH (kW)	GTSH (kW)	Coil Entering Conditions		Coil Leaving Conditions	
					T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)
AHU-1	4372	3000	133	72	27.1	21.6	13.5	13.1
AHU-2	4372	3000	133	72	27.1	21.6	13.5	13.1
AHU-3	4372	3000	133	72	27.1	21.6	13.5	13.1
AHU-4	4372	3000	133	72	27.1	21.6	13.5	13.1

Table 4-6: System 1 ERV Schedule

Unit No.	S/A (L/s)	O/A (L/s)	Air Entering Conditions		Air Leaving Conditions		Notes
			T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)	
ERV-1	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-1
ERV-2	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-2
ERV-3	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-3
ERV-4	3000	3000	33.4	26.6	28.3	22.6	Serves AHU-4

Table 4-7: System 2 Air Handling Unit Schedule

Unit No.	S/A (L/s)	O/A (L/s)	GTH (kW)	GTSH (kW)	Coil Entering Conditions		Coil Leaving Conditions	
					T_{DB} (°C)	T_{WB} (°C)	T_{DB} (°C)	T_{WB} (°C)
AHU-1	8000	3000	181	92.25	27.8	22.9	18.3	17.2
AHU-2	8000	3000	181	92.25	27.8	22.9	18.3	17.2
AHU-3	8000	3000	181	92.25	27.8	22.9	18.3	17.2
AHU-4	8000	3000	181	92.25	27.8	22.9	18.3	17.2

4.2 Energy

The energy analysis was conducted using the building energy analysis program Beaver. The analysis was conducted by comparing the energy consumption of both systems over a 12-month period. The detailed energy analysis resulted are presented Appendix H.

Table 4-8 compares the total energy annual energy consumption as calculated from the energy analysis. The table includes the total annual energy costs per system. The total annual energy consumption is 8% less when an ERV is implemented which equates to an annual cost saving of $8,764.

Table 4-8: Estimated Energy Cost

	System 1 - ERV	System 2 – No ERV
Estimated Energy Consumption per annum (kWh/annum)	365901	398363
Electricity Supply Rate ($/kWh)	$0.27	$0.27
Estimated Electricity Cost per annum ($/annum)	$98,793.27	$107,558.01
Difference in Cost ($)	$8,764.74	

Figure 4-7 compares the total monthly energy consumption for both systems. The ERV system yields significant energy savings of up to 18% in summer months. Review of the data details proportional energy savings in warmer months, however as external conditions become cooler, savings reduce. This is a result of data shown in Figure 4-6 which sees grand total heat becoming equal in these months. The energy consumption for system 1 (ERV) in the winter months exceeds the energy consumption for a non ERV arrangement. This is due to the requirement of an exhaust fan as a component of an ERV. The exhaust fan is required to draw exhaust air through the ERV in order to initiate the energy transfer process. The exhaust fan produces energy consumption on top the components of the air handling unit.

As result of this, further energy analysis was undertaken into the energy consumption of the ERV system if an ERV bypass is installed which disables the exhaust fan operation through the winter months. The results of this are shown in Figure 4-7 where operating the ERV bypass yields up to a 9% energy saving through winter months when compared to the Non-ERV option and over 10% energy savings when compared with the ERV option without an ERV bypass.

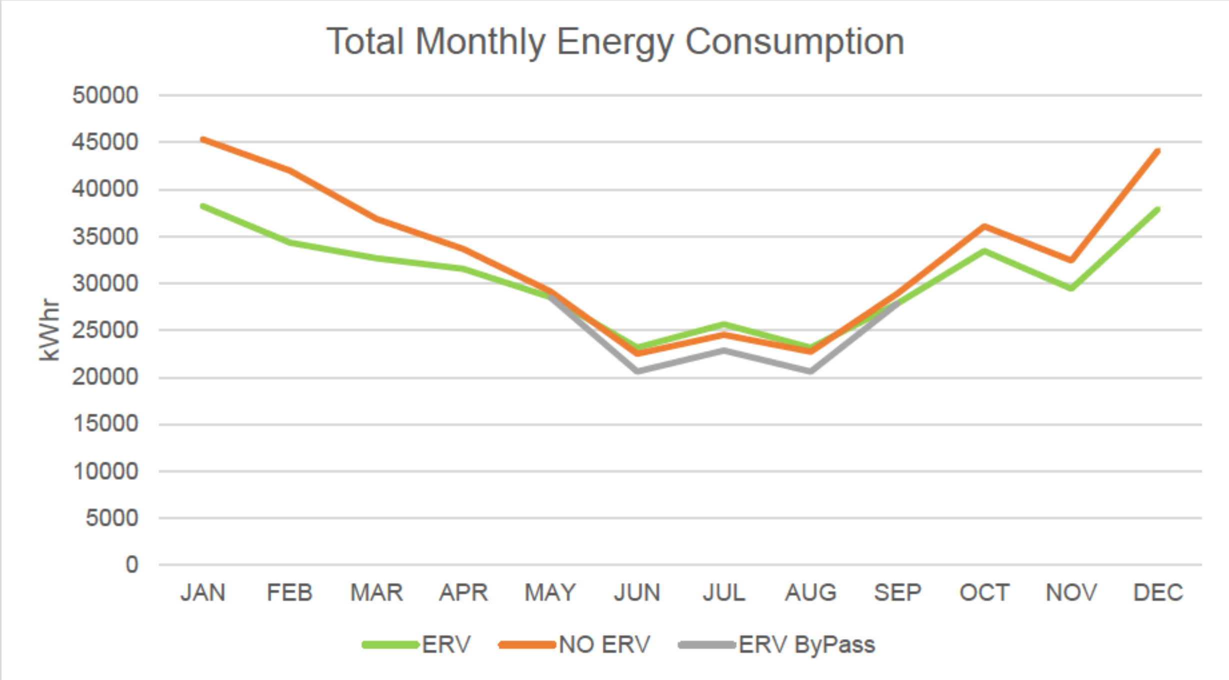


Figure 4-7: Total Monthly Energy Consumption

The data presented in Figure 4-8 provides a comprehensive breakdown of the monthly energy consumption of the two systems. The energy usage is defined by AHU cooling, heating, AHU fans, lights and equipment. Lights and equipment are consistent across the two systems and heating in both systems is negligible.

The energy consumption due to air handling unit fans for system 1 is over 2500kWhr per month and almost double system 2's energy consumption due to the ERV exhaust fan. The energy consumption contributable to AHU cooling for system 2 is more than 7500 kWhr per month higher than system 1 (ERV) from October to March.

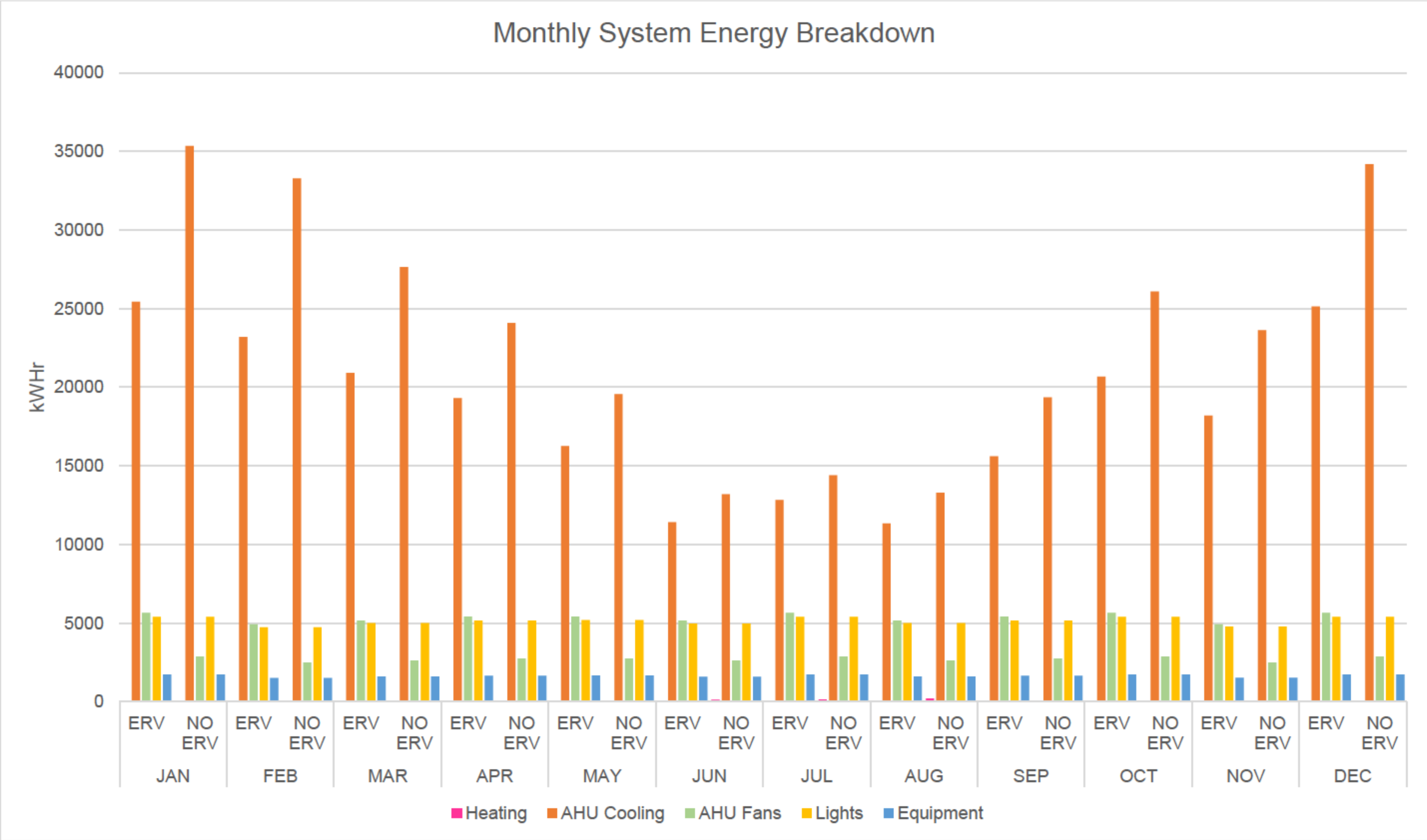


Figure 4-8: Monthly System Energy Breakdown

Figure 4-9 & Figure 4-10 provide a summary of different component contribution to the overall building's energy consumption for each system. It must be noted that heating contributes such a minimal amount to the overall energy consumption of both systems, it is shown as 0%.

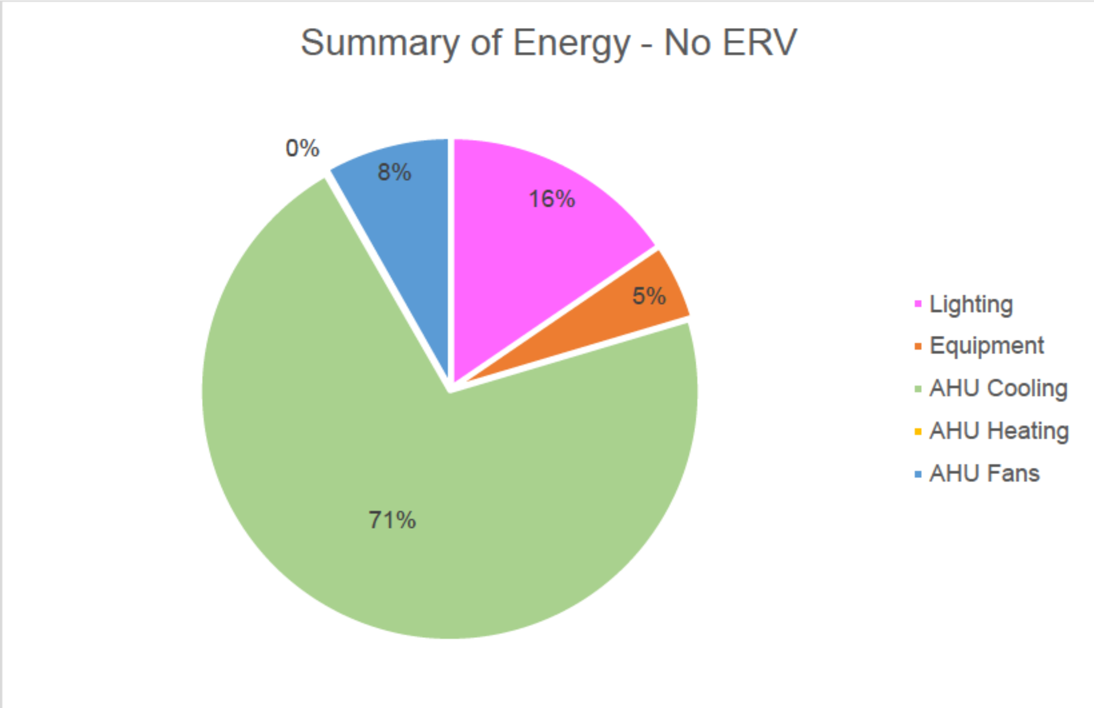


Figure 4-9: Summary of Energy - No ERV

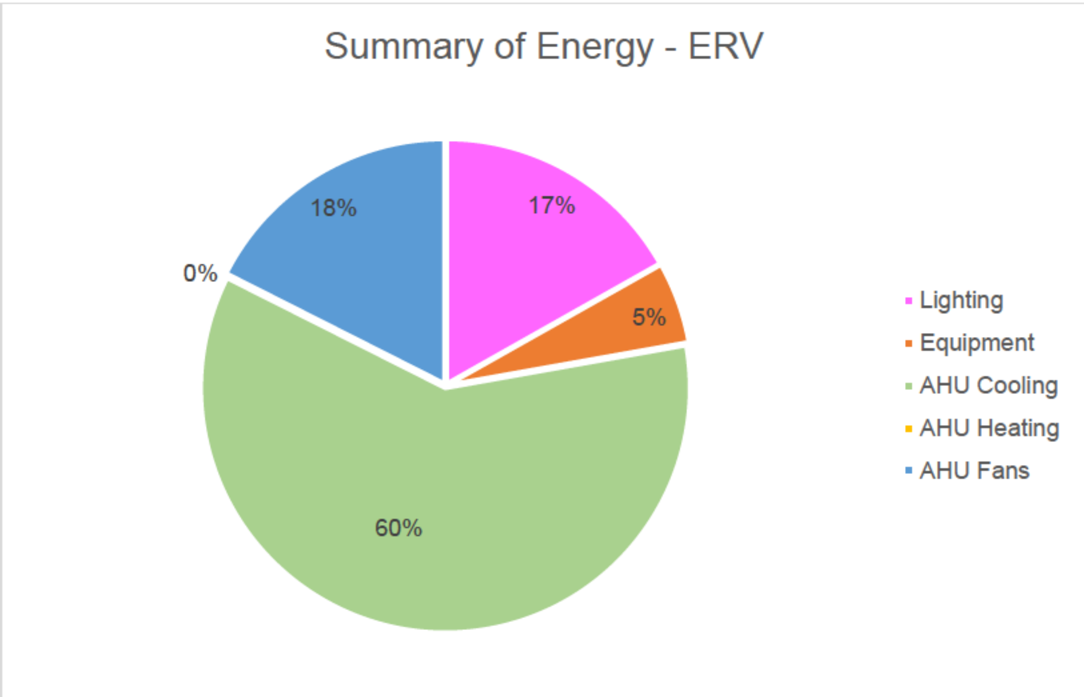


Figure 4-10: Summary of Energy - ERV

4.3 Cost

The results of the capital cost are outlined in Table 4-9. The cost breakdown has multiple exclusions however it is anticipated these items would be of negligible different across both systems. The cost is for the supply of the mechanical services systems only. The results show a significantly higher cost for the ERV air handling units compared to system 2. However, system 2 costs are higher for ductwork and grille items due to the requirement of a larger supply & return air quantities.

Table 4-9: Capital Cost Breakdown

Item	System 1	System 2
Air Handling Equipment	$326,000	$229,000
Ductwork	$80,448	$97,052
Air Grilles	$3,155	$4,656
Total	$409,603	$330,708

Assumptions

1. All mechanical services items to make complete systems were not included in the capital cost comparison. It is assumed that items including, but not limited to, controls, wiring, switchboards & piping are of equal cost (or of negligible difference) for each system and therefore were not included.

Exclusions

- GST
- Preliminaries, site establishment and storage of materials
- Design or construction contingencies
- Mechanical trade labour & installation costs
- Demolition
- Associated builders' works
- Temporary services
- Regional indices
- Haulage
- Spare parts
- Enabling works
- Latent conditions
- Rectification works

Table 4-10: System Cost Comparison

System	Capital Cost	Difference in Capital Cost	Estimated Maintenance Cost per Annum	Estimated Electricity Cost per Annum	Difference in Electricity Cost
System 1 - ERV	$409,603	$78,895	$16,320	$98,793	$8,765
System 2 – No ERV	$330,708		$16,320	$107,558	

A life cycle cost analysis was undertaken for both systems. The analysis applied a 2% inflation rate to all maintenance items as well as a 5% increase annually for energy costs based on historical data. The analysis was undertaken over a 25-year timeframe, as this is the expected economic life of a packaged air handling unit. Figure 4-11 illustrates the results of the analysis, which reveals the ERV system costing 13% more than system 2 in year 1. Over the life cycle of the equipment the ERV system costings increase at a slower rate due to the reduced energy consumption energy costs, this results in the life cycle cost at the end of the 25-year period being 6% less than the non-ERV system. Both systems have a total life cycle cost of over $6 million. The complete results of the life cycle cost are shown in Appendix I.

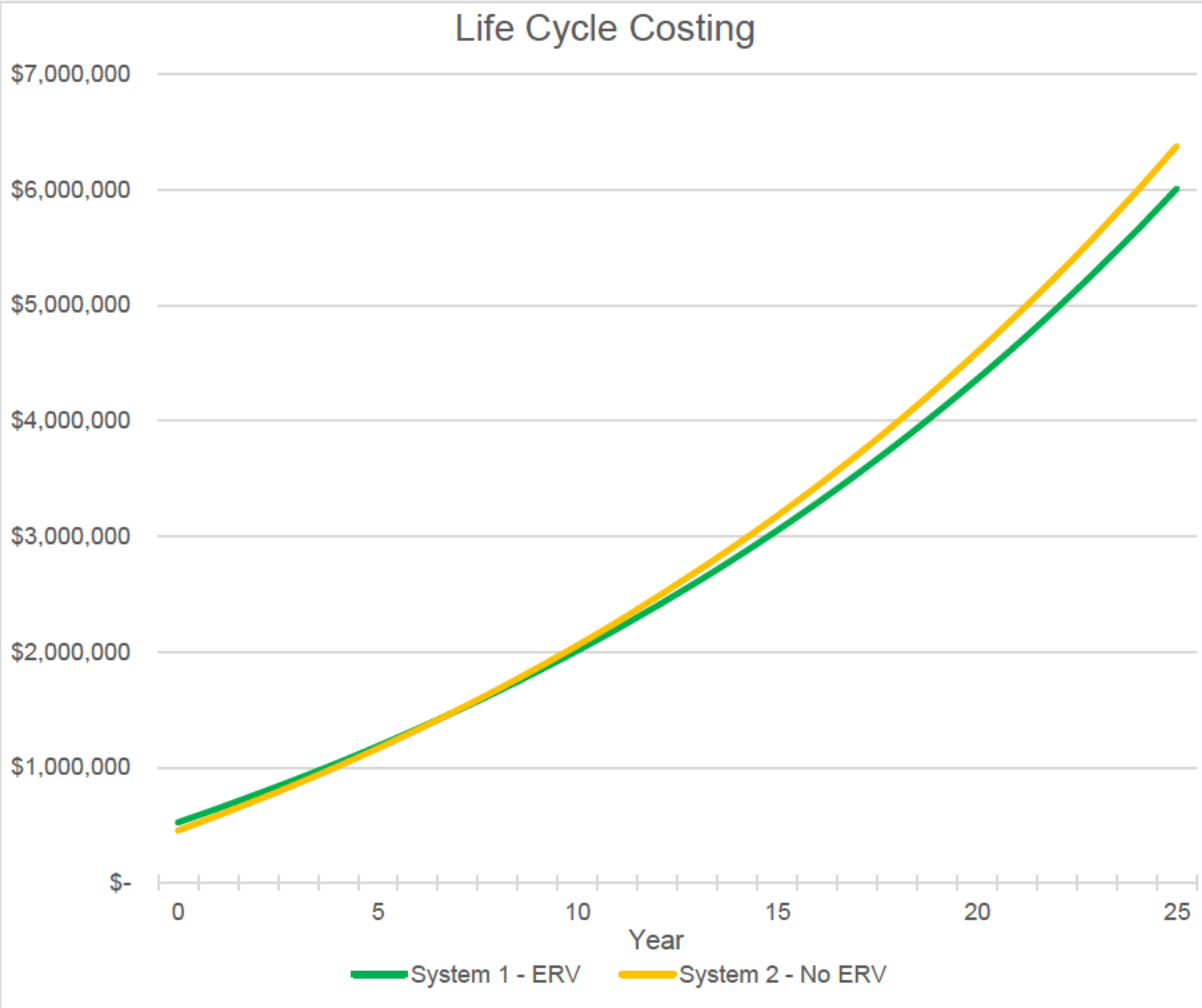


Figure 4-11: Life Cycle Cost Analysis

Figure 4-12 shows the cost deficit between the two systems each year over time as calculated by the life cycle cost analysis. The comparison demonstrates the payback period of the ERV when compared to the non ERV system. As shown in the graph, a positive cost deficit for the ERV occurs in the 7th year, detailing the ERV system has a payback period of between 6 to 7 years. The data reveals an increase in cost deficit once the payback has occurred. System 2 (No ERV) yields a total life cycle cost difference of $369,101 over 25 years when compared to system 1.

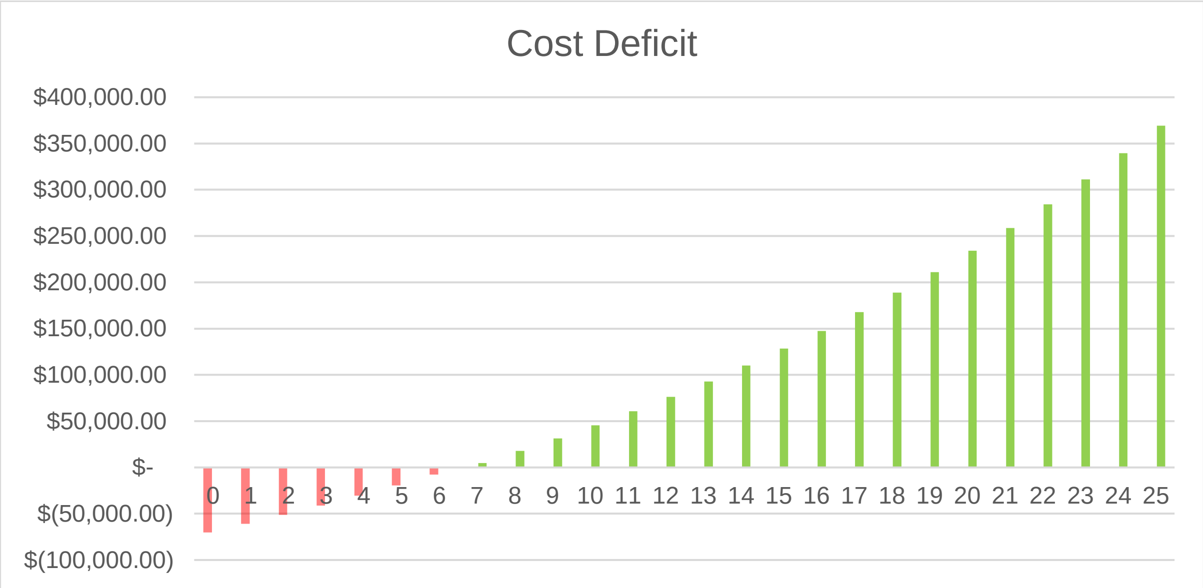


Figure 4-12: System Cost Deficit

A breakdown of the predicted maintenance and energy costs per year over the life cycle of the two systems is provided in Figure 4-13. The data comparison shows maintenance and electrical costs increasing exponentially over time, with the difference in system cost increasing each year. The electricity costs in the final year of the analysis exceeds $300,000 for both systems which is more than triple the amount of the initial energy costs.

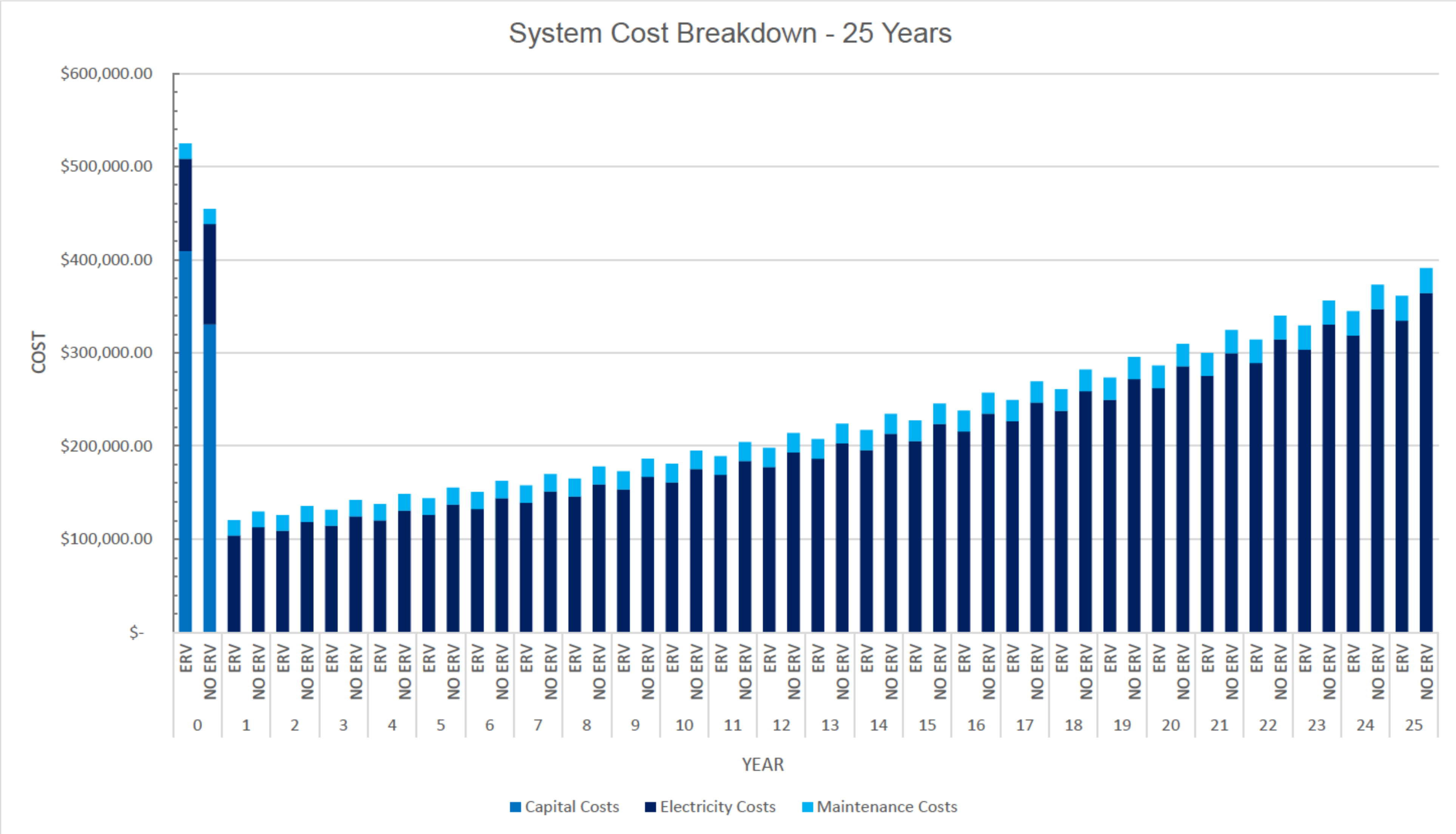


Figure 4-13: Life Cycle Cost Breakdown per year

5 Conclusions

The aims and objectives were formulated in order to successfully execute designs and calculations to yield valid results for the dissertation topic. Comprehensive research was undertaken to investigate energy recovery ventilator technology, to determine design parameters for energy recovery ventilators in air conditioning systems, to apply the relevant Australian Standards, codes and industry guidelines and to review publications and research of previous implementation of energy recovery ventilators and the results.

In order to determine the effectiveness of these systems, a comparative approach was adapted where two systems were designed which entailed a system with and without an ERV installed. These systems were designed to suit a BCA Deemed To Satisfy Section J compliant multi-purpose hall building for consistent results. A heat load simulation was undertaken for both systems which calculated the total cooling capacity required by the air conditioning system. The calculations demonstrated a 27% reduction in the grand total heat when an ERV is implemented in summer months. The grand total heat required by each system was calculated to be equal through the winter periods.

The systems were design and documented to industry standards where it was determined that the system without an ERV required a larger equipment footprint and associated ancillaries including ductwork and air grilles due to the requirement of larger air flows. The system without an ERV also produces less favourable internal room conditions due to the elevated relative humidity from direct outside air being supplied directly to the cooling coil of the air conditioning unit.

An energy analysis was undertaken which included assessment of the air conditioning cooling & heating processes, the air handling unit fans, building lights and equipment loads. The results yielded an 8% reduction in total annual energy consumption and an $8,764 energy cost saving in the first year when an ERV is implemented. An unexpected result saw the energy consumption of the ERV system through winter months exceed that of the non ERV system. This was a result of the proprietary exhaust fan installed in the ERV which consumed energy whilst minimal energy is being reclaimed from the air exchange process as ambient conditions are equal to the conditions produced by the ERV.

However, further calculation of the energy consumption of the ERV system when an ERV bypass is installed and initiated revealed up to a 9% reduction in energy consumption when compared to the Non-ERV system in winter months and energy savings of over 10% for the ERV system when the exhaust fan is not operating throughout the winter months. Further costs would be associated with installing an ERV bypass system and its required controls, these costs were not included in this dissertation.

The energy analysis revealed that cooling without an ERV contributes to over 70% of a building's total energy consumption, compared to when an ERV is used cooling contributes accounts for 60% of the total energy consumption.

The final objective was to undertake a cost analysis of the two systems. It was found that whilst the initial cost of the ERV system is significantly more, cost savings are provided from ductwork and air grilles. Results of the life cycle cost analysis predicted a system payback period between 6 and 7 years and a total cost saving of $369,101 over the 25-year life of the equipment.

As previously mentioned, due to the manufacturing constraints the study was unable to undertake a direct comparison using the non ERV system and internal room design conditions were compromised in order to correctly select an available manufactured air handling unit(s). This further reiterates that the implementation of an ERV produces ideal room conditions for a building. If a direct comparison was able to be made (with both systems producing identical room design conditions), it is expected that the results would see a greater difference in required grand total heat, energy consumption and costs when an ERV is utilised.

With all objectives achieved, the aim of this dissertation was to analyse and compare the effectiveness of energy recovery ventilators for air conditioning systems in the North Queensland region from a performance and cost standpoint. This study validates what has been proven in previous research but in a considerably different application. The comparative analysis undertaken shows that installation of energy recovery ventilators produces significant energy performance and cost benefits as well as improving room conditions. The benefits could stem to the government and large private entities who encounter large expenses as a result of energy consumption. With a payback period of less than 7 years, this study shows that is imperative to consider energy recovery technology when designing air conditioning systems in high occupancy buildings in tropical climates.

5.1 Further Work

Several opportunities for further study and investigation have been identified throughout the compilation of this dissertation. The scope and limitations of this topic were developed to ensure precise results were produced and the gap in literature was targeted. The main limitations of this research project are:

- The analysis is undertaken for a multi-purpose hall application which are typically buildings of high occupancy.
- The analysis is limited to the area of North Queensland, particularly Townsville, which is an area of high temperature and high humidity.

Minor limitations also include building occupancy rates, building parameters and ERV efficiencies. Whilst energy recovery ventilators are an established technology in some parts of the world, it is somewhat only an emerging technology in Australia with very limited research undertaken or literature published. It is recommended further study be undertaken into the effectiveness of energy recovery ventilators with air conditioning systems in different climate zones of Australia to determine if the systems yield similar results for different climatic conditions. Investigations with varied building use, size and occupancy would be beneficial to understand the effectiveness of these devices on a broader spectrum as there is limited research published, particularly in Australia. It is anticipated that energy savings would be greater for larger buildings, particularly if the building occupancy were to increase. For less humid climates, it is expected it would yield similar results however an enthalpy exchanger would not be of any benefit, a sensible only energy recovery device would have to be used.

Further areas of study could also include determining the total energy consumption of a system with modulation of fresh air in accordance with the building occupancy rather than the system operating with the total outside air quantity at all times. It is predicted this would yield further energy savings. As the dissertation is a theoretical and numerical model of the energy and costing savings produced by an energy recovery ventilator, case studies and research could be undertaken to compare these savings with actual installed systems including ERV efficiencies, actual energy savings and costs.

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A Appendix A

ENG4111/4112 Research Project

Project Specification

For: Gene Morgan

Title: The effectiveness of ERVs (Energy Recovery Ventilators) for air-conditioning systems in multi-purpose halls in North Queensland

Major: Mechanical Engineering

Supervisor: Andrew Wandel

Enrolment: ENG4111 – EXT S1,2019

ENG4112 – EXT S2, 2019

Project Aim: Investigate the cost and energy savings of implementation of ERVs in this particular application. Design and document compliant air-conditioning systems for a multi-purpose hall with and without an ERV. Develop and simulate each model using appropriate software.

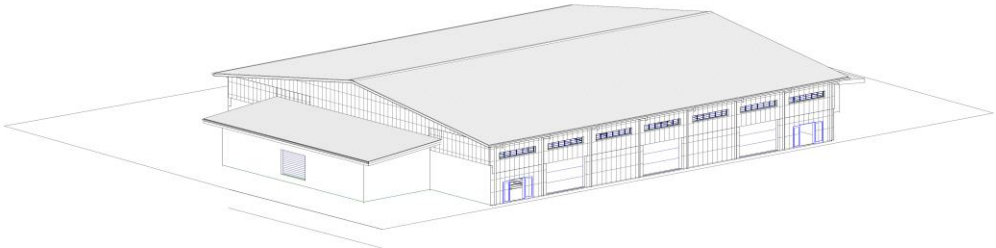
Programme: Version 2, 10.10.2019

1. Review existing ERV technology and research existing applications where these designs have been implemented.
2. Review relevant standards/codes and produce a BCA minimum compliant multi-purpose hall building to base the mechanical services design on.
3. Model the systems using heat load simulation software.
4. Design and documentation of a compliant mechanical services design for an air-conditioning system to serve the multi-purpose hall.
5. Design and documentation of a compliant mechanical services design for an air-conditioning system with an integrated energy recovery ventilator to serve the multi-purpose hall.
6. Provide a cost and energy analysis between the two system variations.
7. Analyse and interpret the results and provide outlines of the effectiveness and benefits of each system.

B Appendix B

Building Plans

The following drawing set comprises of the architectural documentation in which both systems were based upon. The building is compliant to the BCA/NCC Section J for building fabric, glazing, building sealing and air conditioning. The building is a 1600m^2 double basketball court type structure. The plans include 3-D perspective, floor plan, roof plan, sections and elevations.



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Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND

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Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	04.07.19

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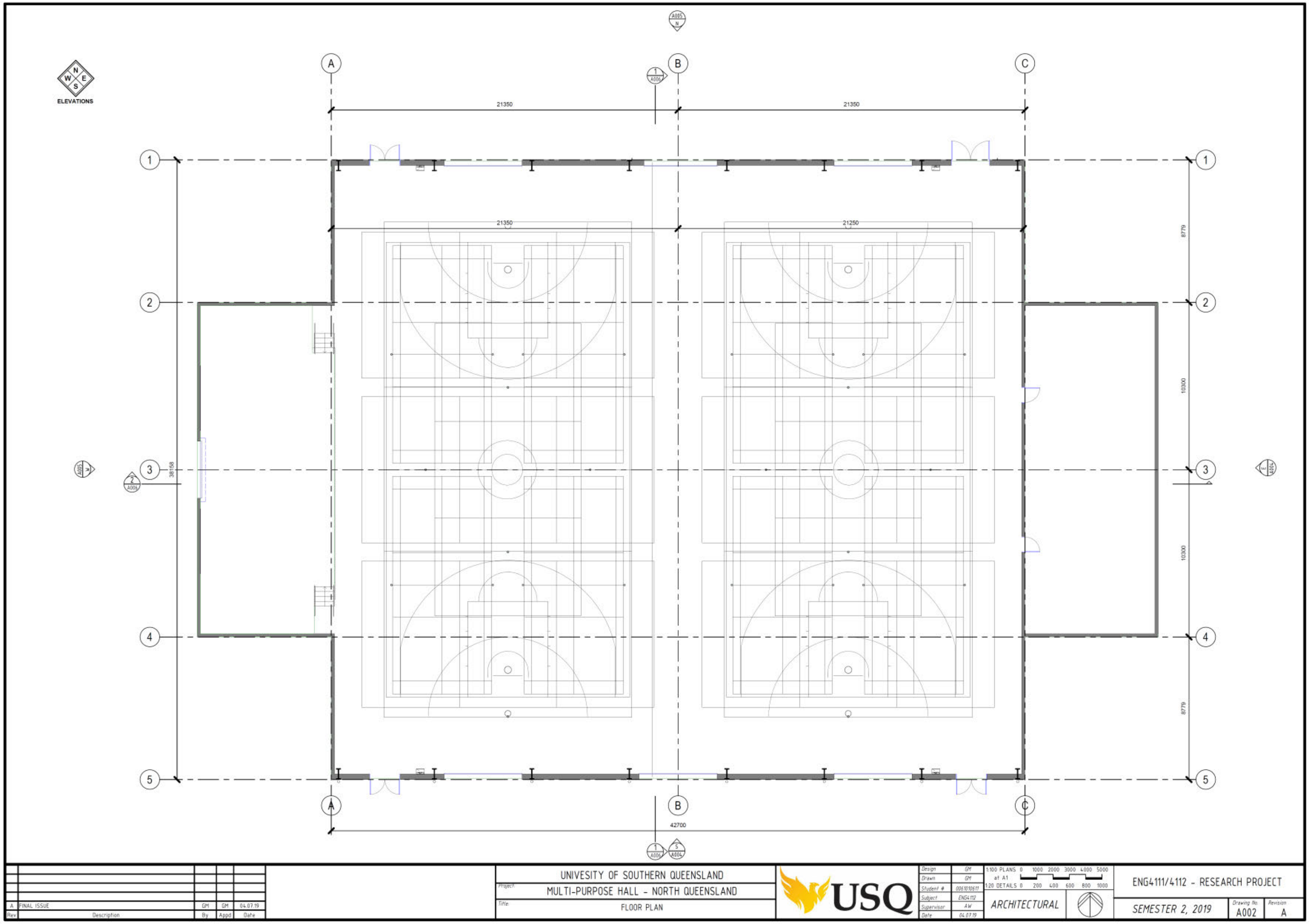
ARCHITECTURAL

ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

Drawing No. A001

Revision A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Drawn GM
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Subject ENG4112
Supervisor AW
Date 04.07.19
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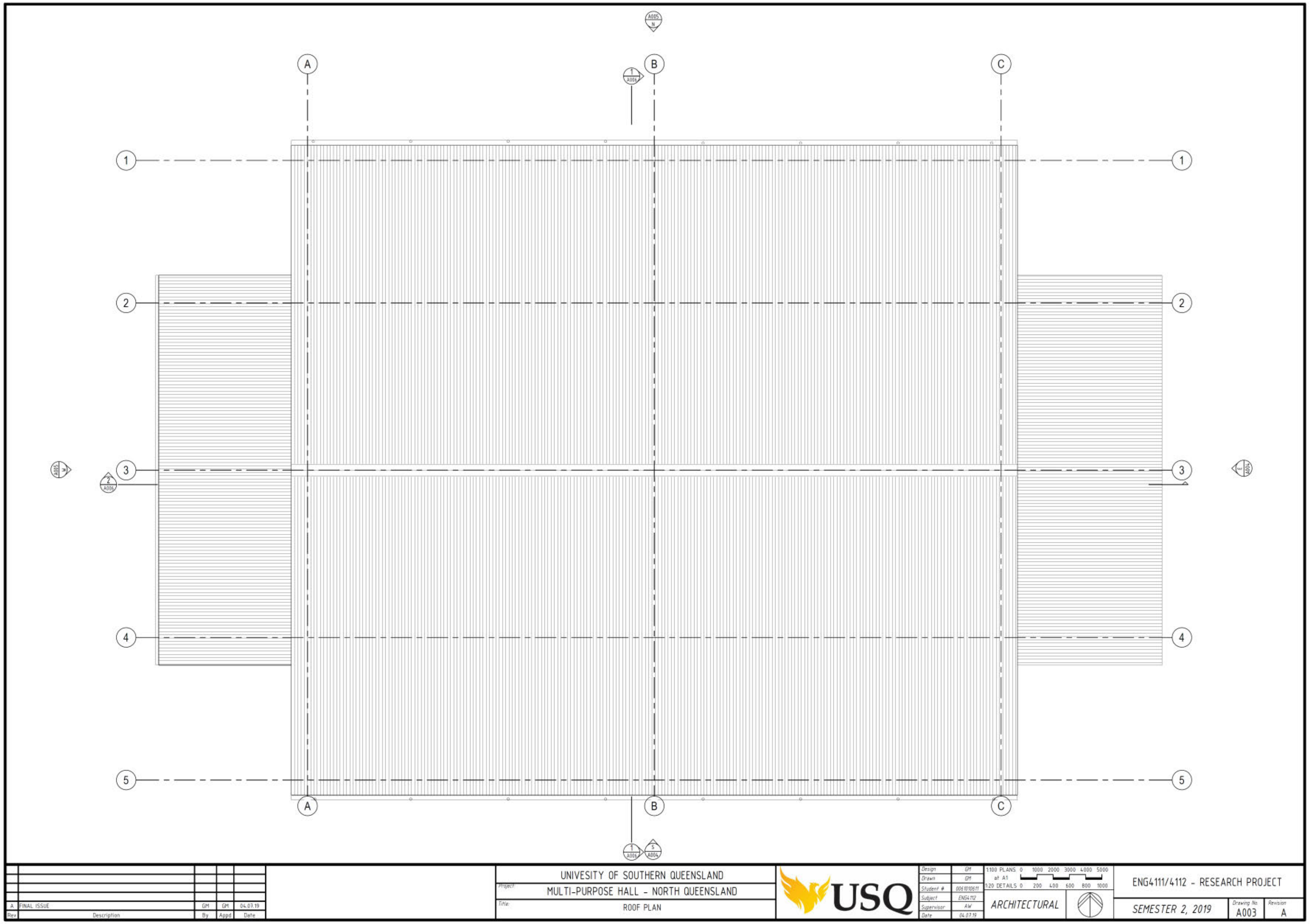
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Supervisor AW
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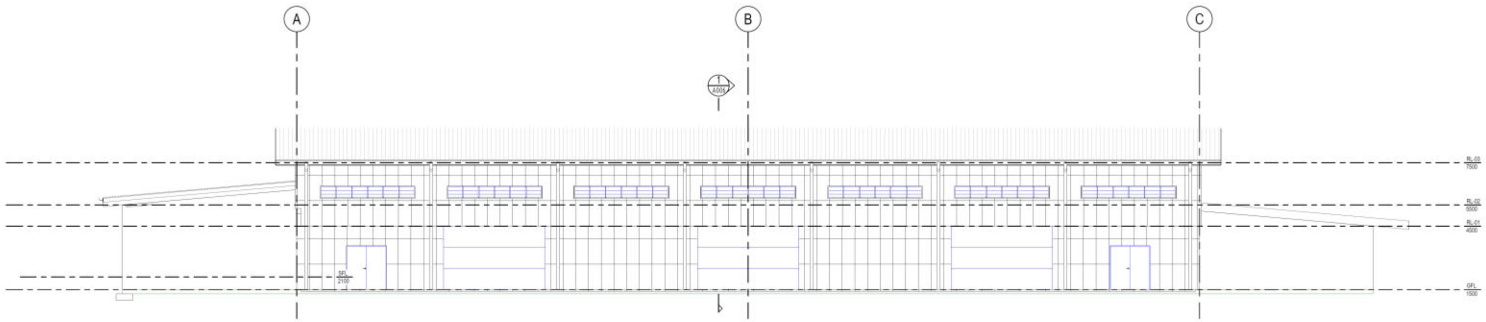

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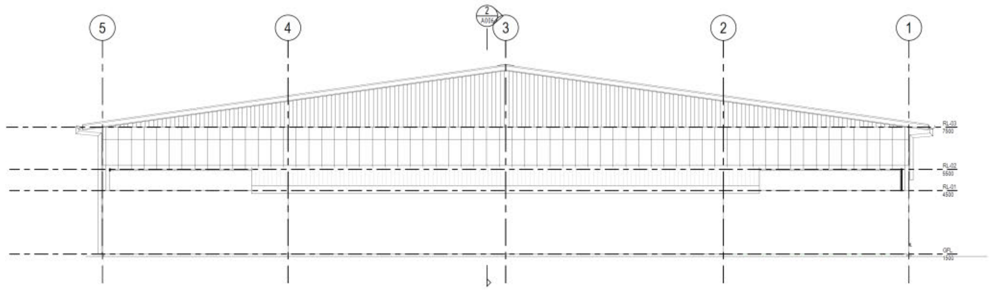

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Student #	0061010611
Subject	ENG4112
Supervisor	AW
Date	04.07.19

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ARCHITECTURAL

ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

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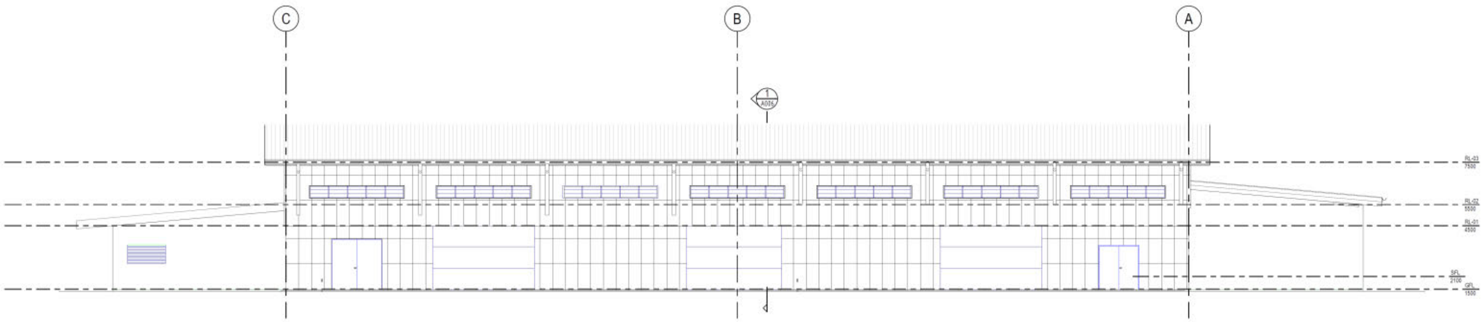

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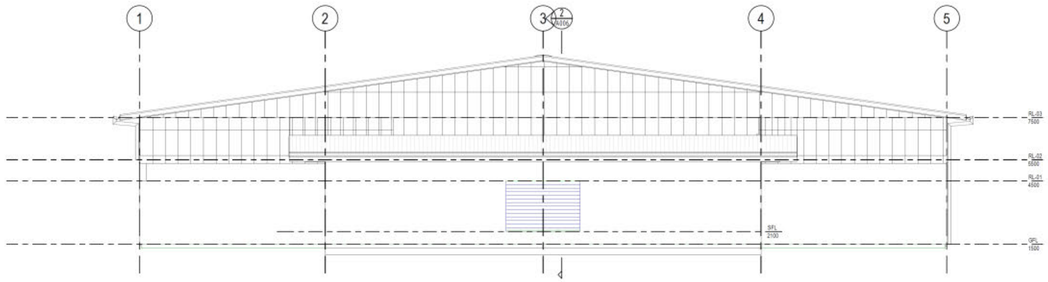

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Project: MULTI-PURPOSE HALL - NORTH QUEENSLAND

Title: ELEVATIONS 2 OF 2

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Supervisor	AW
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ENG4111/4112 - RESEARCH PROJECT

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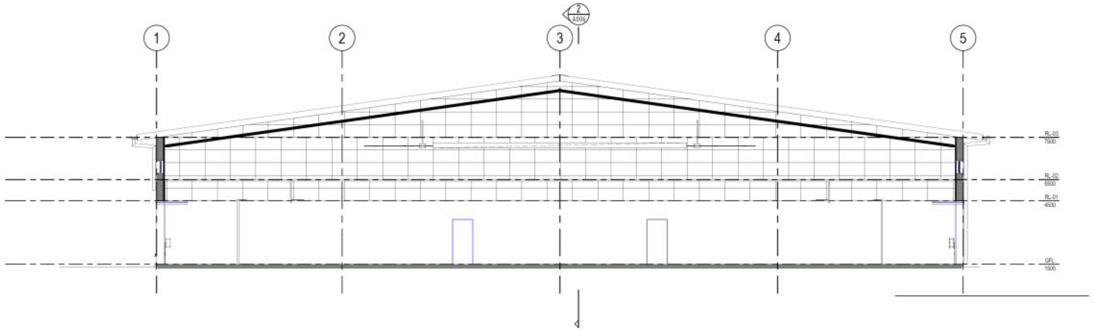

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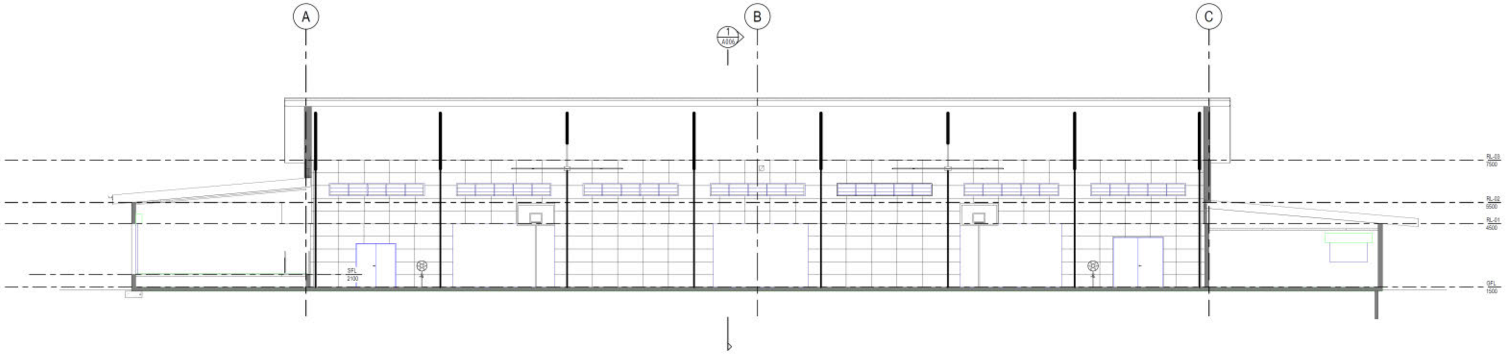

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Subject	ENG4112
Supervisor	AW
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ARCHITECTURAL

ENG4111/4112 - RESEARCH PROJECT

SEMESTER 2, 2019

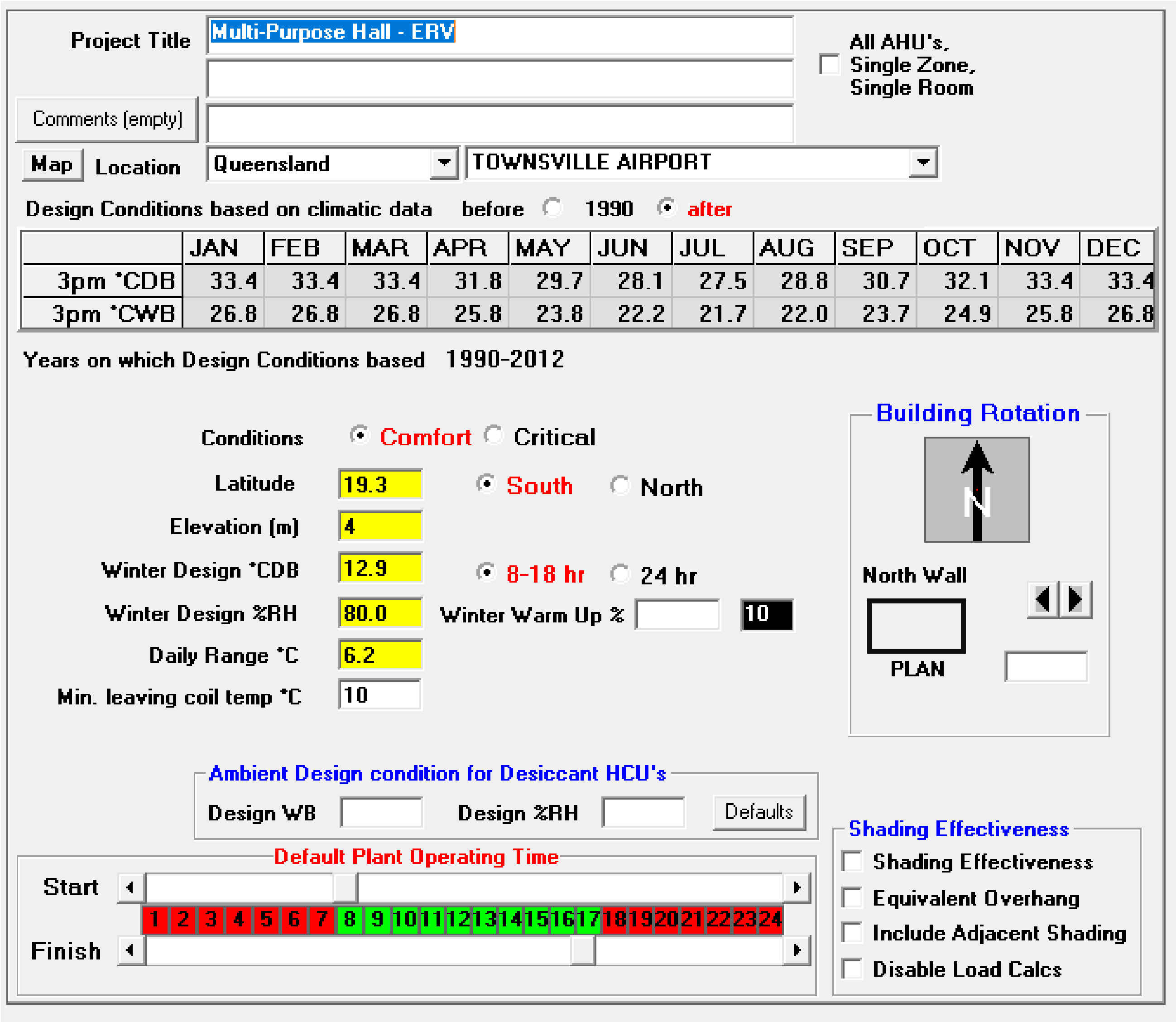
Drawing No: A006

Revision: A

C Appendix C

Heat Load Inputs

The following figures outline the inputs from the heat load calculation from the CAMEL program. Figure C-1 outlines the project location information including climatic data, geographical data, project title and building orientation. Figure C-2 outlines the pre-conditioner inputs for the system including the ERV efficiencies and fan inputs. Figure C-3 includes the titles of the air handling units, the room design conditions and system type. Figure C-4 includes the AHU coil input page where the coil psychrometric characteristics are detailed and the gains due to supply fans and ductwork. The external wall and surface inputs are shown in Figure C-6, this is where wall sizes, wall orientations, shading schemes, glazing elements and building fabric types are defined. The inputs of these are shown in further figures.



Project Title: Multi-Purpose Hall - ERV

All AHU's, Single Zone, Single Room

Comments (empty)

Map | Location: Queensland | TOWNSVILLE AIRPORT

Design Conditions based on climatic data before 1990 after

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
3pm °CDB	33.4	33.4	33.4	31.8	29.7	28.1	27.5	28.8	30.7	32.1	33.4	33.4
3pm °CWB	26.8	26.8	26.8	25.8	23.8	22.2	21.7	22.0	23.7	24.9	25.8	26.8

Years on which Design Conditions based 1990-2012

Conditions: Comfort / Critical

Latitude: 19.3 — South / North

Elevation (m): 4

Winter Design °CDB: 12.9 — 8-18 hr / 24 hr

Winter Design %RH: 80.0 — Winter Warm Up % 10

Daily Range °C: 6.2

Min. leaving coil temp °C: 10

Building Rotation

N

North Wall

PLAN

Ambient Design condition for Desiccant HCU's

Design WB | Design %RH | Defaults

Shading Effectiveness

- Shading Effectiveness
- Equivalent Overhang
- Include Adjacent Shading
- Disable Load Calcs

Default Plant Operating Time

Start

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Finish

Figure C-1: Project Location Inputs

		Temperature Controlled						Humidity Controlled			Fan		Fresh to Exhaust H.E.		
No	Title	Cooling Lvg DB	Cooling Lvg WB	Connected to Chiller	Heating Lvg DB	Connected to Boiler	Pre-cool CW/DX	Select	DX Cap (kW)	Moisture Rem (g/kg)	Fan (kW)	Fan Type	Sensible Efficiency	Latent Efficiency	Enthalpy Efficiency
1	ERV			☐		☐		☐			3	Draw Through	0.65	0.65	
2				☐		☐		☐							
3				☐		☐		☐							
4				☐		☐		☐							
5				☐		☐		☐							
6				☐		☐		☐							
7				☐		☐		☐							
8				☐		☐		☐							
9				☐		☐		☐							
10				☐		☐		☐							

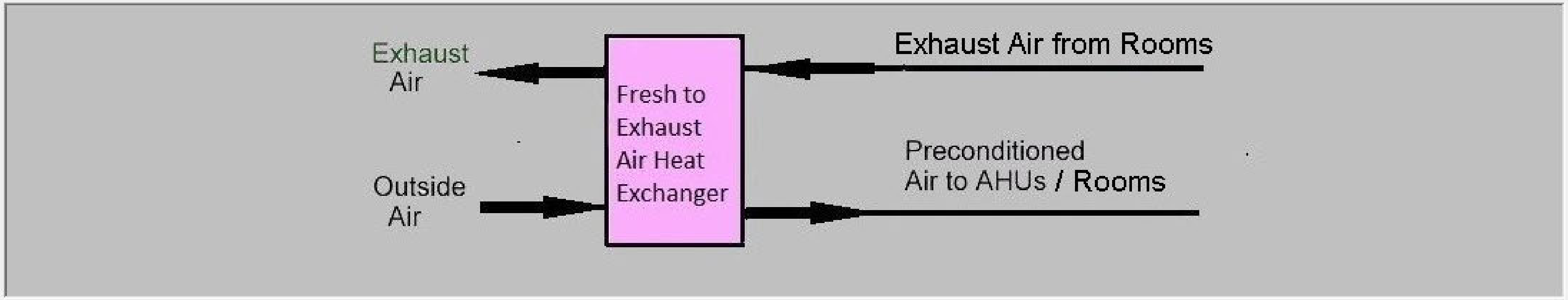


Figure C-2: Pre-conditioner Inputs

AHU Title	No off	System Type	With Reset	Indirect	Connect			Summer		Winter		Operation		Comp Formula	Outside Air			Heat Exch			Humidity Control Unit				Precond.
					Chill	Boil	Circ	°CDB	% RH	°CDB	% RH	First Hour	Last Hour		Units	Value	Direct to room	Temp Eff	Late Eff	Enth Eff	Pre-cool coil	Fan kW	Des DX Cool(kW)	Moisture Removal	
AHU1 - ERV		Single Zone Heating & Cooling						24	50	20	50				Enter in rooms										1 ERV
AHU1 - NO ERV		Single Zone Heating & Cooling						24	50	20	50				Enter in rooms										
AHU1 - NO ERV - Pr		Single Zone Heating & Cooling						24	70	20	50				Enter in rooms										

Figure C-3: AHU Input Parameters

AHU | AHU - Coil | | Zone & Rooms

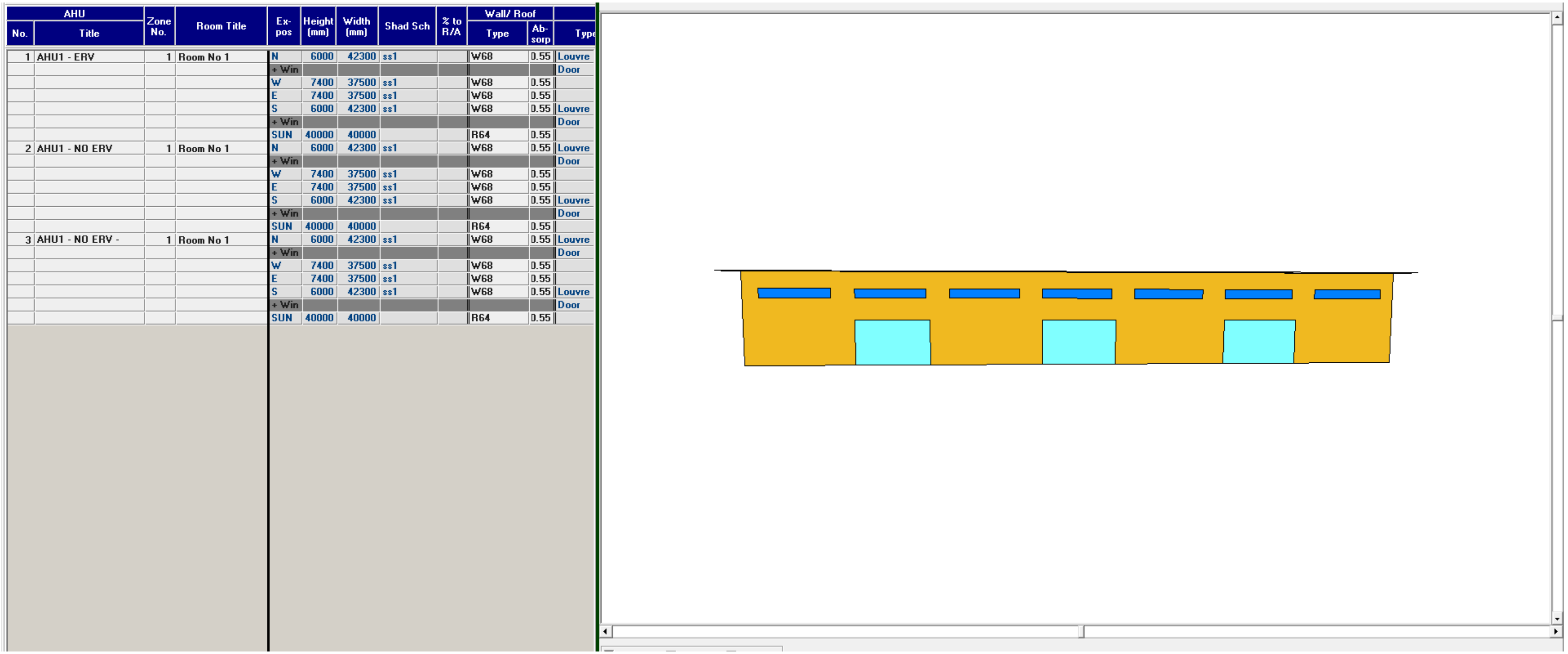
Air Handling Unit - Coil

AHU Title	Psychrometrics							Evap Eff%	Indirect Evap		Supply Fan			Return Fan		Ret. Duct Gains			Cool Safe %	Heat Safe %	Print Load Chart		
	Type	B.P. Fact.	Lvg DB	Lvg WB	l/s	ByPass Type	ADP °C		Type	Value	Type	Unit	Value	Unit	Value	Heat %	Leak %	kW			At time of	Hr	Mth
AHU1 - ERV	B.P.Factor	0.11					12				DT	%	5			3	2		5	5	Room Pk		
AHU1 - NO ERV	B.P.Factor	0.11					12				DT	%	5			3	2		5	5	Room Pk		

Figure C-4: AHU Coil Input Parameters

AHU		Zone				Room			Floor Area (m²)	Ceiling Height (mm)	St. Mass (kg/m²)		Infil AC/Hr	Vap gain (kW)	Outside Air		Extracted Air from Room		Minimum S/A		Supply Duct Gain			Connected to Return Air Room
No.	AHU Title	No.	No. off	Air Dis'n	T.Down %	Room Title	No. off	Thermostat (Blank= RA)			Enter	Calc			Units	Value	litres/sec	Spill to	Units	Value	% Heat Gain	% Leak Loss	Ext (kW)	
1	AHU1 - ERV	1		LOAD		Room No 1	1		1600	7400		291	1		l/s per person	7.5								
2	AHU1 - NO ERV	1		LOAD		Room No 1	1		1600	7400		291	1		l/s per person	7.5								
3	AHU1 - NO ERV -	1		LOAD		Room No 1	1		1600	7400		291	1		l/s per person	7.5								

Figure C-5: Room Input Parameters



AHU No.	AHU Title	Zone No.	Room Title	Ex-pos	Height (mm)	Width (mm)	Shad Sch	% to R/A	Wall/ Roof Type	Wall/ Roof Ab-sorp	Type
1	AHU1 - ERV	1	Room No 1	N	6000	42300	ss1		W68	0.55	Louvre
				+ Win							Door
				W	7400	37500	ss1		W68	0.55	
				E	7400	37500	ss1		W68	0.55	
				S	6000	42300	ss1		W68	0.55	Louvre
				+ Win							Door
				SUN	40000	40000			R64	0.55	
2	AHU1 - NO ERV	1	Room No 1	N	6000	42300	ss1		W68	0.55	Louvre
				+ Win							Door
				W	7400	37500	ss1		W68	0.55	
				E	7400	37500	ss1		W68	0.55	
				S	6000	42300	ss1		W68	0.55	Louvre
				+ Win							Door
				SUN	40000	40000			R64	0.55	
3	AHU1 - NO ERV -	1	Room No 1	N	6000	42300	ss1		W68	0.55	Louvre
				+ Win							Door
				W	7400	37500	ss1		W68	0.55	
				E	7400	37500	ss1		W68	0.55	
				S	6000	42300	ss1		W68	0.55	Louvre
				+ Win							Door
				SUN	40000	40000			R64	0.55	

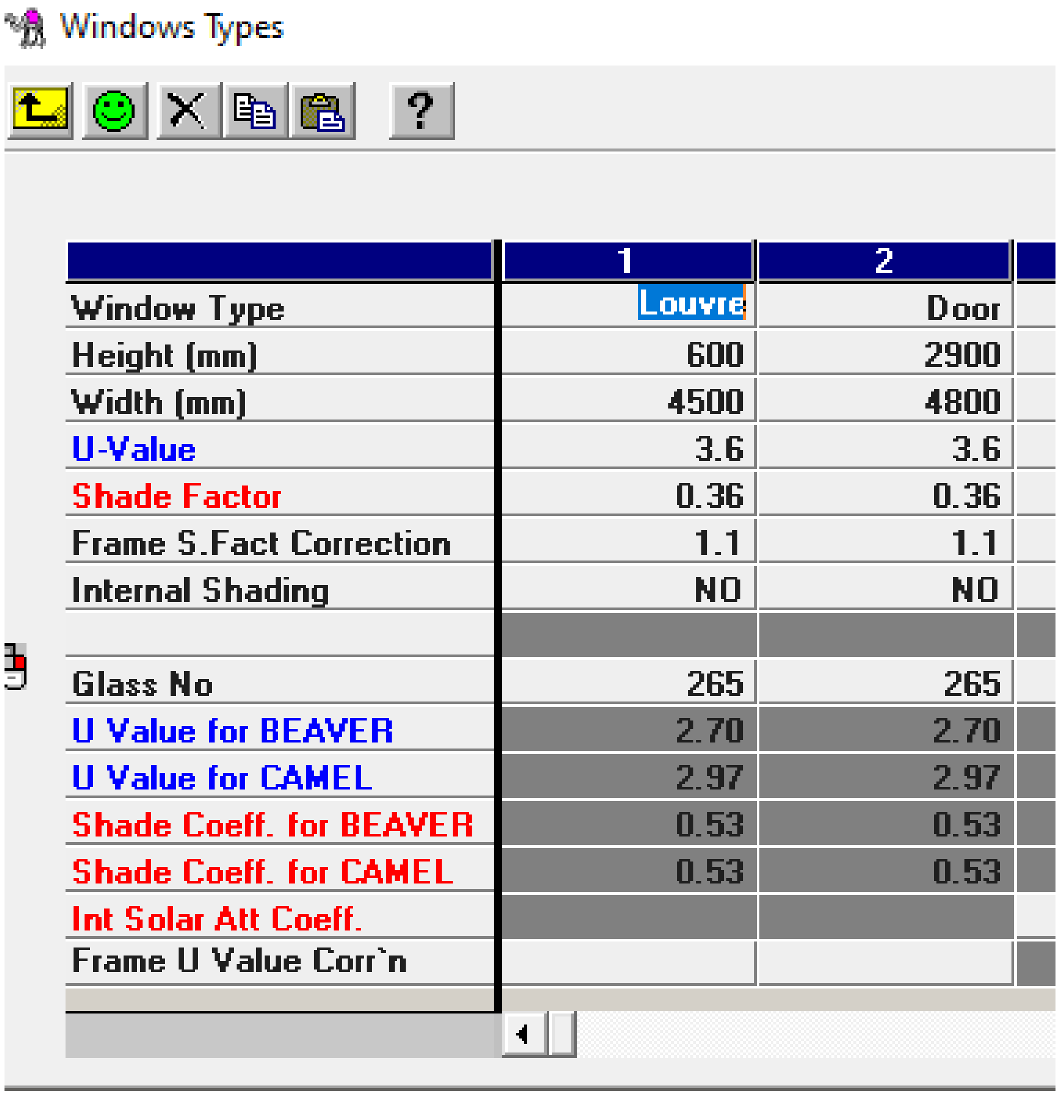
Figure C-6: External Wall Modelling

AHU No.	AHU Title	Zone No.	Room Title	Ex-pos	Height (mm)	Width (mm)	Shad Sch	% to R/A	Wall/ Roof Type	Wall/ Roof Ab-sorp	Windows / Skylight Type	No.	Dir	Shad Sch	Betwn (mm)	V-off (mm)	H-off (mm)
1	AHU1 - ERV	1	Room No 1	N	6000	42300	ss1		W68	0.55	Louvre	7	H		1500	4300	1000
				+ Win							Door	3	H		7200		6950
				W	7400	37500	ss1		W68	0.55							
				E	7400	37500	ss1		W68	0.55							
				S	6000	42300	ss1		W68	0.55	Louvre	7	H		1500	4300	1000
				+ Win							Door	3	H		7200		6950
				SUN	40000	40000			R64	0.55							
2	AHU1 - NO ERV	1	Room No 1	N	6000	42300	ss1		W68	0.55	Louvre	7	H		1500	4300	1000
				+ Win							Door	3	H		7200		6950
				W	7400	37500	ss1		W68	0.55							
				E	7400	37500	ss1		W68	0.55							
				S	6000	42300	ss1		W68	0.55	Louvre	7	H		1500	4300	1000
				+ Win							Door	3	H		7200		6950
				SUN	40000	40000			R64	0.55							
3	AHU1 - NO ERV -	1	Room No 1	N	6000	42300	ss1		W68	0.55	Louvre	7	H		1500	4300	1000
				+ Win							Door	3	H		7200		6950
				W	7400	37500	ss1		W68	0.55							
				E	7400	37500	ss1		W68	0.55							
				S	6000	42300	ss1		W68	0.55	Louvre	7	H		1500	4300	1000
				+ Win							Door	3	H		7200		6950
				SUN	40000	40000			R64	0.55							

Figure C-7: External Wall Modelling (Continued)

AHU No.	AHU Title	Zone No.	Room Title	People Units	People Load	People Sched. No.	People % RA	People % for Heating	Activity	Lights Units	Lights Load	Lights Sched. No.	Lights % RA	Lights % for Heating	Light Type	Sensible Units	Sensible Load	Sensible Sched. No.	Sensible % RA	Sensible % for Heating
1	AHU1 - ERV	1	Room No 1	N	1600				1	W/m²	15				FLE	W/m²	5			
2	AHU1 - NO ERV	1	Room No 1	No.	1600				1	W/m²	15				FLE	W/m²	5			
3	AHU1 - NO ERV -	1	Room No 1	No.	1600				1	W/m²	15				FLE	W/m²	5			

Figure C-8: Internal Building Loads


Windows Types

	1	2
Window Type	Louvre	Door
Height (mm)	600	2900
Width (mm)	4500	4800
U-Value	3.6	3.6
Shade Factor	0.36	0.36
Frame S.Fact Correction	1.1	1.1
Internal Shading	NO	NO
Glass No	265	265
U Value for BEAVER	2.70	2.70
U Value for CAMEL	2.97	2.97
Shade Coeff. for BEAVER	0.53	0.53
Shade Coeff. for CAMEL	0.53	0.53
Int Solar Att Coeff.		
Frame U Value Corr`n		

Figure C-9:Window Inputs

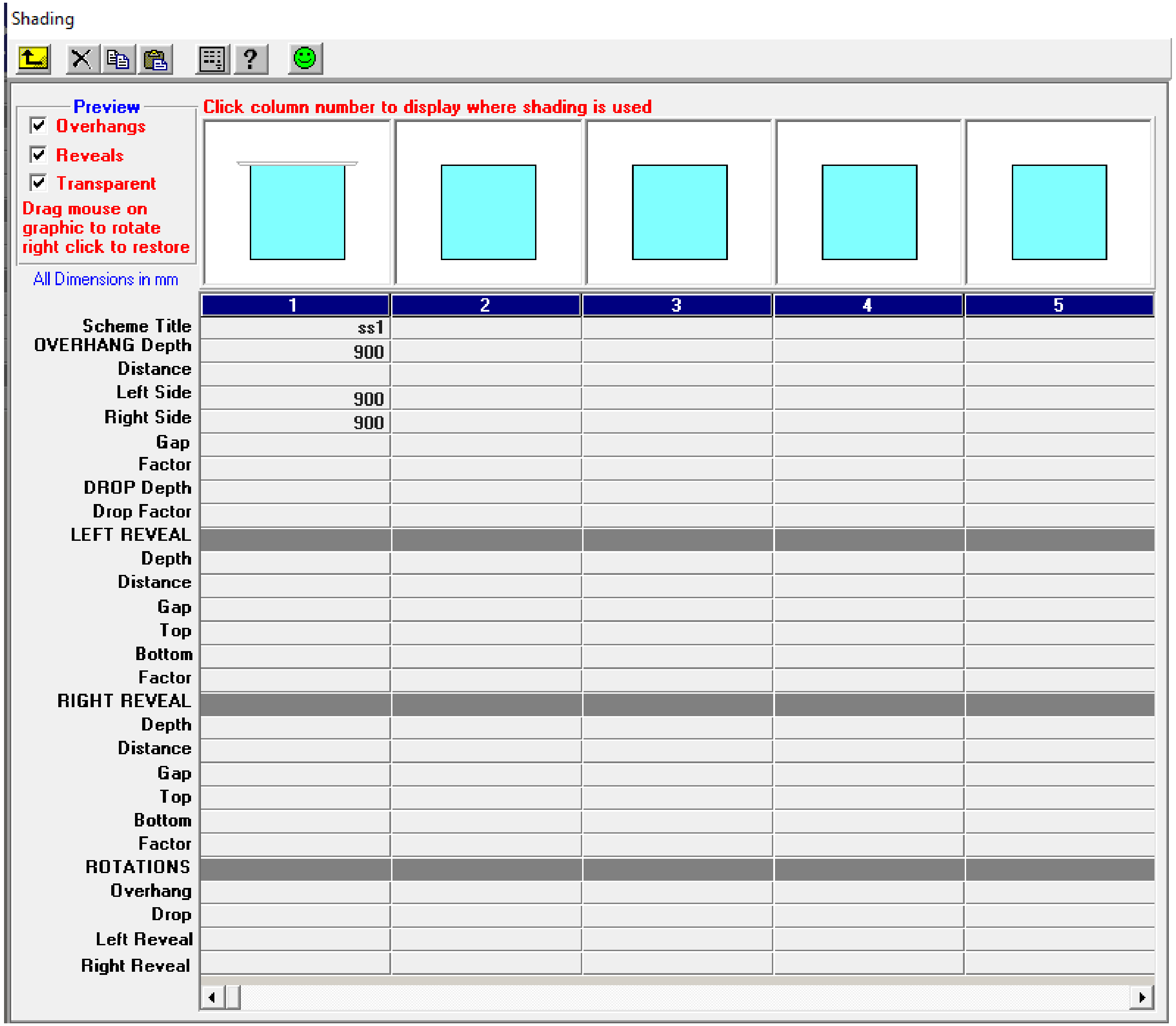


Figure C-10: Shading Schemes

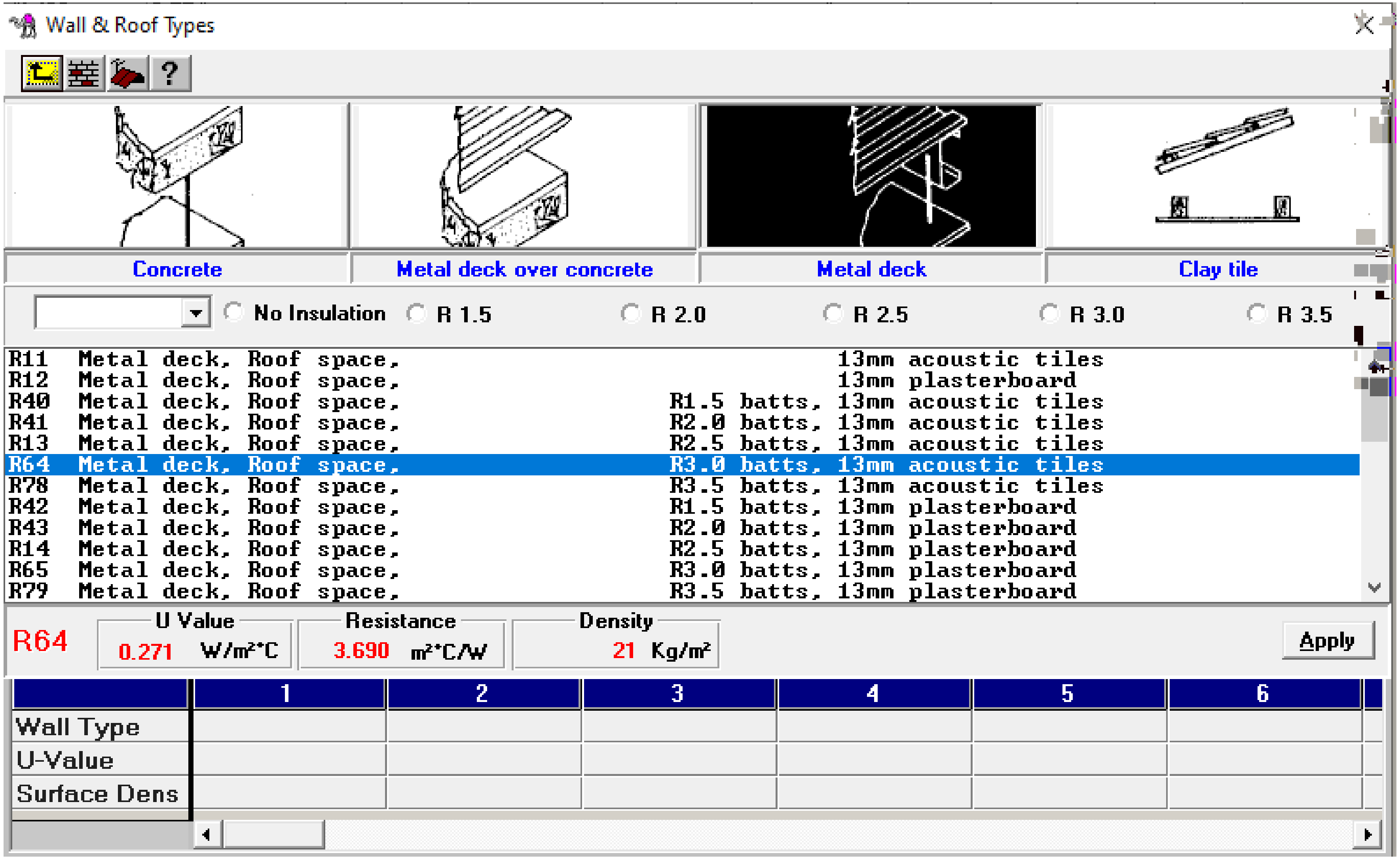


Figure C-11: Roof Types

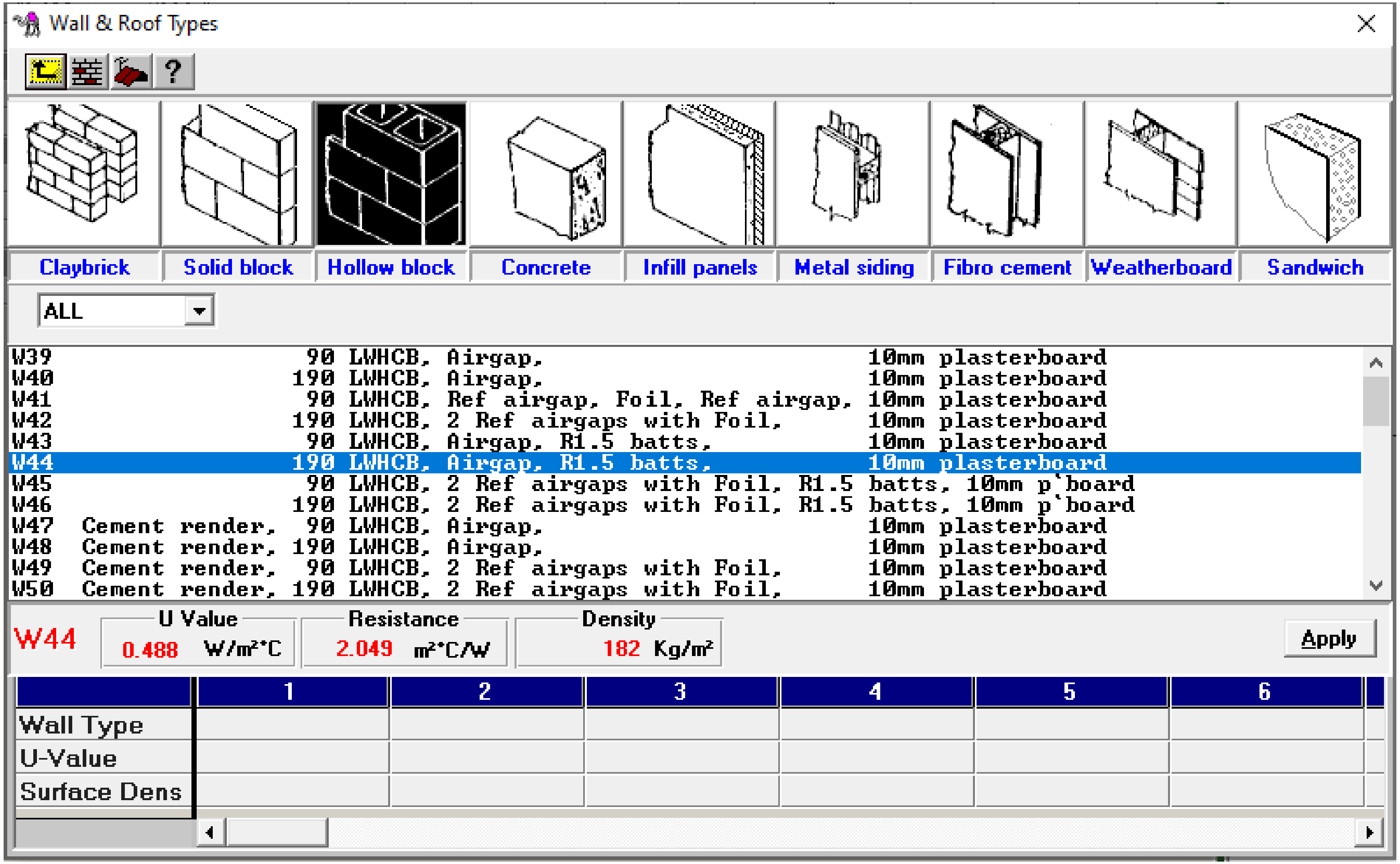


Figure C-12: Wall Types

D Appendix D

Glazing Calculator

Figure D-1: Glazing Calculation

NCC VOLUME ONE GLAZING CALCULATOR (first issued with NCC 2014)

Building name/description: **Multi-purpose hall**

Application: **other**

Climate zone: **1**

Storey: **Ground**

Facade areas

	N	NE	E	SE	S	SW	W	NW	internal
Option A	252m²				252m²				
Option B									n/a
Glazing area (A)	*60.1m²*				*60.1m²*				

Number of rows preferred in table below **20** *(as currently displayed)*

GLAZING ELEMENTS, ORIENTATION SECTOR, SIZE and PERFORMANCE CHARACTERISTICS									SHADING		CALCULATED OUTCOMES OK (if inputs are valid)					
Glazing element		Facing sector		Size			Performance		P&H or device		Shading		Multipliers		Size	Outcomes
ID	Description (optional)	Option A facades	Option B facades	Height (m)	Width (m)	Area (m²)	Total System U-Value (AFRC)	Total System SHGC (AFRC)	P (m)	H (m)	P/H	G (m)	Heating (S_H)	Cooling (S_C)	Area used (m²)	Element share of % of allowance used
1	W1	N		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.77	2.70	4% of 87%
2	W1	N		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.77	2.70	4% of 87%
3	W1	N		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.77	2.70	4% of 87%
4	W1	N		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.77	2.70	4% of 87%
5	W1	N		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.77	2.70	4% of 87%
6	W1	N		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.77	2.70	4% of 87%
7	W1	N		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.77	2.70	4% of 87%
8	W2	N		2.80	4.90		3.6	0.54				0.00	1.00	1.00	13.72	24% of 87%
9	W2	N		2.80	4.90		3.6	0.54				0.00	1.00	1.00	13.72	24% of 87%
10	W2	N		2.80	4.90		3.6	0.54				0.00	1.00	1.00	13.72	24% of 87%
11	W1	S		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.87	2.70	4% of 59%
12	W1	S		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.87	2.70	4% of 59%
13	W1	S		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.87	2.70	4% of 59%
14	W1	S		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.87	2.70	4% of 59%
15	W1	S		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.87	2.70	4% of 59%
16	W1	S		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.87	2.70	4% of 59%
17	W1	S		0.60	4.50		3.6	0.54	0.900	1.600	0.56	1.00	1.00	0.87	2.70	4% of 59%
18	W2	S		2.80	4.90		3.6	0.54				0.00	1.00	1.00	13.72	24% of 59%
19	W2	S		2.80	4.90		3.6	0.54				0.00	1.00	1.00	13.72	24% of 59%
20	W2	S		2.80	4.90		3.6	0.54				0.00	1.00	1.00	13.72	24% of 59%

if inputs are valid ✓

E Appendix E

Heat Load Calculation Output

ACADS BSG Program

CAMEL

Version Number 5.11.1

ACADS BSG advises that the program CAMEL is intended to be used only by persons who are proficient in its use and application and that these results should be verified independently. The results must not be used without acceptance of the ACADS-BSG's License Agreement for this program.

Multi-Purpose Hall - ERV

```
INPUT FILE NAME ~C:/USERS/GENE/GOOGLE DRIVE/USQ/ENG4111/HEATLOAD/SYSTEM 1 ERV/R
 .. 2\THESIS_SYSTEM 1-2_FINAL.DAT
OUTPUT FILE NAME ~C:/USERS/GENE/GOOGLE DRIVE/USQ/ENG4111/HEATLOAD/SYSTEM 1 ERV/
 .. R2\THESIS_SYSTEM 1-2_FINAL.OUT

CALCULATION BUILD NUMBER 5.11.1A

OUTDOOR DESIGN CONDITIONS ~ with ACADS WEATHER DATA FILE (May 2015) for
Location 32040   TOWNSVILLE AERO                        QLD
Latitude -19.3 DEG(SOUTH)  Daily Range  6.2  Building Rotation  0.0
Elevation     4.0 m (from file)

WINTER OUTDOOR DESIGN  12.9 CDB  80.0 RH

TOTAL FLOOR AREA IS   4800.0 m2
FLOOR AREA SERVED BY CHILLER IS      0.0 m2
FLOOR AREA SERVED BY PRE-CONDITIONER UNITS
  ERV                        1600.0 m2
```

AHU SUMMARY - COOLING

At Time of Peak Grand Total Heat (GTH)

TITLE	NO. OFF	S/A l/s	OUT/AIR l/s	OUT/AIR %	GTH kW	GTSH kW	COIL ENT CDB	COIL ENT CWB	COIL LVG CDB	COIL LVG CWB	PRECON NO.
AHU1 - ERV	1	17527	12000	68	532	288	27.1	21.6	13.5	13.1	1
AHU1 - NO ERV	1	18148	12000	66	772	369	30.7	24.6	13.9	13.6	
AHU1 - NO ERV - Prac	1	32000	12000	37	723	369	27.8	22.9	18.3	17.2	
PRE-CONDITIONERS WITH HEAT EXCHANGER ONLY											
ERV			12000	100							1

AHU SUMMARY COOLING SUPPLEMENTARY DATA

Note 1: at time of peak AHU adjusted sensible heat
2: increased air quantity or reduced leaving coil CDB are alternatives

Title	Time Peak GTH	Adj Sens kW	Time Peak Adj Sens	Adj Sens kW	REVISED GTH kW	REVISED AQ l/s	REVISED % var	REVISED Lvg CDB	REVISED Diff CDB
AHU1 - ERV	3pm Dec	Peak adj. sens. occurs at same time as peak GTH							
AHU1 - NO ERV	3pm Dec	Peak adj. sens. occurs at same time as peak GTH							
AHU1 - NO ERV - Prac	3pm Dec	Peak adj. sens. occurs at same time as peak GTH							

AHU SUMMARY - COOLING CHECK FIGURES and HEATING

TITLE	% O/A	FLOOR AREA	W/ m2	CH/ Hr	l/s/ m2	SHF	HEATING S/A	HEATING O/A	HEATING kW	FAN kW SUP	FAN kW RET
AHU1 - ERV	68	1600.0	332	5.3	11.0	.54	17527	12000	84.0	10.6	DT
AHU1 - NO ERV	66	1600.0	483	5.5	11.3	.48	18148	12000	155	10.6	DT

AHU1 - NO ERV - Prac	37	1600.0	452	9.7	20.0	.51	32000	12000	155	10.6 DT
Whole Building	**53**	**4800.0**	**422**	**6.9**	**14.1**	**(at building peak time: 3pm Dec)**				

COOLING OUTDOOR DESIGN TEMPERATURES (C)

(DB - DRY BULB WB - WET BULB MC - MOISTURE CONTENT g/kg)

		JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JLY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
7AM	DB	27.9	27.9	27.9	26.3	24.2	22.6	22.0	23.3	25.2	26.6	27.9	27.9
	WB	25.5	25.5	25.5	24.4	22.3	20.6	20.1	20.4	22.2	23.5	24.4	25.5
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
8AM	DB	27.9	27.9	27.9	26.3	24.2	22.6	22.0	23.3	25.2	26.6	27.9	27.9
	WB	25.5	25.5	25.5	24.4	22.3	20.6	20.1	20.4	22.2	23.5	24.4	25.5
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
9AM	DB	28.9	28.9	28.9	27.3	25.2	23.6	23.0	24.3	26.2	27.6	28.9	28.9
	WB	25.7	25.7	25.7	24.7	22.6	20.9	20.4	20.7	22.5	23.7	24.7	25.7
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
10AM	DB	29.2	29.2	29.2	27.6	25.5	23.9	23.3	24.6	26.5	27.9	29.2	29.2
	WB	25.8	25.8	25.8	24.7	22.6	21.0	20.4	20.7	22.5	23.8	24.7	25.8
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
11AM	DB	30.2	30.2	30.2	28.6	26.5	24.9	24.3	25.6	27.5	28.9	30.2	30.2
	WB	26.0	26.0	26.0	25.0	22.9	21.3	20.7	21.1	22.8	24.1	25.0	26.0
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
NOON	DB	30.4	30.4	30.4	28.8	26.7	25.1	24.5	25.8	27.7	29.1	30.4	30.4
	WB	26.1	26.1	26.1	25.0	23.0	21.3	20.8	21.1	22.9	24.1	25.0	26.1
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
1PM	DB	31.4	31.4	31.4	29.8	27.7	26.1	25.5	26.8	28.7	30.1	31.4	31.4
	WB	26.3	26.3	26.3	25.3	23.3	21.6	21.1	21.4	23.1	24.4	25.3	26.3
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
2PM	DB	32.4	32.4	32.4	30.8	28.7	27.1	26.5	27.8	29.7	31.1	32.4	32.4
	WB	26.6	26.6	26.6	25.6	23.5	21.9	21.4	21.7	23.4	24.6	25.6	26.6
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
3PM	DB	33.4	33.4	33.4	31.8	29.7	28.1	27.5	28.8	30.7	32.1	33.4	33.4
	WB	26.8	26.8	26.8	25.8	23.8	22.2	21.7	22.0	23.7	24.9	25.8	26.8
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
4PM	DB	32.4	32.4	32.4	30.8	28.7	27.1	26.5	27.8	29.7	31.1	32.4	32.4
	WB	26.6	26.6	26.6	25.6	23.5	21.9	21.4	21.7	23.4	24.6	25.6	26.6
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6
5PM	DB	32.2	32.2	32.2	30.6	28.5	26.9	26.3	27.6	29.5	30.9	32.2	32.2
	WB	26.5	26.5	26.5	25.5	23.5	21.8	21.3	21.6	23.4	24.6	25.5	26.5
	MC	19.6	19.6	19.6	18.5	16.1	14.4	13.9	13.8	15.6	16.9	17.9	19.6

AHU 2 AHU1 - NO ERV

Type ~ Single Zone H & C No. Off ~ 1
Temperature Control ~ Return Air

Connected to ~ Chiller No Boiler No
Floor Area ~ 1600 m2 Volume ~11840.0 m3 Average Ceiling Height ~ 7400. mm

AHU COOLING LOAD SUMMARY

DESIGN COOLING LOAD IS 772 kW AT 3PM DEC

DESIGN COOLING LOAD IS AT PEAK AHU GTH
AHU OPERATING HOURS 7AM TO 5PM. CALCS BASED ON 12 HOURS OPERATION FROM 6AM

			CDB	**CWB**	**g/kg**	**%RH**
GTSH	369 kW	AVERAGE ROOM AIR	24.0	19.3	12.03	64.4
GTLH	403 kW	AHU O/A	33.4	26.8	19.60	
AHU SH FACT	0.48					
SUPPLY AIR	18148 l/s	COIL DEW POINT	12.0 (N)		8.74	
AHU O/A	12000 l/s	COIL LEAVING AIR	13.9	13.6	9.57	
DEHUMID AIR	18148 l/s	COIL ENTERING AIR	30.7	24.6	17.03	
AIR ch/hr	5.5	RETURN AIR	25.4	19.7	12.03	
l/s/m2	11.3	AVERAGE ROOM ENT.	14.3	13.7	9.56	
l/s/kW	23.5	BYPASS FACTOR	0.10			
W/m2	483	MIX R/A AND O/A	30.7	24.6	17.03	

NOTE : (N) MEANS NOMINATED VALUE USED

AHU COOLING LOAD CHART AT MAXIMUM LOAD 3PM DEC

AHU OPERATING HOURS 7AM TO 5PM. CALCS BASED ON 12 HOURS OPERATION FROM 6AM

ACCUMULATED ZONE/ROOM ADJUSTED HEAT

S/F DRAW THRU 5.0% 211826 = 10591

```
    ADJUSTED ROOM SENSIBLE                                      = 211826
    ADJUSTED ROOM LATENT                                        = 133035
                                                                _______________
                                        ADJUSTED TOTAL HEAT =         355452
```

OTHER GAINS

```
    O/A SENSIBLE                12000 l/s    9.4 CDB  1.21 = 136424
    O/A LATENT                  12000 l/s   7.6 g/kg  2.97 = 269635
    RETURN DUCT HEAT GAIN AND LEAKAGE LOSS            5.0% =  10591
                                                                _______________
                                          TOTAL OTHER GAINS =         416650
                                                                       ________
                                  COOLING GRAND TOTAL HEAT =         772103
                          COOLING GRAND TOTAL SENSIBLE HEAT =         369432
                            COOLING GRAND TOTAL LATENT HEAT =         402670
```

AHU HEATING LOAD CHART & SUMMARY

SENSIBLE

```
FABRIC LOAD                                 =   38.7 kW
WARM UP (  8.8% = 10.00% x  0.92 x  0.96)   =   3.41 kW

OUTDOOR AIR   12000 l/s x  7.10 CDB x 1.21  =    103 kW
WARM UP (  9.6% = 10.00% x  0.96)           =   9.87 kW
TOTAL AHU HEATING LOAD (EXCL. HUMIDIFIER)   =    155 kW
```

LATENT

```
INFILTRATION   3289. l/s x-0.14 g/kg x 2.97 =  -1.32 KW
AHU O/A       12000. l/s x-0.14 g/kg x 2.97 =  -4.83 KW
                                               _______
                         HUMIDIFIER LOAD =    0.00 KW (0 g/min water)

SUPPLY AIR    18148 l/s         ROOM AIR           20.0 CDB 50.0%RH  13.8 CWB
AHU O/A       12000 l/s         OUTDOOR AIR        12.9 CDB 80.0%RH
W/m2             97             RETURN AIR         20.0 CDB
W/m3           13.1             COIL LEAVING AIR   22.4 CDB
                                COIL ENTERING AIR  15.3 CDB
```

AHU 3 AHU1 - NO ERV - Prac

```
Type ~ Single Zone H & C                                   No. Off ~  1
Temperature Control ~ Return Air

Connected to ~ Chiller No   Boiler  No
Floor Area ~  1600 m2   Volume ~11840.0 m3   Average Ceiling Height ~ 7400. mm
```

AHU COOLING LOAD SUMMARY

DESIGN COOLING LOAD IS 723 kW AT 3PM DEC

```
DESIGN COOLING LOAD IS AT PEAK AHU GTH
AHU OPERATING HOURS  7AM TO  5PM. CALCS BASED ON 12 HOURS OPERATION FROM 6AM
                                                   CDB      CWB      g/kg  %RH
GTSH            369 kW          AVERAGE ROOM AIR   24.0     20.1     13.09 70.0
GTLH            354 kW          AHU O/A            33.4     26.8     19.60
AHU SH FACT    0.51
SUPPLY AIR    32000 l/s (N)     COIL DEW POINT     14.6              10.38
AHU O/A       12000 l/s         COIL LEAVING AIR   18.3     17.2     11.81
DEHUMID AIR   32000 l/s         COIL ENTERING AIR  27.8     22.9     15.53
AIR ch/hr       9.7             RETURN AIR         24.4     20.2     13.09
l/s/m2         20.0             AVERAGE ROOM ENT.  18.5     17.3     11.81
l/s/kW         44.2             BYPASS FACTOR      0.28
W/m2            452             MIX R/A AND O/A    27.8     22.9     15.53
```

NOTE : (N) MEANS NOMINATED VALUE USED

AHU COOLING LOAD CHART AT MAXIMUM LOAD 3PM DEC

AHU OPERATING HOURS 7AM TO 5PM. CALCS BASED ON 12 HOURS OPERATION FROM 6AM

ACCUMULATED ZONE/ROOM ADJUSTED HEAT

```
    S/F DRAW THRU                             5.0% 211826 =  10591
    ADJUSTED ROOM SENSIBLE                                = 211826
    ADJUSTED ROOM LATENT                                  = 122101
                                                           _______________
                                        ADJUSTED TOTAL HEAT =         344518
```

OTHER GAINS

O/A SENSIBLE 12000 l/s 9.4 CDB 1.21 = 136424
O/A LATENT 12000 l/s 6.5 g/kg 2.97 = 231639
RETURN DUCT HEAT GAIN AND LEAKAGE LOSS 5.0% = 10591

TOTAL OTHER GAINS = 378655

COOLING GRAND TOTAL HEAT = 723173
COOLING GRAND TOTAL SENSIBLE HEAT = 369432
COOLING GRAND TOTAL LATENT HEAT = 353740

AHU HEATING LOAD CHART & SUMMARY

SENSIBLE

FABRIC LOAD = 38.7 kW
WARM UP (8.8% = 10.00% x 0.92 x 0.96) = 3.41 kW

OUTDOOR AIR 12000 l/s x 7.10 CDB x 1.21 = 103 kW
WARM UP (9.6% = 10.00% x 0.96) = 9.87 kW
TOTAL AHU HEATING LOAD (EXCL. HUMIDIFIER) = 155 kW

LATENT

INFILTRATION 3289. l/s x-0.14 g/kg x 2.97 = -1.32 KW
AHU O/A 12000. l/s x-0.14 g/kg x 2.97 = -4.83 KW

HUMIDIFIER LOAD = 0.00 KW (0 g/min water)

SUPPLY AIR	32000 l/s	ROOM AIR	20.0 CDB 50.0%RH 13.8 CWB
AHU O/A	12000 l/s	OUTDOOR AIR	12.9 CDB 80.0%RH
W/m2	97	RETURN AIR	20.0 CDB
W/m3	13.1	COIL LEAVING AIR	21.3 CDB
		COIL ENTERING AIR	17.3 CDB

OUTSIDE AIR SUMMARY

AHU NO	ZONE NO	TITLE	FLOOR AREA m2	NO. OF PERS.	OUTDOOR AIR ENTERED UNIT	VALUE	l/s	TOTAL %	S/A l/s	OUTDOOR AIR AHU %	AHU l/s	DIRECT l/s
2		**AHU1 - NO ERV**	**1600**	**1600.0**				**66**	**18148**	**66**	**12000**	
	1	Room No 1	1600	1600.0	LP	7.5	12000	66	18148	66	12000	
3		**AHU1 - NO ERV - Prac**	**1600**	**1600.0**				**37**	**32000**	**37**	**12000**	
	1	Room No 1	1600	1600.0	LP	7.5	12000	37	32000	37	12000	

Legend: LP(l/s/person), LM(l/m2), AC(A.C./hr) & LS(l/s)

ZONES AND ROOMS COOLING RESULTS

(excluding Outside Air and Return Duct Gains)

AHU NO	ZON NO	TITLE	NO. OFF #	ADJUSTED SENS kW	ADJUSTED LAT kW	S/A l/s	VAV TURN DWN%	AHU O/A l/s	RE-HEAT kW	ROOM COND DB MIN	DB MAX	% RH
1		**AHU1 - ERV**	**1**	**222**	**135**	**17527**		**12000**		**24.0**		**63**
2		**AHU1 - NO ERV**	**1**	**222**	**133**	**18148**		**12000**		**24.0**		**64**
3		**AHU1 - NO ERV - Prac**	**1**	**222**	**122**	**32000**		**12000**		**24.0**		**70**

Note 1~ The room S/A is proportion of the zone air quantity at zone peak
Note 2~ The ROOM MIN/MAX is a rough estimate of the room temperature variation.
Note 3~ The ROOM maximum sensible heat may be greater than the AHU sensible heat.

ZONES AND ROOMS COOLING CHECK FIGURES

(uses adjusted sensible for l/s/kW and W/m2)

AHU NO	ZONE NO	TITLE	FLOOR AREA	VOL m3	CH/hr	MIN CH/hr	l/s/ m2	l/s/ kW	TIME OF PEAK	W/m2	AQ MUL

1	**AHU1 - ERV**	**1600**	**11840**	**5.3**		**11.0**	**78.8**	**3PM DEC**	**139**	**1.00**
2	**AHU1 - NO ERV**	**1600**	**11840**	**5.5**		**11.3**	**81.6**	**3PM DEC**	**139**	**1.00**
3	**AHU1 - NO ERV - Prac**	**1600**	**11840**	**9.7**		**20.0**	**143.9**	**3PM DEC**	**139**	**1.00**

Note 1~ Values are at peak times except room CH/Hr and l/s/m2 is at zone peak.
Note 2~ The zone air quantities are distributed to the rooms in the ratio of the room floor areas or in the ratio of the room peak sensible loads.
Note 3~ Air change rates with an asterisk have reached either the user entered minimum (airchange, l/s/m2 or l/s) or outdoor air, whichever is the greater.
Note 4~ AQ MUL greater than unity indicates that the design air quantities have been increased to satisfy room minimums. The room with the largest AQ MUL has the most effect.

ZONES AND ROOMS COMBINED RESULTS

					<---COOLING									--->			
			FLOOR	**No**					**SUPPLY AIR**		**<---OUTSIDE AIR--->**				**Lvg**		
AHU	**ZON**	**ROOM**	**AREA**	**of**	**GTH**		**ADJ**	**SENS**		**per**		**per**	**per**	**%of**	**Coil**	**HEATING**	
NO	**NO**	**No**	**M2**	**PEOP**	**kW**	**W/m2**	**kW**	**W/m2**	**l/s**	**m2**	**l/s**	**m2**	**PERS**	**S.A**	**CDB**	**kW**	**W/m2**
1		**AHU1 - ERV**															
			1600	1600	532	332	222	139	17527	11.0	12000	7.50	7.5	68	13.5	84.0	52
2		**AHU1 - NO ERV**															
			1600	1600	772	483	222	139	18148	11.3	12000	7.50	7.5	66	13.9	155	97
3		**AHU1 - NO ERV - Prac**															
			1600	1600	723	452	222	139	32000	20.0	12000	7.50	7.5	37	18.3	155	97

AHU 1 AHU1 - ERV, Zone 1, Rm 1 Room No 1

ROOM COOLING LOAD CHART AT 3PM DEC

(SUN POSITION ~ ALTITUDE = 47.8 AZIMUTH =256.0)
AHU OPERATING HOURS 7AM TO 5PM. CALCS BASED ON 12 HOURS OPERATION FROM 6AM

SOLAR GAIN GLASS (291 kg/m2. Modified storage load factors used)

No	**SUN**	**EXPOSE**	**AREA**	**GAIN**	**FRAME S.FAC**	**DEW**	**STOR**	**SHADE**	**ROOM**	**WATTS**
#1	OFF	0.0	18.90	47	1.10	0.94	1.90	0.36	100% =	630
#1 +W1	OFF	0.0	41.76	47	1.10	0.94	1.90	0.36	100% =	1391
#4	SHADE	180.0	18.90	142	1.10	0.94	.629	0.36	100% =	630
#4 +W1	ON	180.0	27.00	142	1.10	0.94	.629	0.36	100% =	899
#4 +W1	SHADE	180.0	14.76	142	1.10	0.94	.629	0.36	100% =	492

SOLAR AND TRANSMISSION GAINS WALLS AND ROOFS (Using light wt roof data)

No	**SUN**	**EXPOSE**	**S.DENS**	**ABS**	**AREA**	**T-DIFF**	**UVALUE**	**ROOM**	
#1	OFF	0.0	(219	0.55)	193.14	9.8	0.33	100% =	614
#2	ON	270.0	(219	0.55)	239.26	14.1	0.33	100% =	1097
#2	SHADE	270.0	(219	0.55)	38.24	10.4	0.33	100% =	130
#3	OFF	90.0	(219	0.55)	277.50	9.8	0.33	100% =	889
#4	ON	180.0	(219	0.55)	56.56	10.2	0.33	100% =	189
#4	SHADE	180.0	(219	0.55)	136.58	9.6	0.33	100% =	428
#5		SUN	(21	0.55)	1600.00	32.7	0.27	100% =	14186

TRANSMISSION GAIN EXCEPT WALLS AND ROOFS

No	**ITEM**	**AREA**	**T-DIFF**	**UVALUE**	**ROOM**	
#1	GLASS	18.90	9.4	3.60	100% =	640
#1 +W1	GLASS	41.76	9.4	3.60	100% =	1413
#4	GLASS	18.90	9.4	3.60	100% =	640
#4 +W1	GLASS	41.76	9.4	3.60	100% =	1413
	INFILTRATION	3289.	9.4	1.21	=	37390

INTERNAL HEAT GAIN

PEOPLE (ACTIV = 1)		1600.0	67.	100% =	107200
LIGHTS (FLE 291 kg/m2)	1600.0	15.00	0.98	100% =	23470
APPLIANCES		8.0	1000.	100% =	8000

```
                                      SAFETY FACTOR   5.0% =  10087
                                                            _________________
                                        ROOM SENSIBLE HEAT = 211826

                                                               ________________
   ADJUSTED ROOM SENSIBLE HEAT (EXCL. FAN DRAW THRU HEAT) =           211826
```

LATENT HEAT GAIN

```
   INFILTRATION                            3289    7.8  2.97 =  75693
   PEOPLE (ACTIV = 1)                    1600.0    33.  100% =  52800
                                      SAFETY FACTOR   5.0% =   6425
                                                               ________________
                                         ROOM LATENT HEAT = 134918

                                                               ________________
                               ADJUSTED ROOM LATENT HEAT =            134918
```

F Appendix F

Equipment Specifications and manufacturers literature.

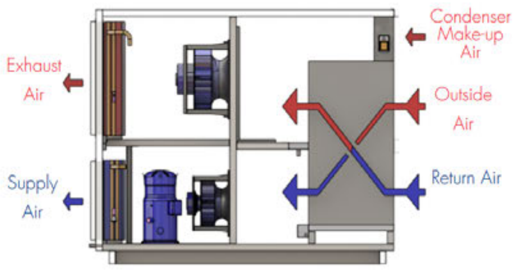
ERV – System 1

AIR CHANGE

ROOFTOP PACKAGED UNITS

ACL125RCRTP

Technical Data



Contact your Air Change representative for a psychrometric unit selection

Airflow

Supply Air	5000l/s (nominal)
Return Air	5000l/s (nominal)
Outside Air	100%
Condenser Make-up Air	3000/s
Exhaust Air (RA + CMA)	8000l/s (nominal)

Refrigeration

Reverse Cycle	Yes
Cooling Capacity	125kWr (nominal)
Heating Capacity	156kWr (nominal)
Compressor Type	Dual Stage DOL (standard)
	BLDC Inverter (optional)
Refrigerant	R-407C (Single Stage DOL)
	R-410A (BLDC Inverter option)

Air-to-Air Heat Exchanger*

HEX Type	Air-to-Air Counterflow Plate
HEX Media	Enthalpy or Sensible-Only

Fans (Nominal Selection)

Supply

Type	EC Plug
Total Fans	2x
Nominal Power	3.4kW (each)
Fan Diameter	560mm
Fan Speed (max.)	1550RPM
Motor Efficiency Class	IE4
Ingress Protection Class	IP54
Impeller Construction	Non-metallic Composite
Speed Control	Integrated Constant Volume Control
	or via External Speed Signal

* The plate heat exchangers are designed to operate to a maximum 300Pa pressure differential (inlet condition) between primary and secondary air streams.

Fans (Nominal Selection)

Exhaust Air

Type	EC Plug
Total Fans	3x
Nominal Power	3.4kW (each)
Fan Diameter	560mm
Fan Speed (max.)	1550RPM
Motor Efficiency Class	IE4
Ingress Protection Class	IP54
Impeller Construction	Non-metallic Composite
Speed Control	Integrated Constant Volume Control
	or via External Speed Signal

Electrical & Controls

Electrical Input	415V / 3ph / 50Hz
Full Load Amps	Refer to electrical page
Controls	Low Level Interface (standard)
	ClimaSync Control System (optional)

Cabinet

Weatherproof	Yes
Panel Construction	50mm PIR Sandwich Panel
	(FM Approved 4880/4881 - Class 1)
Panel Finish	Colorbond "Surfmist"
Panel R-Value	2.63K.m²/W
Panel Joiner Material	UV Resistant Polymer
Base Frame	Galvanised Steel with Lifting Lugs
Filter Section	Not included
	(filters to be mounted in RA & OA ductwork)

Operating Modes

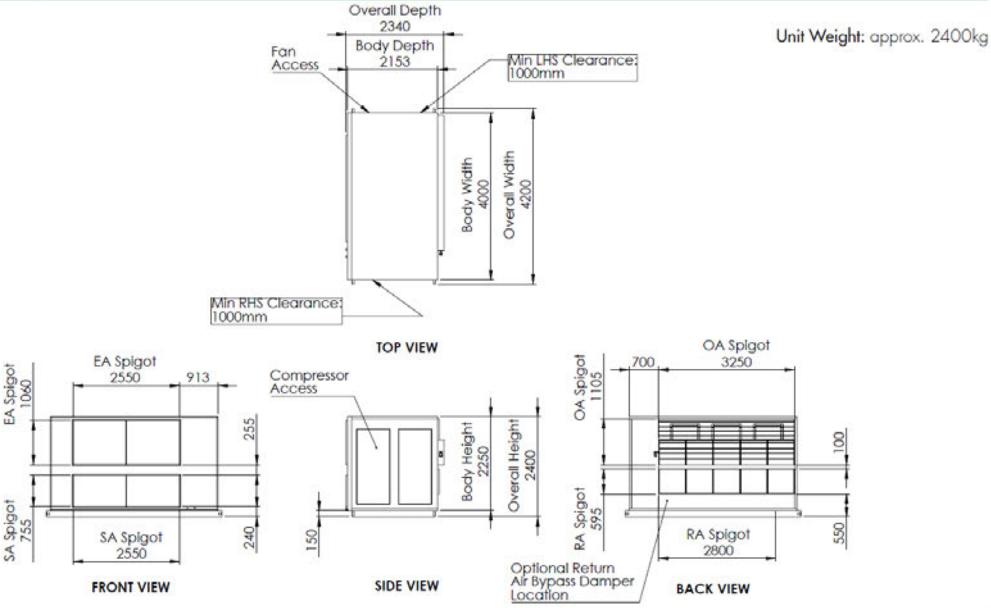
Energy Recovery	Default
Economy Cycle	HEX Bypass for Free Cooling (optional)
Return Air Bypass	HEX Bypass for Recirculation (optional)

ACL125RCRTPTECHAU01.01

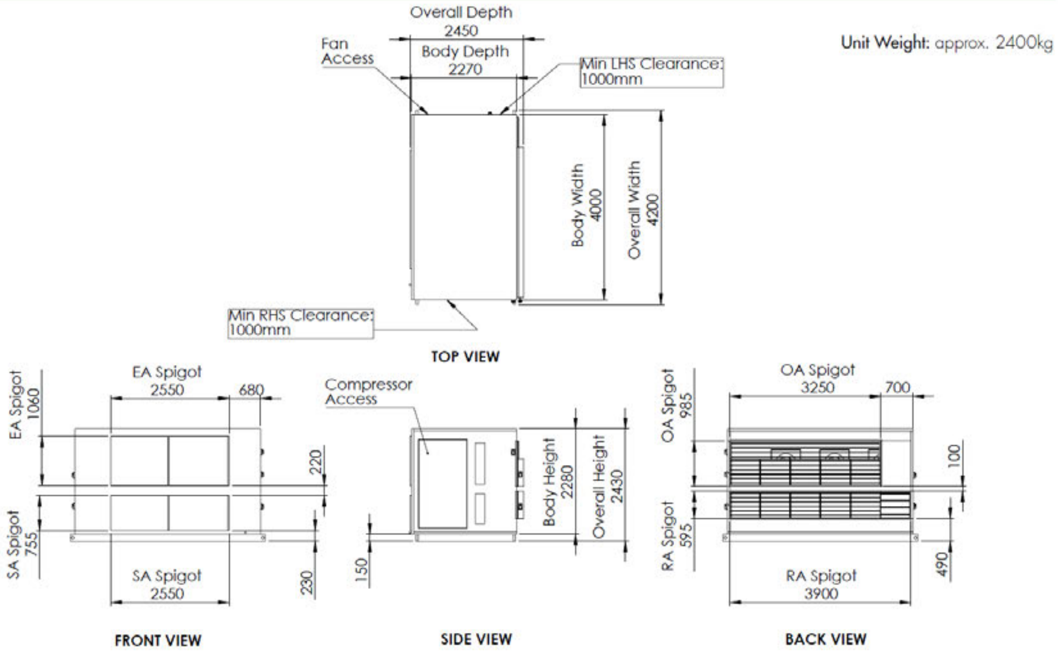
ACL125RCRTP

Dimensions

Standard Configuration*



Economy Cycle Configuration*

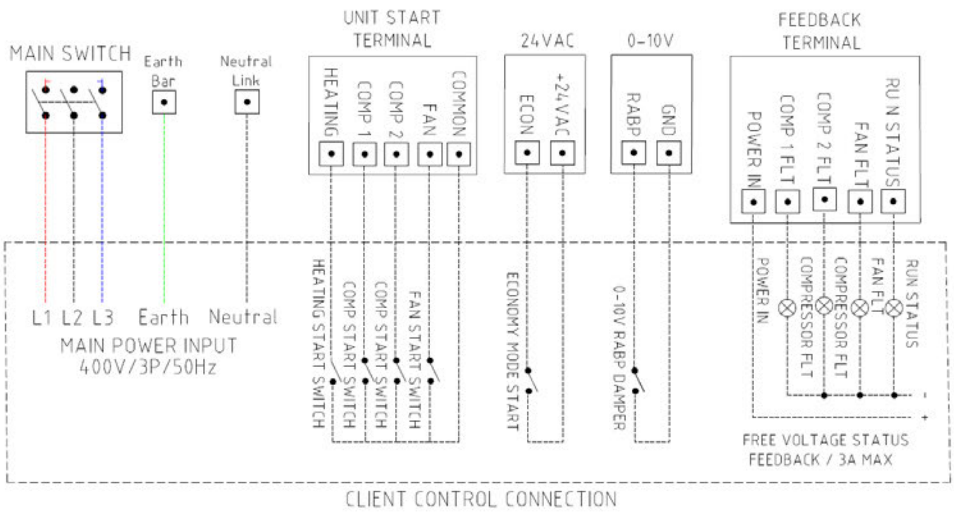


* Dimensions and weight are subject to change, depending on project requirements (incl. compressor option). Refer to project certified drawings for finalised details.

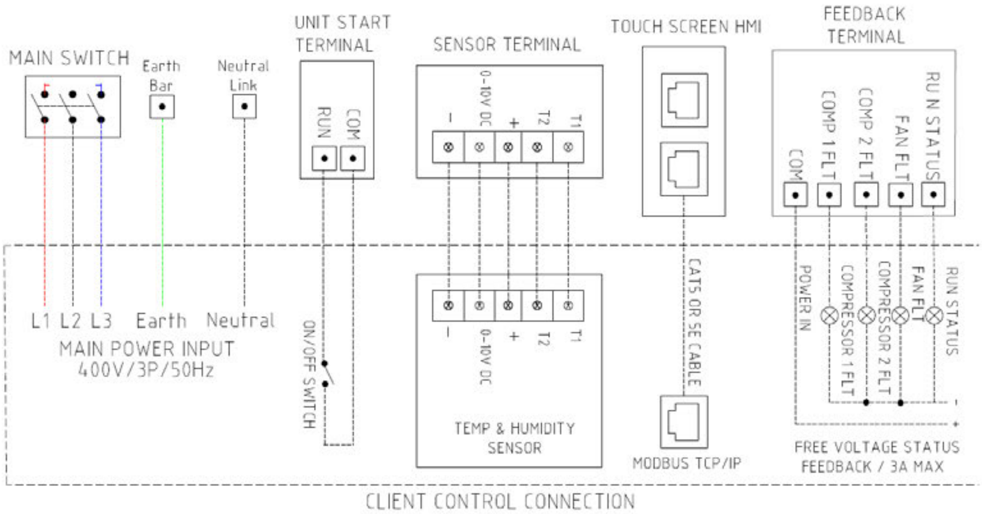
ACL125RCRTP

Electrical

Wiring Diagram (Standard Low Level Control Interface)*



Wiring Diagram (Optional ClimaSync Control System)*



Electrical Input

Indicative Electrical Input details†

	DOL Compressor (standard)	BLDC Inverter Compressor (optional)
Voltage / Phases / Frequency	415V / 3ph / 50Hz	415V / 3ph / 50Hz
Full Load Amps	97A	114A

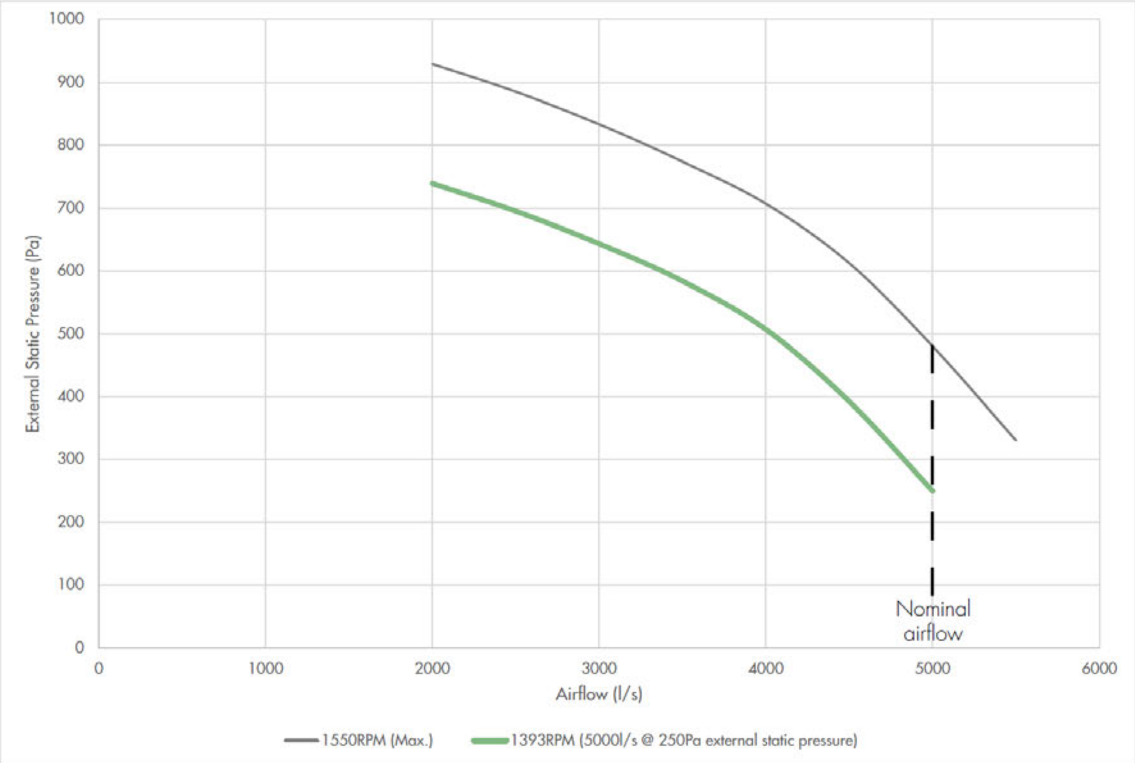
* Connection details are subject to change, depending on project requirements. Refer to project certified electrical diagrams for finalised details.

† Unit FLA is subject to change, depending on project requirements. Refer to project certified electrical diagrams for finalised details.

ACL125RCRTP

Airflow & Noise

Supply Air Fan Curve*



* Fan curve makes allowance for internal pressure drop of unit. This pressure drop is subject to change, depending on project requirements. Supply air fan selection options are available.

Supply Air Fan Acoustics (Sound Power)†

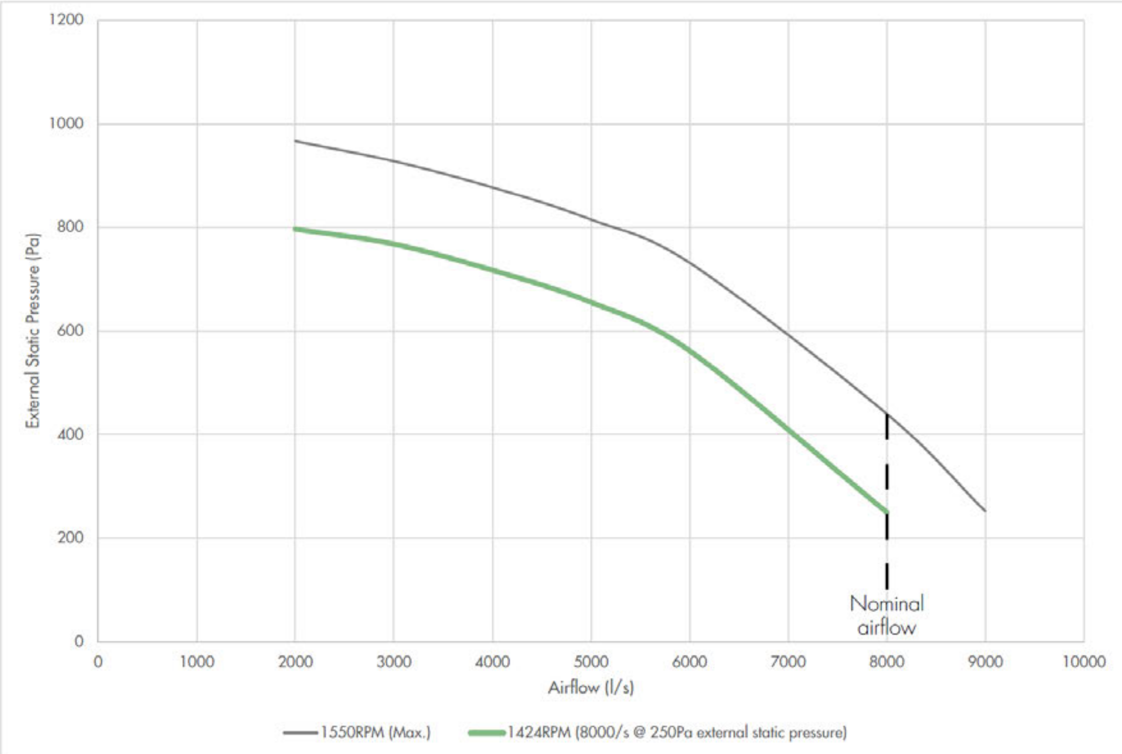
5000l/s @ 250Pa External Static Pressure									
Inlet									
Frequency (Hz)	sum	63	125	250	500	1000	2000	4000	8000
A-weighted (dB)	80	44	70	72	71	73	73	70	63
Non A-weighted (dB)	86	69	84	80	74	73	71	69	64
Outlet									
Frequency (Hz)	sum	63	125	250	500	1000	2000	4000	8000
A-weighted (dB)	85	48	74	75	79	79	77	74	68
Non A-weighted (dB)	90	74	88	83	81	79	76	73	69

† Noise data considers supply air fans only, without attenuation by the cabinet. Filter drop to be factored into the 250Pa external static pressure allowance.

ACL125RCRTP

Airflow & Noise

Exhaust Air Fan Curve (incl. Condenser Make-up Air)*



* Fan curve makes allowance for internal pressure drop of unit. This pressure drop is subject to change, depending on project requirements. Exhaust air fan selection options are available.

Exhaust Air Fan Acoustics (Sound Power)†

8000l/s @ 250Pa External Static Pressure									
Inlet									
Frequency (Hz)	sum	63	125	250	500	1000	2000	4000	8000
A-weighted (dB)	83	47	73	75	75	76	75	73	67
Non A-weighted (dB)	89	72	87	83	78	76	74	72	68
Outlet									
Frequency (Hz)	sum	63	125	250	500	1000	2000	4000	8000
A-weighted (dB)	88	51	77	78	82	82	80	77	72
Non A-weighted (dB)	93	76	90	86	85	82	78	76	73

† Noise data considers exhaust air fans only, without attenuation by the cabinet. Filter drop to be factored into the 250Pa external static pressure allowance.

No ERV – System 2

R410A Refrigerant

DUNNAIR
(Aust) Pty Ltd

PH200

Rooftop Packaged

PERFORMANCE DATA

INDOOR COIL ENTERING AIR TEMP °c		OUTDOOR COIL ENTERING TEMPERATURE °C											
		30°C			35°C			40°C			45°C		
DB °C	WB °C	Tot. Cap KW	Sens.Cap KW	LWB °C	Tot. Cap KW	Sens.Cap KW	LWB °C	Tot. Cap KW	Sens.Cap KW	LWB °C	Tot. Cap KW	Sens.Cap KW	LWB °C
21	17	205.1	110.1	12.5	187.8	117.7	12.1	177.0	113.0	12.6	169.5	113.0	12.8
	18	205.1	110.1	12.5	194.5	105.6	13.3	183.1	100.6	13.6	175.9	97.5	14.0
	19	212.2	97.6	14.3	201.2	93.1	14.6	189.4	88.1	15.1	182.5	85.3	15.3
	20	220.1	84.5	15.3	208.6	79.8	15.7	196.1	74.9	16.1	189.3	71.8	16.5
23	17	198.8	145.8	11.7	188.6	141.6	12.1	177.8	136.9	12.5	170.2	133.8	12.8
	18	205.1	133.7	12.9	194.5	129.1	13.2	183.1	124.2	13.6	175.9	121.1	14.0
	19	212.2	121.2	14.1	201.4	116.7	14.5	189.5	112.0	15.0	182.5	108.9	15.3
	20	220.3	108.1	15.3	208.6	103.4	15.7	196.2	98.5	16.1	189.5	95.4	16.4
	21	228.2	95.1	16.4	216.4	190.4	16.8	203.9	85.1	17.2	196.6	82.0	17.6
25	17	200.8	167.7	11.6	190.5	163.0	11.9	179.8	157.9	12.5	172.8	154.7	12.7
	18	205.6	162.1	13.0	195.0	153.8	13.3	183.7	148.8	13.8	176.5	145.7	14.1
	19	212.3	154.4	14.1	201.4	140.2	14.5	189.5	135.5	15.0	182.8	132.5	15.2
	20	220.3	145.5	15.3	208.9	127.2	15.7	196.5	121.9	16.1	189.5	119.2	16.4
	21	228.3	135.8	16.4	216.4	105.9	16.8	203.9	108.6	17.2	196.6	105.9	17.4
27	17	203.9	185.9	11.5	194.7	180.4	11.8	184.2	174.0	12.2	177.5	170.1	12.6
	18	208.0	181.8	12.8	196.9	177.4	13.1	185.6	172.4	13.5	180.3	169.3	13.8
	19	214.4	168.7	13.9	201.8	164.3	14.3	190.0	159.3	14.7	183.1	156.3	15.0
	20	220.5	156.8	15.2	208.9	152.1	15.5	196.5	147.3	15.9	189.5	144.4	16.1
	21	228.4	142.1	16.4	210.6	137.4	16.8	203.9	132.2	17.2	196.7	129.4	17.4
29	17	209.5	192.2	11.4	200.0	194.8	11.8	189.5	187.1	12.2	181.8	183.0	12.5
	18	211.4	188.9	12.7	201.1	191.8	13.1	190.0	185.9	13.5	183.1	177.4	13.8
	19	214.4	185.6	14.0	203.6	189.5	14.3	191.7	184.6	14.7	183.8	174.1	15.1
	20	220.5	179.9	15.2	209.1	175.1	15.5	196.7	169.6	16.0	189.8	167.1	16.3
	21	228.4	165.7	16.4	216.6	160.9	16.8	203.9	155.8	17.2	196.7	152.9	17.4
31	17	216.1	214.8	11.0	207.0	206.6	11.4	195.9	197.1	11.8	189.8	191.4	12.0
	18	217.2	212.3	12.5	207.2	205.6	12.8	196.7	196.5	13.2	190.8	190.7	13.5
	19	218.3	210.0	13.8	208.0	204.8	14.2	196.7	195.5	14.6	190.8	190.1	14.8
	20	221.9	204.5	15.1	210.8	200.1	15.5	198.3	193.0	15.9	191.4	189.6	16.3
	21	228.9	191.0	16.4	216.9	186.2	16.8	203.9	188.9	17.2	196.9	178.2	17.6

Capacity multipliers should be applied to the above capacities to adjust for reduced or increased air flow

Technical Specification PH200 Rooftop Packaged Model

Total Cooling Capacity (kW)*	201.8	Number of Compressors	2
Sensible Cooling Capacity (kW)*	164.3	Power Requirements (Volt /Phase)	415 / 3
Heating Capacity (kW)**	196.2	Normal Max. Current (Amps /Phase)	163.7
Nominal Evaporator Air Flow (L/S)	10500	Power Input (kW)	78.8
*Entering air @ 27/19 °C and ambient 35°C		** Entering air @ 21 °C DB and 7°C ambient	

Cooling Performance Correction

Capacity	% Rated Air Quantity - Nominal 10500 l/s				
	80	90	100	110	120
Total Cooling	0.95	0.98	1.00	1.02	1.04
Sensible Cooling	0.89	0.95	1.00	1.05	1.09

Heating Performance Data

	Outdoor Coil Entering DB temperature °C				
	0	4	8	12	18
Heating Capacity (kW)	147.3	162.6	188.4	207.0	249.0

Heating cap. Is based on 21 °C DB. Frost formation will have greatest effect at amb. 4-6 °C. Above 8 °C defrost is unlikely & a factor of 1 may be used.

Heating Performance Correction

% Rated Air Quantity	Multiplier	Return Air Temp °C	Multiplier	Outdoor Air Temp °C	Approx. Defrost Factor
80	0.93	15	1.05	0	0.80
90	0.97	18	1.03	2	0.78
100	1.00	21	1.00	4 - 6	0.75
110	1.03	24	0.97	7	0.87
120	1.05	27	0.95	8	1.00

Compressor

Number Per Unit	2
Type	Hermetic Scroll
RPM (Nom)	2900
Normal Max Current (Amps /Phase)	2 x 58.2
Locked Rotor Current (Amps /Phase)	2 x 320
Displacement (m^3/h)	2 x 60

Electrical Controls and Safeties

High Pressure Switch (Setting kPa)	4000	Defrost	
Low Pressure Switch (Setting kPa)	300	Initiation Temperature (°C)	-2
Indoor Fan Overload	Internal	Termination Temperature (°C)	18
Outdoor Fan Overload	Internal	Min. Period Between De-Ice (min)	30
Compressor Delay Timer	300 sec	Max De-Ice Period (min)	10

Standard Features

Auto reset high pressure and low pressure cutouts	
Thermal overload protection on all motors	Suction line accumulator
Compressor crankcase heater	Automatic de-ice system
Limit start timer (anti short cycling)	25 mm insulation to indoor unit
240 Volt Control	Sight Glass

Evaporator (Coil)

Type	Copper Tube / Aluminium Fins
Face Area (m^2)	2 x 1.78
Air Quantity (l/s)	10500

Evaporator (Fan Motor)

Number of Fans	1
Type	Centrifugal
Drive	Belt
Motor Voltage /Phase /Frequency	415 /3 /50
Motor Power (kW)	15.0
Maximum Fan Speed (rpm)	604

Electrical

Power Requirements	3 Phase /415V /50Hz
Normal Max. Current (Amps /Phase)	163.7

Condenser (Coil)

Type	Copper Tube /Aluminium Fins
Face Area(m^2)	2 x 3.35

Condenser (Fan Motor)

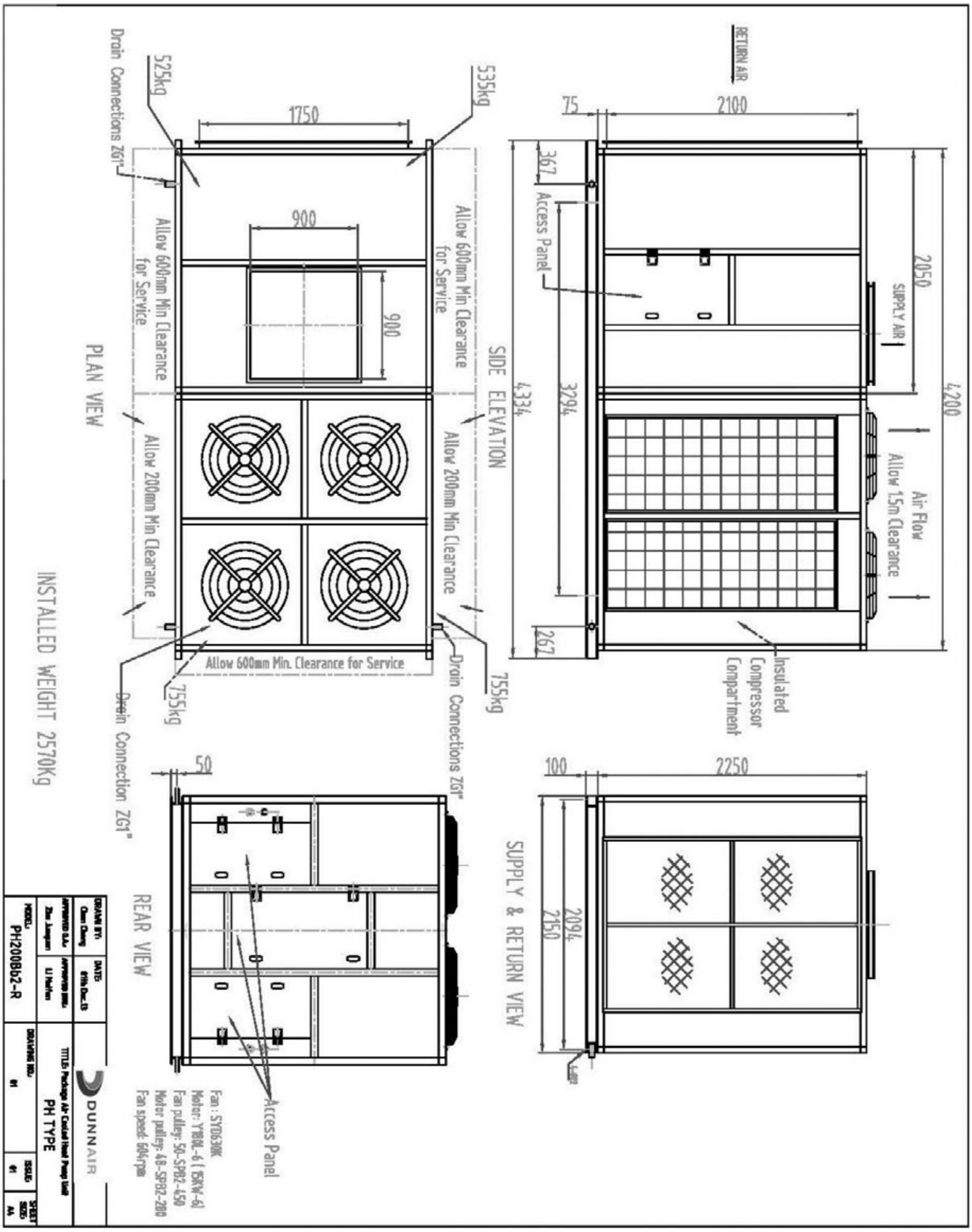
Number of Fans	4
Type	Axial
Drive	Direct
Motor Type	Enclosed
Motor Power (kW)	4 x 1.8
Motor Voltage /Phase /Frequency	415 / 3 / 50

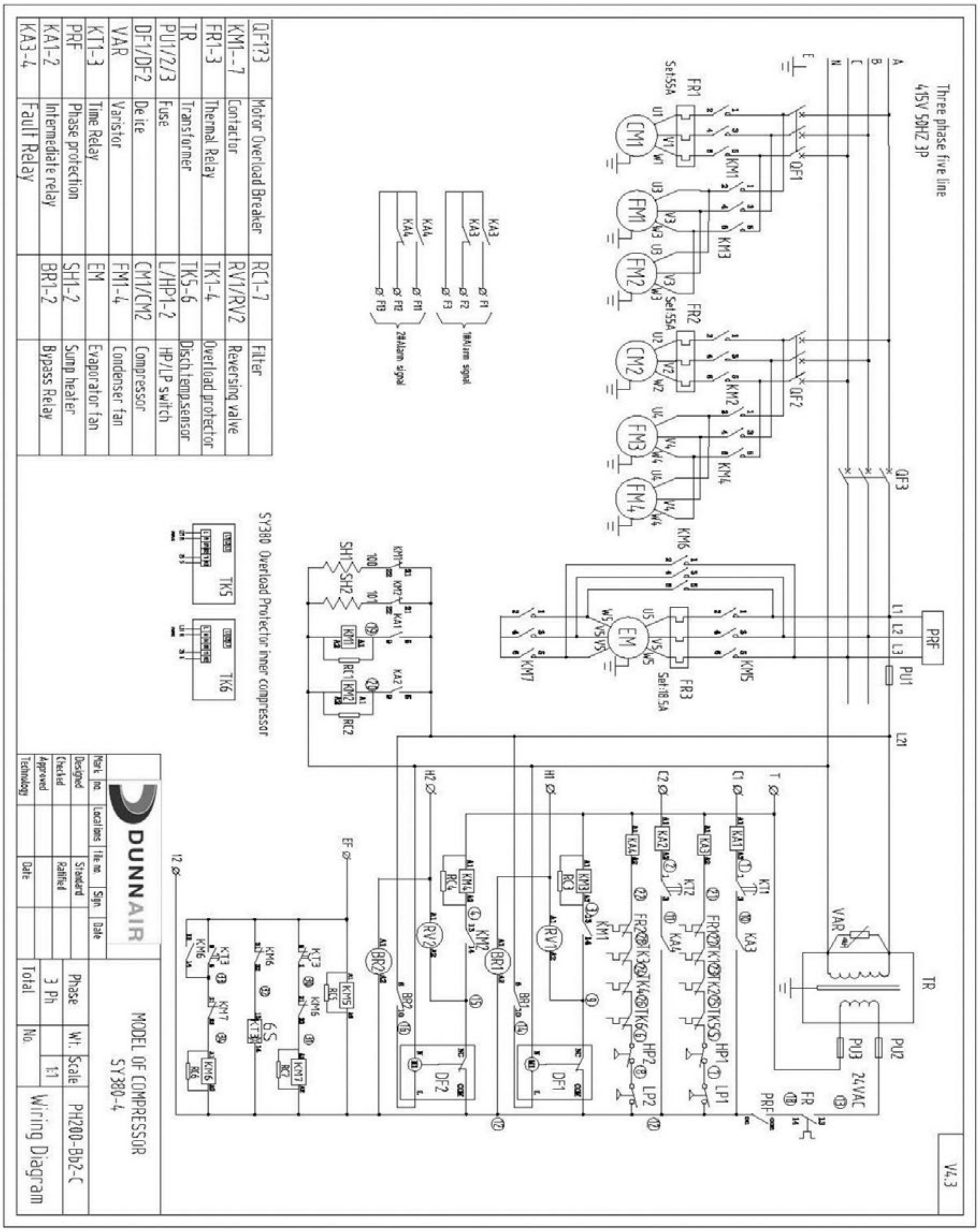
Refrigeration System

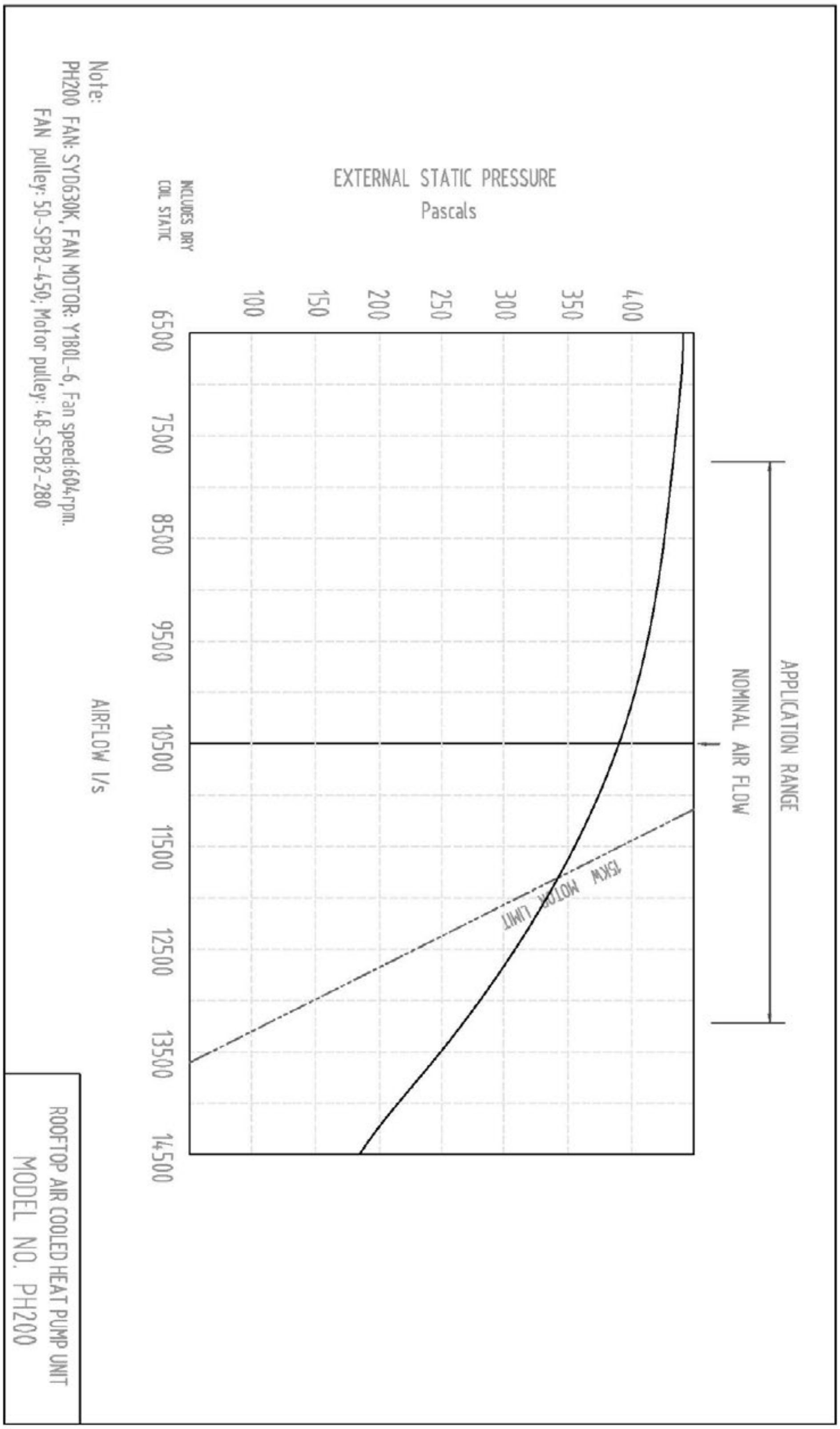
Refrigerant Type	R410A
Charge(kg)	2 x 25.4
Service Connections	Rotor Lock Valves
Expansion Control - In / Outdoor unit	TX Valve

Evaporator unit is supplied with a variable speed motor pulley.

DUNNAIR (Aust) Pty Ltd supports a policy of continuous improvement. Therefore specifications and designs are subject to change without prior notice. Page 2
Released May 2015 V3.5


PLAN VIEW
SIDE ELEVATION
SUPPLY & RETURN VIEW
REAR VIEW
INSTALLED WEIGHT 2570Kg
RETURN AIR
SUPPLY AIR
Air Flow
Allow 1.5m Clearance
Insulated Compressor Compartment
Access Panel
Allow 600mm Min Clearance for Service
Allow 200mm Min Clearance
Allow 600mm Min. Clearance for Service
Drain Connections ZG1"
Drain Connection ZG1"
525kg
535kg
755kg
755kg
1750
900
900
4334
75
2100
367
3294
267
2050
4200
50
100
2250
2094
2150
DUNNAIR
PH TYPE


Three phase five line
415V 50HZ 3P
SY380 Overload Protector inner compressor
MODEL OF COMPRESSOR
SY380-4
Phase 3 Ph
Scale 1:1
PH200-Bb2-C
Wiring Diagram
V4.3
QF1?3 Motor Overload Breaker
KM1--7 Contactor
FR1-3 Thermal Relay
TR Transformer
PU1/2/3 Fuse
DF1/DF2 De ice
VAR Varistor
KT1-3 Time Relay
PRF Phase protection
KA1-2 Intermediate relay
KA3-4 Fault Relay
RC1-7 Filter
RV1/RV2 Reversing valve
TK1-4 Overload protector
TK5-6 Disch.temp.sensor
L/HP1-2 HP/LP switch
CM1/CM2 Compressor
FM1-4 Condenser fan
EM Evaporator fan
SH1-2 Sump heater
BR1-2 Bypass Relay

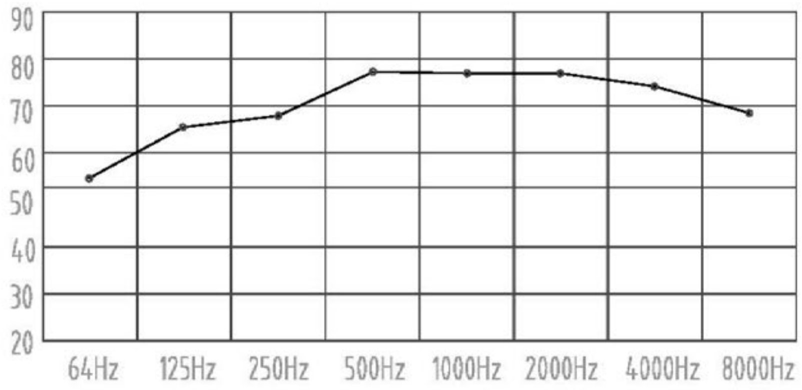

Note:
PH200 FAN: SYD630K, FAN MOTOR: Y180L-6, Fan speed:604rpm.
FAN pulley: 50-SPB2-450; Motor pulley: 48-SPB2-280
EXTERNAL STATIC PRESSURE
Pascals
INCLUDES DRY COIL STATIC
100
150
200
250
300
350
400
6500
7500
8500
9500
10500
11500
12500
13500
14500
AIRFLOW l/s
APPLICATION RANGE
NOMINAL AIR FLOW
15KW MOTOR LIMIT
ROOFTOP AIR COOLED HEAT PUMP UNIT
MODEL NO. PH200

PH200 Sound Pressure Curve

A Class: 83.2dB

Hz	dB
64Hz	53
125Hz	66
250Hz	68
500Hz	78
1000Hz	77
2000Hz	78
4000Hz	75
8000Hz	68

Sound Pressure Curve (A Class: 83.2dB) dB



Note: Occupant at least 1.0m from sound source.

DRAWN BY: Chen Cheng	DATE: 13th.Feb.2014	DUNNAIR		
APPROVED Q.A.: Zhu Junquan	APPROVED ENG.: Li Meifen	TITLE: Packaged Air Cooled Heat Pump Unit PH TYPE		
MODEL: PH200		DRAWING NO.: 01	ISSUE: 01	SHEET SIZE: A4

G Appendix G

Manufacturers Literature – Air Grilles

Supply Air Grilles

Series DD-20 & 32 – Supply Grilles & Registers

HOLYOAKE
AIR MANAGEMENT SOLUTIONS

Grille - Two Sets of Louver Blades

Model **DDL-20**

Two sets of louver blades. Front set parallel to long dimension. Rear set parallel to short dimension. All louver blades individually adjustable for any degree of deflection.

Model **DDS-20**

Same as DDL-20 except front louver blades parallel to short dimension, rear parallel to long dimension.

Register - Two Sets of Louver Blades

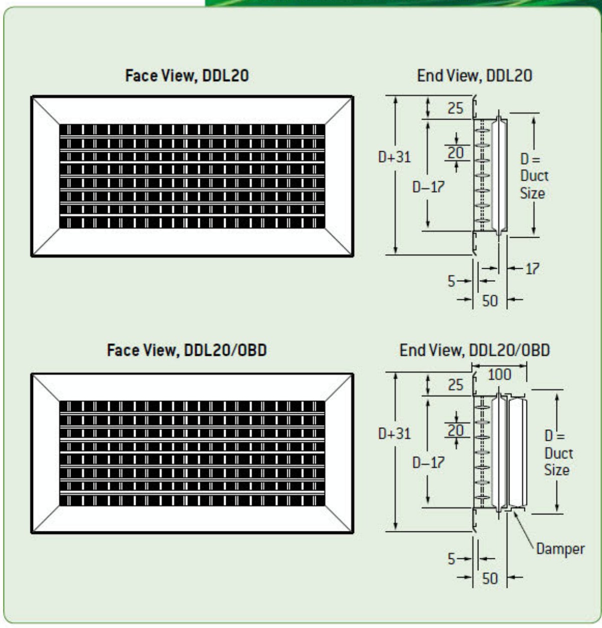
Model **DDL-20/OBD**

Two sets of louver blades. Front set parallel to long dimension. Rear set parallel to short dimension. All louver blades individually adjustable for any degree of deflection. Opposed blade damper, screwdriver operated from face.

Model **DDS-20/OBD**

Same as DDL-20/OBD except front louver blades parallel to short dimension, rear parallel to long dimension.

All Aluminium. 20mm Airfoil Louvers



Grille - Two Sets of Louver Blades

Model **DDL-32.**

Two sets of louver blades. Front set parallel to long dimension. Rear set parallel to short dimension. All louver blades individually adjustable for any degree of deflection.

Model **DDS-32.**

Same as DDL-32 except front louver blades parallel to short dimension, rear parallel to long dimension.

Register - Two Sets of Louver Blades

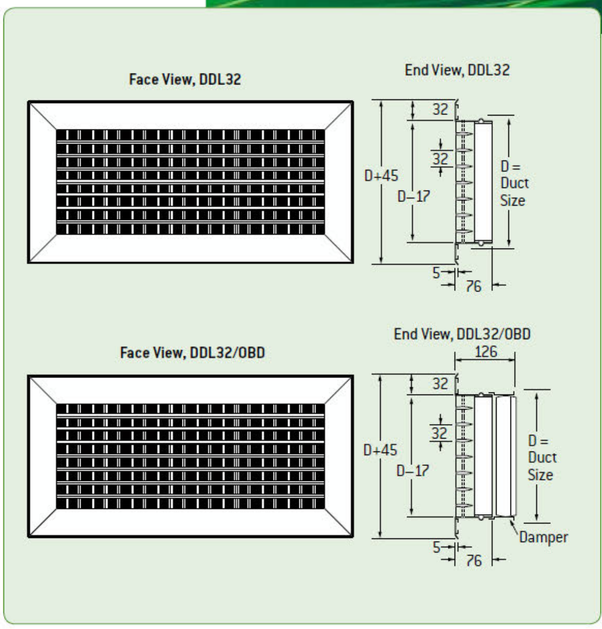
Model **DDL-32/OBD.**

Two sets of louver blades. Front set parallel to long dimension. Rear set parallel to short dimension. All louver blades individually adjustable for any degree of deflection. Opposed blade damper, screwdriver operated from face.

Model **DDS-32/OBD**

Same as DDL-32/OBD except front louver blades parallel to short dimension, rear parallel to long dimension.

All Aluminium. 32mm Airfoil Louvers



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Sidewall Supply Grilles

Size W X H													
									NC 20		NC 30		NC 40
	Vel. m/s		1.52	2.03	2.54	3.05	3.56	4.06	5.08	6.10	7.11	8.13	9.14
	Vel. Press	(Pa)	2	3	5	6	8	10	16	23	31	40	51
	Tot Press	0°	2	4	7	10	13	17	27	39	53	69	87
	(Pa)	22.5°	3	5	8	11	14	19	30	44	59	77	98
		45°	4	7	12	16	22	29	45	66	89	116	147
175 x 100	m³/s		0.020	0.028	0.035	0.042	0.050	0.057	0.071	0.085	0.099	0.113	0.127
150 x 125	NC		-	-	-	-	13	17	23	29	34	38	41
	Throw	0°	1.2-1.8-3.7	1.5-2.4-4.3	2.1-3.4-4.9	2.4-3.7-5.2	2.7-4.0-5.8	3.4-4.3-6.1	4.0-4.9-6.7	4.3-5.2-7.3	4.6-5.8-7.9	4.9-6.1-8.5	5.2-6.7-9.2
Ac = 0.014m²	in	22.5°	0.9-1.5-3.1	1.2-1.8-3.4	1.8-2.4-4.0	1.8-3.1-4.9	2.1-3.1-4.3	2.7-3.4-5.9	2.1-4.0-5.5	3.4-4.3-5.8	3.7-4.6-6.4	4.0-4.9-6.7	4.3-5.5-7.3
	m	45°	0.6-0.9-1.8	0.9-1.2-2.1	0.9-1.5-2.4	1.2-1.8-2.7	1.5-2.1-2.7	1.5-2.1-3.1	1.8-2.4-3.4	2.1-2.7-3.7	2.4-2.7-4.0	2.4-3.1-4.3	2.7-3.4-4.6
200 x 100	m³/s		0.026	0.033	0.042	0.052	0.059	0.068	0.085	0.101	0.118	0.137	0.153
175 x 125	NC		-	-	-	10	15	19	25	31	36	40	43
150 x 150	Throw	0°	1.2-2.1-4.0	1.8-2.4-4.6	2.1-3.4-5.2	2.7-4.0-5.8	3.1-4.6-6.1	3.4-4.9-6.7	4.3-5.2-7.3	4.6-5.8-7.9	5.2-6.4-8.8	5.5-6.7-9.5	5.8-7.3-10.2
Ac = 0.017m²	in	22.5°	0.9-1.8-3.1	1.5-1.8-3.7	1.8-2.7-4.3	2.1-3.1-4.3	2.4-3.7-4.9	2.7-4.0-5.5	3.4-4.3-5.8	3.7-4.6-6.4	4.3-5.2-7.0	4.3-5.5-7.6	4.6-5.8-7.9
	m	45°	0.6-0.9-2.1	0.9-1.2-2.4	1.2-1.5-2.7	1.2-2.1-3.1	1.5-2.1-3.1	1.8-2.4-3.4	2.1-2.7-3.7	2.4-3.1-4.0	2.4-3.1-4.3	2.7-3.4-4.6	3.1-3.7-4.9
250 x 100	m³/s		0.031	0.042	0.052	0.061	0.073	0.083	0.104	0.125	0.146	0.165	0.186
200 x 125	NC		-	-	-	10	15	19	25	31	36	40	43
175 x 150	Throw	0°	1.2-2.1-4.3	2.1-3.1-5.2	2.4-3.7-5.8	2.7-4.6-6.4	3.4-4.9-7.0	4.0-5.8-8.2	4.9-5.8-8.2	5.2-6.4-8.8	5.8-7.9-8.0	6.1-7.6-10.4	6.4-7.9-11.0
Ac = 0.020m²	in	22.5°	0.9-1.8-3.4	1.8-2.4-4.3	1.8-3.1-4.6	2.1-3.7-5.2	2.7-4.5-5.0	4.0-4.6-6.7	4.3-5.2-6.7	4.3-5.2-7.0	4.6-5.5-7.9	4.9-6.1-9.2	5.2-6.4-8.8
	m	45°	0.6-1.2-2.1	0.9-1.5-2.7	1.2-1.8-3.1	1.5-2.1-3.1	1.8-2.4-3.4	1.8-2.7-3.7	2.4-3.1-4.0	2.7-3.4-4.6	2.7-3.7-4.9	3.1-3.7-5.2	3.4-4.0-5.5
300 x 100	m³/s		0.038	0.050	0.061	0.073	0.085	0.099	0.123	0.146	0.172	0.196	0.222
250 x 125	NC		-	-	-	11	16	20	26	32	37	41	44
200 x 150	Throw	0°	1.5-2.4-4.9	2.1-3.4-5.8	2.7-4.0-6.4	3.1-4.9-7.0	3.7-5.2-7.3	4.3-5.8-7.9	5.2-6.4-8.8	5.8-7.0-9.8	6.1-7.6-10.7	6.7-7.9-11.3	7.0-8.2-12.2
Ac = 0.024m²	in	22.5°	1.2-1.8-4.0	1.8-3.1-4.6	2.1-3.1-5.2	2.4-4.0-5.5	3.1-4.3-5.8	3.4-4.6-6.4	4.3-5.2-7.0	4.6-5.5-7.9	4.9-6.1-8.5	5.5-6.4-9.2	5.5-6.7-9.8
	m	45°	0.9-1.2-2.4	1.2-1.5-2.7	1.2-2.1-3.1	1.5-2.4-3.4	1.8-2.7-3.7	2.1-2.7-4.0	2.4-3.4-4.6	2.7-3.7-4.9	3.1-4.0-5.2	3.4-4.0-5.5	3.7-4.3-6.1
350 x 100	m³/s		0.042	0.057	0.071	0.085	0.099	0.113	0.142	0.170	0.188	0.227	0.255
	NC		-	-	-	11	16	20	26	32	37	41	44
Ac = 0.027m²	Throw	0°	1.5-2.7-5.2	2.4-3.4-6.1	2.7-4.3-6.7	3.4-5.2-7.3	4.0-5.8-7.9	4.6-6.1-8.5	5.5-7.0-9.5	6.1-7.6-10.4	6.7-8.2-11.3	7.3-8.8-12.2	7.6-9.2-12.8
	in	22.5°	1.2-2.1-4.3	1.8-2.7-4.9	2.1-3.4-5.5	2.7-4.3-5.8	3.1-4.6-6.4	3.7-4.9-6.7	4.3-5.5-7.6	4.9-6.1-8.2	5.5-6.7-9.2	6.8-7.0-9.8	6.1-7.3-10.4
	m	45°	0.9-1.2-2.4	1.2-1.8-3.1	1.5-2.1-3.4	1.8-2.4-3.7	2.1-2.7-4.0	2.4-3.1-4.3	2.7-3.4-4.9	3.1-3.7-5.2	3.4-4.0-5.8	3.7-4.3-6.1	3.7-4.6-6.4
400 x 100	m³/s		0.047	0.064	0.080	0.097	0.113	0.127	0.161	0.194	0.224	0.257	0.288
300 x 125	NC		-	-	-	12	17	21	27	33	38	42	45
250 x 150	Throw	0°	1.5-2.7-5.5	2.4-3.4-6.4	3.1-4.6-7.3	3.7-5.8-7.9	4.3-6.1-8.5	4.9-6.7-9.2	6.1-7.3-10.1	6.7-7.9-11.3	7.0-8.5-12.2	7.6-9.2-12.8	7.9-9.8-13.7
Ac = 0.030m²	in	22.5°	1.2-2.1-4.3	1.8-3.1-5.2	2.4-3.7-5.8	3.1-4.6-6.4	3.4-4.9-6.7	4.0-5.5-7.3	4.9-5.8-7.9	5.5-6.4-9.2	5.5-6.7-9.8	6.1-7.3-10.4	6.4-7.9-11.0
	m	45°	0.9-1.2-2.7	1.2-1.8-3.4	1.5-2.4-3.7	1.8-2.7-4.0	2.1-3.1-4.3	2.4-3.4-4.6	3.1-3.7-5.2	3.4-4.0-5.5	3.7-4.3-6.1	3.7-4.6-6.4	4.0-4.9-6.7
450 x 100	m³/s		0.054	0.073	0.092	0.111	0.130	0.146	0.184	0.222	0.257	0.295	0.337
350 x 125	NC		-	-	-	13	18	22	28	34	39	43	46
300 x 150	Throw	0°	1.8-2.7-5.7	2.7-4.0-7.0	3.4-4.9-7.6	4.0-5.8-8.5	4.6-6.7-9.2	5.2-7.0-9.8	6.4-7.9-11.0	7.0-8.2-12.2	7.6-9.2-12.8	8.2-10.1-13.7	8.5-10.7-14.6
200 x 200	in	22.5°	1.5-2.1-4.6	2.1-3.1-5.5	2.7-4.0-6.1	3.1-4.6-6.7	3.7-5.5-7.3	4.3-5.5-7.9	5.2-6.4-8.8	5.5-6.7-9.8	6.1-7.3-10.4	6.7-7.9-11.0	6.7-8.5-11.6
Ac = 0.036m²	m	45°	0.9-1.5-3.1	1.2-1.8-3.4	1.5-2.4-4.0	2.1-3.1-4.3	2.4-3.4-4.6	2.7-3.7-4.9	3.4-4.0-5.5	3.7-4.3-6.1	3.7-4.6-6.4	4.0-4.9-7.0	4.3-5.2-7.3
								NC 20		NC 30		NC 40	

See Notes and Tables on Page 190E

Supply Performance Data

HOLYOAKE
AIR MANAGEMENT SOLUTIONS

							NC 20		NC 30		NC 40		
Size W X H	Vel. m/s		1.52	2.04	2.54	3.05	3.56	4.06	5.08	6.10	7.11	8.13	9.14
	Vel. Press (Pa)		2	3	5	6	8	10	16	23	31	40	51
	Tot Press	0°	2	4	7	10	13	17	27	39	53	69	87
	(Pa)	22.5°	3	5	8	11	14	19	30	44	59	77	98
		45°	4	7	12	16	22	29	45	66	89	116	147
600 x 200	m^3/s		0.168	0.222	0.279	0.335	0.390	0.446	0.557	0.670	0.779	0.892	1.000
500 x 250	NC		-	-	12	17	22	26	32	38	43	47	50
350 x 350	Throw	0°	3.1-5.2-10.4	4.6-7.0-12.2	5.8-8.5-13.4	7.0-10.7-14.6	8.2-11.6-15.9	9.5-12.2-17.1	11.0-13.7-18.9	12.2-14.6-20.4	13.1-15.9-22.3	13.7-17.1-23.81	14.6-18.0-25.3
	in	22.5°	2.4-4.3-8.2	3.7-5.5-9.8	4.6-6.7-10.7	5.5-8.5-11.6	6.7-9.2-12.8	7.6-9.8-13.7	8.8-11.0-15.3	9.8-11.6-16.5	10.4-12.8-17.7	11.0-13.7-18.9	11.6-14.3-20.1
Ac = 0.11 m²	m	45°	1.5-2.4-5.2	2.4-3.4-6.1	3.1-4.3-6.7	3.7-5.2-7.3	4.0-5.8-7.9	4.6-6.1-8.5	5.5-6.7-9.5	6.1-7.3-10.4	6.4-7.9-11.0	7.0-8.5-11.9	7.3-9.2-12.5
900 x 150	m^3/s		0.189	0.253	0.316	0.380	0.444	0.505	0.633	0.760	0.888	1.010	1.140
700 x 200	NC		-	-	13	18	23	27	33	39	44	48	51
500 x 300	Throw	0°	3.4-5.5-11.0	4.9-7.3-12.8	6.1-9.2-14.3	7.3-11.3-15.6	8.5-12.2-17.1	9.8-13.1-18.0	11.9-14.3-19.8	12.8-15.9-22.0	13.7-17.1-23.8	14.6-18.3-25.3	15.6-19.2-27.2
450 x 300	in	22.5°	2.7-4.3-8.8	4.0-5.8-10.4	4.9-7.3-11.6	5.8-9.2-12.5	6.7-9.8-13.7	7.9-10.4-14.3	9.5-11.6-15.9	10.4-12.8-17.7	11.0-13.7-18.9	11.6-14.6-20.1	12.5-15.3-21.7
400 x 350 Ac = 0.12m²	m	45°	1.8-2.7-5.5	2.4-3.7-6.4	3.1-4.6-7.0	3.7-5.5-7.6	4.3-6.1-8.5	4.9-6.4-8.8	5.8-7.0-10.1	6.4-7.9-11.0	7.0-8.5-11.9	7.3-9.2-12.9	7.9-9.8-13.4
600 x 250	m^3/s		0.227	0.302	0.378	0.453	0.529	0.604	0.756	0.907	1.060	1.210	1.360
550 x 300	NC		-	-	13	18	23	27	33	39	44	48	51
450 x 350	Throw	0°	4.0-6.1-12.2	5.5-7.9-14.0	6.7-9.8-15.6	8.2-11.9-17.1	9.5-13.1-18.3	10.7-14.0-19.5	12.8-15.6-22.0	14.0-17.1-24.1	14.9-18.6-25.9	16.2-19.8-27.8	17.1-21.0-29.6
400 x 400	in	22.5°	3.1-4.9-9.8	4.3-6.4-11.3	5.5-7.9-12.5	6.7-9.5-13.7	7.6-10.4-14.6	8.5-11.3-15.6	10.4-12.5-17.7	11.3-13.7-19.2	11.9-14.9-20.7	12.8-15.9-22.3	13.7-16.8-23.8
Ac = 0.14m²	m	45°	1.8-3.1-6.1	2.7-4.0-7.0	3.4-4.9-7.6	4.0-6.1-8.5	4.6-6.7-9.2	5.2-7.0-9.8	6.4-7.9-11.0	7.0-8.5-11.9	7.6-9.2-13.1	7.9-9.8-14.0	8.5-10.7-14.6
750 x 250	m^3/s		0.255	0.340	0.425	0.510	0.595	0.680	0.850	1.020	1.190	1.360	1.530
600 x 300	NC		-	-	14	19	24	28	34	40	45	49	52
500 x 350	Throw	0°	4.0-6.4-12.8	5.8-8.5-14.6	7.3-10.7-16.8	8.8-13.1-18.0	9.8-14.0-19.2	11.3-14.9-20.7	13.7-16.8-23.2	14.6-18.3-25.6	15.9-19.8-27.5	17.1-21.0-29.6	18.3-22.3-31.4
450 x 400	in	22.5°	3.1-5.2-10.4	4.6-6.7-11.6	5.8-8.5-13.4	7.0-10.4-14.3	7.9-11.3-15.3	9.2-11.9-16.5	11.0-13.4-18.6	11.6-14.6-20.4	12.8-15.9-22.0	13.7-16.8-23.8	14.6-17.7-25.0
Ac = 0.16m²	m	45°	2.1-3.4-6.4	2.7-4.3-7.3	3.7-5.2-8.2	4.3-6.4-8.8	4.9-7.0-9.8	5.8-7.3-10.4	6.7-8.2-11.6	7.3-9.2-11.8	7.9-9.8-13.7	8.5-10.7-14.6	9.2-11.3-15.6
750 x 300	m^3/s		0.295	0.392	0.491	0.590	0.689	0.784	0.982	1.180	1.370	1.570	1.770
900 x 250	NC		-	-	14	19	24	28	34	40	45	49	52
500 x 400 600 x 350	Throw	0°	4.3-7.0-13.7	6.1-9.2-15.9	7.9-11.6-17.7	9.2-13.4-19.2	10.7-14.9-20.7	12.2-16.2-22.3	14.6-18.0-25.0	15.9-19.5-27.5	17.1-21.0-29.6	18.3-22.9-31.7	19.5-24.1-33.6
450 x 450	in	22.5°	3.4-5.5-11.0	4.9-7.3-12.8	6.4-9.2-14.0	7.3-10.7-15.3	8.5-11.9-16.5	9.8-12.8-17.7	11.6-14.3-20.1	12.8-15.6-22.0	13.7-16.8-23.8	14.6-18.3-25.3	15.6-19.2-26.8
Ac = 0.20m²	m	45°	2.1-3.4-7.0	3.1-4.6-7.9	4.0-5.8-8.8	4.6-6.7-9.8	5.2-7.6-10.4	6.1-11.0-11.3	7.3-8.8-12.5	7.9-9.8-13.7	8.5-10.7-14.6	9.2-11.3-15.9	9.8-12.2-16.8
650 x 350	m^3/s		0.347	0.463	0.576	0.694	0.812	0.925	1.160	1.390	1.620	1.850	2.080
600 x 400	NC		-	-	15	20	25	29	35	41	46	50	53
500 x 450	Throw	0°	4.6-7.6-14.9	6.7-10.1-17.4	8.2-12.2-18.9	9.8-14.6-20.7	11.6-16.5-22.6	13.1-17.4-24.4	15.9-19.5-27.2	17.4-21.4-29.6	18.6-23.2-32.3	19.8-24.7-34.5	21.4-26.5-36.6
500 x 500	in	22.5°	3.7-6.1-11.9	5.5-7.9-14.0	6.7-9.8-15.3	7.9-11.6-16.5	9.2-13.1-18.0	10.4-14.0-19.5	12.8-15.6-21.7	14.0-17.1-23.8	14.9-18.6-25.9	15.9-19.8-27.5	17.1-21.4-29.3
Ac = 0.22m²	m	45°	2.1-3.7-7.3	3.4-4.9-8.5	4.3-6.1-9.5	4.9-7.3-10.4	5.8-8.2-11.3	6.7-8.5-12.2	7.9-9.8-13.7	8.5-10.7-14.9	9.8-11.6-16.7	10.1-12.8-17.1	10.7-13.1-18.3
900 x 300	m^3/s		0.390	0.524	0.656	0.788	0.921	1.050	1.310	1.580	1.840	2.100	2.360
650 x 400	NC		-		16	21	26	30	36	42	47	51	54
600 x 450	Throw	0°	4.9-7.9-15.9	7.0-10.4-18.3	8.8-12.8-20.4	10.7-15.3-22.	12.2-17.4-24.1	13.7-18.6-25.9	16.8-20.7-29.0	20.1-22.9-31.7	19.8-24.7-34.2	21.4-26.5-37.2	22.6-28.4-39.0
550 x 500	in	22.5°	4.0-6.4-12.8	5.5-8.2-14.6	7.0-10.4-16.5	8.5-12.2-17.7	9.8-14.0-19.2	11.0-14.9-20.7	13.4-16.5-23.2	14.6-18.3-25.3	15.9-19.8-27.5	17.1-21.4-29.9	18.0-22.6-31.1
Ac = 0.25m²	m	45°	2.4-4.0-7.9	3.7-5.2-9.2	4.3-6.4-10.1	5.2-7.6-11.3	6.1-8.5-12.2	7.0-9.2-12.8	8.5-10.4-14.3	9.2-11.3-15.9	10.1-12.2-17.1	10.7-13.1-18.6	11.3-14.0-19.5
						NC 20			NC 30	NC 40		NC 50	

NC 50

See Notes and Tables on Page 190E

Supply Performance Data

HOLYOAKE AIR MANAGEMENT SOLUTIONS

						NC 20			NC 30	NC 40		NC 50	
Size	Vel. m/s		1.52	2.03	2.54	3.05	3.56	4.06	5.08	6.10	7.11	8.13	9.14
W X H	Vel. Press	(Pa)	2	3	5	6	8	10	16	23	31	40	51
	Tot Press	0°	2	4	7	10	13	17	27	39	53	69	87
	(Pa)	22.5°	3	5	8	11	14	19	30	44	59	77	98
		45°	4	7	12	16	22	29	45	66	89	116	147
750 x 400	m³/s		0.441	0.585	0.747	0.883	1.030	1.180	1.470	1.760	2.050	2.350	2.640
650 x 450	NC		-	-	16	21	26	30	36	42	47	51	54
600 x 500	Throw	0°	5.2-8.2-16.8	7.3-11.0-19.2	10.4-13.7-21.7	12.5-16.2-23.8	14.3-18.3-25.6	14.6-19.5-27.5	17.7-22.0-30.5	19.5-24.1-33.6	21.0-26.2-36.0	22.6-28.1-39.0	24.1-29.6-41.2
550 x 550	in	22.5°	1.3-6.7-13.4	3.1-8.8-15.3	8.2-11.0-17.4	10.1-12.8-18.9	11.6-14.6-20.4	11.6-15.6-22.0	14.0-17.7-24.4	15.6-19.2-26.8	16.8-21.0-28.7	18.0-22.6-31.1	19.2-23.8-32.9
Ac = 0.28m²	m	45°	2.4-4.3-8.5	3.7-5.5-9.5	5.2-6.7-10.7	6.1-7.9-11.9	7.0-9.2-12.8	7.3-9.8-12.7	8.8-11.0-15.3	9.8-12.2-16.8	10.7-13.1-18.0	11.3-14.0-19.5	12.2-14.9-20.4
900 x 400	m³/s		0.510	0.680	0.850	1.020	1.190	1.360	1.700	2.040	2.380	2.730	3.070
750 x 450	NC		-	10	17	22	27	31	37	43	48	52	55
700 x500	Throw	0°	5.5-8.8-18.0	7.9-11.6-20.7	9.8-14.3-23.2	11.6-17.1-25.6	13.4-19.8-27.5	15.6-21.0-29.6	19.2-23.8-32.9	21.0-26.2-36.0	22.9-28.4-39.0	24.4-30.2-41.8	26.2-32.0-44.5
600 x 600	in	22.5°	4.3-7.0-14.3	6.4-9.2-16.5	7.9-11.6-18.6	9.2-13.7-20.4	10.7-15.9-22.0	12.5-16.8-23.8	15.3-18.9-26.2	16.8-21.0-28.7	18.3-22.6-31.1	18.3-24.1-33.6	19.2-23.8-32.9
Ac = 0.33m²	m	45°	2.7-4.3-8.8	4.0-5.8-10.4	4.9-7.0-11.6	5.8-8.5-12.8	6.7-9.8-13.7	7.6-10.7-14.6	9.5-11.9-16.5	10.7-13.1-18.0	11.6-14.0-19.5	12.2-15.3-21.0	12.2-14.9-20.4
900 x 450	m³/s		0.610	0.812	1.010	1.210	1.420	1.620	2.030	2.430	2.890	3.240	3.640
800 x 500	NC		-	11	18	23	28	32	38	44	49	53	56
700 x 550	Throw	0°	5.8-9.5-19.5	8.5-12.5-22.6	10.7-15.3-25.3	12.8-18.3-27.8	14.9-21.7-29.9	17.1-23.2-32.3	21.0-25.9-36.0	23.2-28.4-39.	25.0-31.1-42.7	26.8-32.9-45.4	28.1-35.1-48.2
	in	22.5°	4.6-7.6-15.6	6.7-10.1-18.0	8.5-12.2-20.1	10.4-14.6-22.3	11.9-17.4-23.8	13.7-18.6-25.9	16.8-20.7-28.7	18.6-22.6-31.7	20.1-25.0-34.2	21.4-26.2-36.3	22.6-28.1-38.4
Ac =0.39m²	m	45°	3.1-4.6-9.8	4.3-6.1-11.3	5.2-7.6-12.8	6.4-9.2-14.0	7.3-10.7-14.9	8.5-11.6-16.2	10.4-13.1-18.0	11.6-14.3-19.8	12.5-15.6-21.4	13.4-16.5-22.9	14.0-17.4-24.1
900 x 500	m³/s		0.660	0.878	1.100	1.320	1.540	1.760	2.200	2.630	3.070	3.510	3.950
750 x 600	NC		-	11	18	23	28	32	38	44	49	53	56
700 x 650	Throw	0°	6.1-10.1-20.4	8.8-13.1-23.8	11.0-16.5-26.5	13.4-19.8-29.0	15.6-22.6-31.4	17.7-24.1-33.6	22.0-27.2-37.5	24.1-29.6-41.2	26.2-32.0-44.5	27.8-34.5-47.6	29.3-36.6-50.0
	in	22.5°	4.9-7.9-16.5	7.0-10.4-18.9	8.8-13.1-21.4	10.7-15.9-23.2	12.5-18.0-25.0	14.0-19.2-26.8	17.7-21.7-29.9	19.2-23.8-32.9	21.0-25.9-35.7	22.3-27.5-38.1	23.5-29.3-40.0
Ac = 0.42 m²	m	45°	3.1-4.9-10.1	4.6-6.7-11.9	5.5-8.2-13.1	6.7-9.8-14.6	7.6-11.3-15.9	8.8-12.2-16.8	11.0-13.4-18.6	11.9-14.9-20.4	13.1-15.9-22.3	14.0-17.1-23.8	14.6-18.3-25.0
1200 x 450	m³/s		0.788	1.050	1.320	1.580	1.850	2.110	2.630	3.160	3.690	4.220	4.720
900 x 600	NC		-	12	19	24	29	33	39	45	50	54	57
	Throw	0°	6.7-11.0-22.3	9.5-14.3-25.9	12.2-18.0-29.0	14.3-22.0-31.7	16.8-24.7-34.5	19.2-26.5-37.2	24.1-29.6-39.6	26.5-32.6-45.1	28.4-35.4-48.8	30.5-38.1-52.2	32.3-40.3-54.9
	in	22.5°	5.5-8.8-17.7	7.6-11.6-20.7	9.8-14.4-23.3	11.6-17.7-25.3	13.4-19.8-27.5	15.3-21.4-29.9	19.2-23.8-32.9	21.4-26.2-36.0	22.6-28.4-39.7	24.4-30.5-41.8	25.9-32.0-42.7
Ac = 0.51m²	m	45°	3.4-5.5-11.3	4.9-7.0-13.1	6.1-9.2-14.6	7.0-11.0-15.9	8.5-12.5-17.4	9.5-13.4-18.6	11.9-14.9-20.4	13.1-16.2-22.6	14.3-17.7-24.4	15.3-18.9-26.2	17.2-20.1-27.5
1200 x 500	m³/s		0.888	1.180	1.470	1.770	2.070	2.360	2.950	3.540	4.130	4.720	5.290
750 x 750	NC		-	13	20	25	30	34	40	46	51	55	58
	Throw	0°	7.0-11.3-23.8	10.1-14.9-27.5	12.8-18.9-30.5	15.3-22.9-31.4	17.7-26.2-36.3	20.4-28.4-39.0	25.6-31.7-43.6	28.1-34.5-47.6	29.9-37.5-51.5	32.3-40.3-54.9	34.2-42.7-58.6
	in	22.5°	5.5-9.2-18.9	7.9-11.9-22.0	10.4-15.3-24.4	12.2-18.3-25.0	14.0-21.0-29.0	16.5-22.6-31.1	20.4-25.3-34.8	22.6-27.5-38.1	23.8-29.9-41.2	25.9-32.0-42.7	27.5-34.2-46.7
Ac = 0.56m²	m	45°	3.7-5.8-11.9	5.2-7.6-13.7	6.4-9.5-15.3	7.6-11.3-15.6	8.8-13.1-18.3	10.4-14.0-19.5	12.8-15.9-22.0	14.0-17.4-23.8	14.9-18.6-25.9	16.2-20.1-29.3	17.1-21.4-29.3
						NC 20		NC 30		NC 40	NC 50		

See Notes and Tables on Page 190E

HOLYOAKE
AIR MANAGEMENT SOLUTIONS

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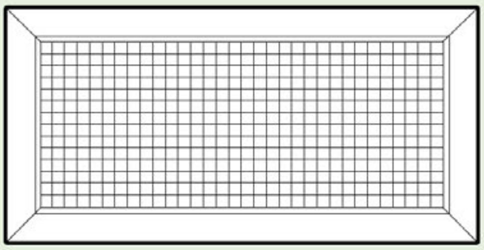
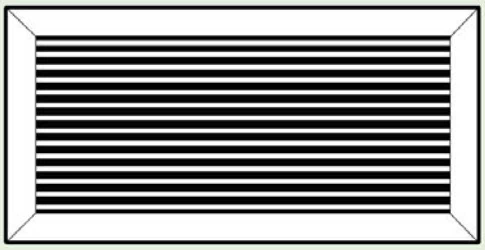
AIR MANAGEMENT SOLUTIONS

Exhaust and Return Grilles – Series EC, HI & RL



Model: EC-125

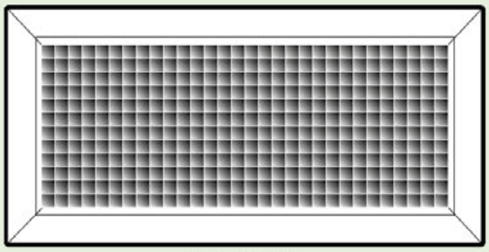


Model: RLL-25

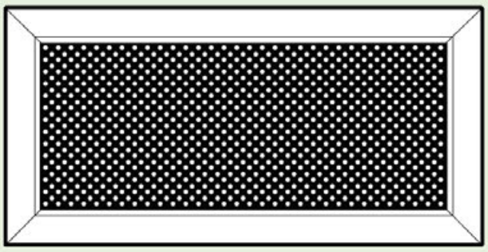
The Holyoake range of 'Egg Crate', 'Obscure Egg Crate', 'Louvered Return' and 'Perforated Face' grilles are available in various configurations with Removable Core, Opposed Blade Damper and Filter Return options, making them a versatile option for wall and ceiling applications.

Long and short, curved and parallel blade versions compliment the range.

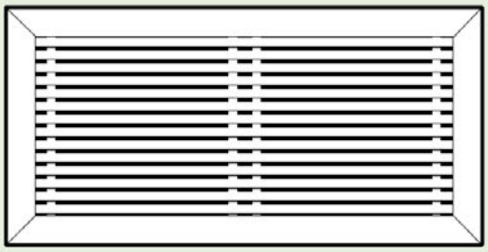
Guide Product Weights		
Approximate Weight in Kg.		
Size	EC125FR	MEC125-FR
300 x 300	1.30	-
400 x 400	1.75	-
550 x 550	2.50	-
595 x 595	-	2.70



Model: HI-35

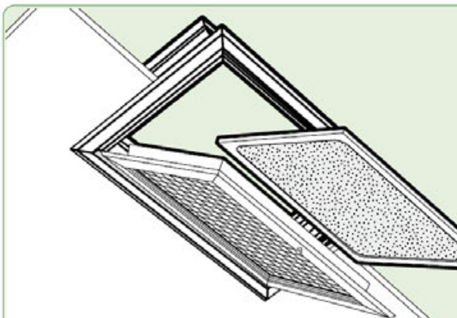


Model: RLP

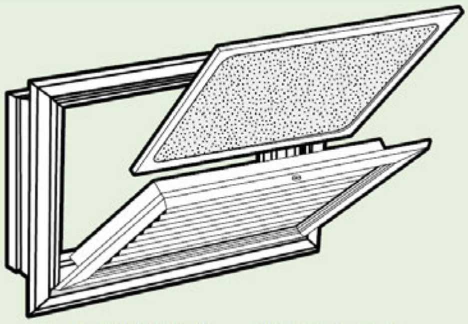


Model: RLHL

Filter Return FR



Model: EC-125-FR (Ceiling illustrated).



Model: RLL-25-FR (Wall illustrated).

These units are of the same construction for both ceiling and wall application. Other models available as filter returns of similar construction are: RLS-25-FR;RLL-23-FR, RLS-23-FR; RLHL-FR; RLHS-FR. HI-35-FR; RLP-FR, RLWL-FR, RLWS-FR and AMG-FR.

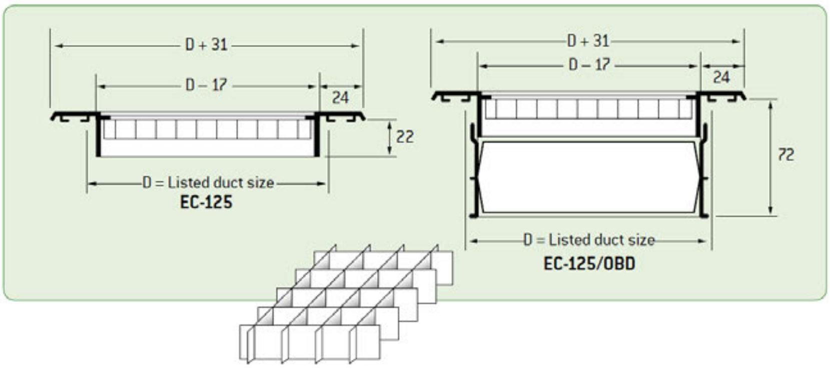
Other Product Series may be available as Filter Returns, please contact your local Holyoake branch, for filter details.

See page 215E for more details.

Model: **EC-125**

Features 12.5 x 12.5 x 12.5mm aluminium core. Provides maximum free area.

Guide Product Weights		
Approximate Weight in Kg.		
Size	EC125	HI35
200 x 200	0.40	0.50
300 x 300	0.58	0.74
400 x 400	0.80	1.03
500 x 500	1.05	1.35
595 x 595	1.70	2.18

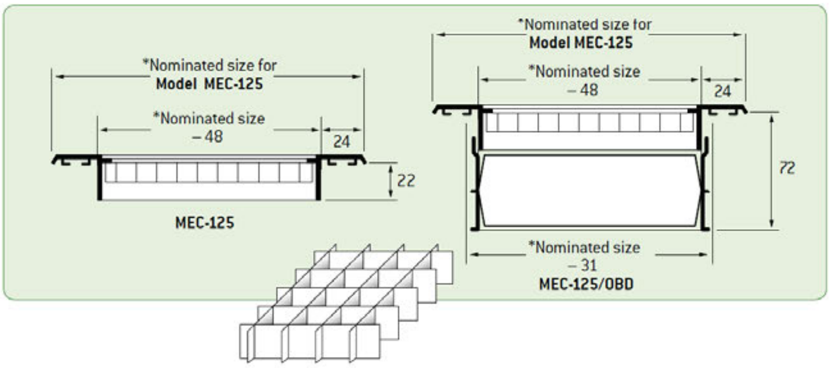


Model: **MEC-125**

Similar to Model EC-125, but for module of size nominated (lay-in application).

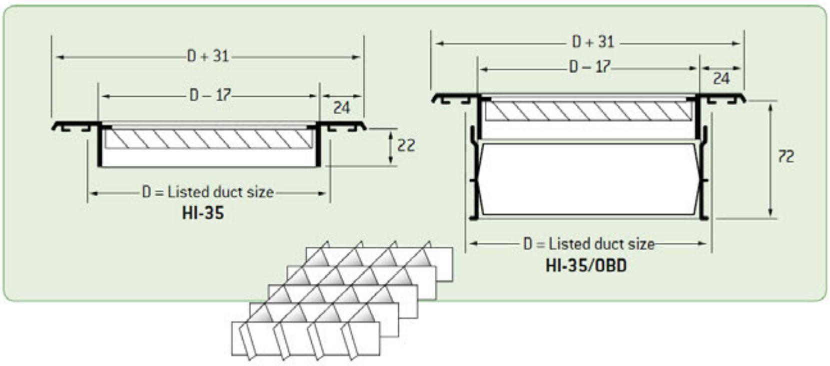
*595 x 595 or 595 x 1195 overall.
+ 600 x 600 or 600 x 1200 Nominated T.Bar opening.

Guide Product Weights		
Approximate Weight in Kg.		
Size	MEC125	MHI-35
595 x 595	1.40	1.80



Model: **HI-35**

Features diagonal blades at 9.5mm centres and 35° pitch, vertical mullion at 12.5mm centres and 0° pitch. Aluminium core.



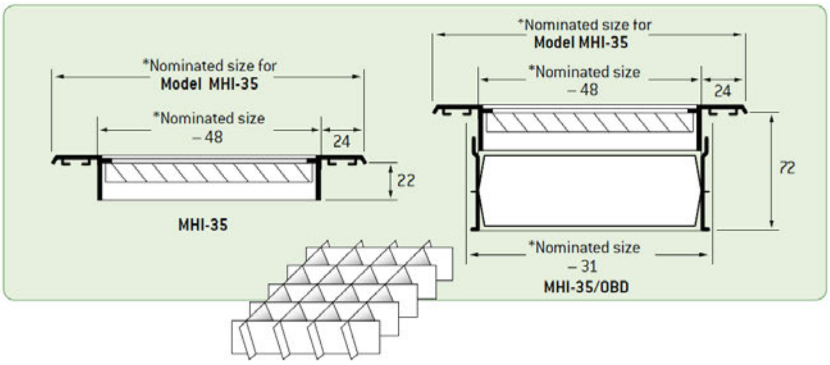
Model: **MHI-35**

Similar to Model HI-35, but for module of size nominated (lay-in application).

*595 x 595 or 595 x 1195 overall.
+ 600 x 600 or 600 x 1200 Nominated T.Bar opening.

Options:

1. Removeable core frame (RC), (see page 216E).
2. 14 mm Flanged Surround.
3. 40mm flanged surround.
4. Filter Return (FR), (see page 215E).



Return & Exhaust Grilles

Models: EC-125 and HI-35

NC 20 NC 30

CORE AREA m^2	NOMINAL SIZE(mm)	CORE VEL. m/s	1.53	2.04	2.55	3.06	3.57	4.08	5.10	6.12	7.14	8.16
		VEL. PRESS	2	3	4	6	8	10	16	23	31	40
		NEG. SP	3	5	8	12	16	20	31	45	54	80
0.014	175 x 100	m^3/s	0.021	0.028	0.035	0.043	0.050	0.057	0.071	0.085	0.099	0.113
	150 x 125	NC					11	15	22	27	32	36
0.017	200 x 100 150 x 150	m^3/s	0.026	0.033	0.043	0.052	0.059	0.068	0.085	0.102	0.118	0.137
	175 x 125	NC					12	16	23	28	33	37
0.020	250 x 100 175 x 150	m^3/s	0.031	0.043	0.052	0.061	0.073	0.083	0.104	0.125	0.146	0.165
	200 x 125 200 x 125	NC					13	17	24	29	34	38
0.024	300 x 100 200 x 150	m^3/s	0.038	0.050	0.061	0.073	0.085	0.099	0.123	0.146	0.172	0.196
	250 x 125	NC					14	18	25	30	35	39
0.028	350 x 100	m^3/s	0.043	0.057	0.071	0.085	0.099	0.113	0.142	0.170	0.198	0.227
		NC				10	15	19	26	31	36	40
0.032	400 x 100 250 x 150	m^3/s	0.047	0.064	0.080	0.097	0.113	0.127	0.161	0.194	0.224	0.257
	300 x 125	NC				11	16	20	27	32	37	41
0.036	450 x 100 300 x 150	m^3/s	0.054	0.073	0.092	0.111	0.130	0.146	0.184	0.222	0.251	0.295
	350 x 125 200 x 200	NC				12	17	21	28	33	38	42
0.043	500 x 100 350 x 150	m^3/s	0.066	0.087	0.109	0.130	0.151	0.175	0.217	0.260	0.300	0.347
	400 x 125 250 x 200	NC				13	18	22	29	34	39	43
0.048	600 x 100 400 x 150	m^3/s	0.073	0.099	0.123	0.146	0.172	0.196	0.245	0.295	0.345	0.392
	450 x 125	NC				14	19	23	30	35	40	44
0.056	700 x 100 450 x 150 250 x 250	m^3/s	0.085	0.113	0.142	0.170	0.198	0.227	0.283	0.340	0.397	0.453
	500 x 125 300 x 200	NC				15	20	24	31	36	41	45
0.064	750 x 100 500 x 150 300 x 250	m^3/s	0.097	0.130	0.163	0.196	0.229	0.260	0.326	0.392	0.456	0.519
	600 x 125 350 x 200	NC				15	20	24	31	36	41	45
0.075	900 x 100 550 x 150 350 x 250	m^3/s	0.116	0.153	0.191	0.229	0.267	0.307	0.382	0.458	0.533	0.614
	700 x 125 400 x 200	NC			10	16	21	25	32	37	42	46
0.084	1000 x 100 650 x 150 400 x 250	m^3/s	0.127	0.170	0.212	0.255	0.297	0.340	0.425	0.510	0.595	0.680
	750 x 125 450 x 200 300 x 300	NC			11	17	22	26	33	38	43	47
0.099	1225 x 100 750 x 150 350 x 300	m^3/s	0.151	0.203	0.253	0.302	0.354	0.404	0.505	0.604	0.708	0.807
	900 x 125 450 x 250	NC			12	18	23	27	34	39	44	48
0.118	850 x 150 500 x 250 350 x 350	m^3/s	0.168	0.222	0.279	0.335	0.389	0.446	0.557	0.670	0.779	0.892
	600 x 200 400 x 300	NC			13	19	24	28	35	40	45	49
0.125	1525 x 100 900 x 150 400 x 350	m^3/s	0.189	0.253	0.316	0.380	0.447	0.505	0.633	0.760	0.887	1.010
	1225 x 125 450 x 300	NC			14	20	25	29	36	41	46	50
0.149	1825 x 100 600 x 250 450 x 350	m^3/s	0.227	0.302	0.378	0.453	0.529	0.604	0.755	0.906	1.060	1.210
	750 x 200 550 x 300 400 x 400	NC			15	21	26	30	37	42	47	51
0.167	1525 x 125 900 x 200 450 x 400 600 x 300	m^3/s	0.255	0.340	0.425	0.510	0.595	0.680	0.850	1.020	1.190	1.360
	1225 x 150 750 x 250 500 x 350	NC			15	21	26	30	37	42	47	51
0.193	1825 x 125 1000 x 200 750 x 300 500 x 400	m^3/s	0.295	0.392	0.491	0.590	0.689	0.784	0.982	1.180	1.370	1.570
	1525 x 150 900 x 250 600 x 350 450 x 450	NC		10	16	22	27	31	38	43	48	52
0.228	1825 x 150 800 x 300 600 x 400	m^3/s	0.347	0.463	0.576	0.694	0.812	0.925	1.160	1.390	1.620	1.850
	1225 x 200 650 x 350 500 x 450	NC		11	17	23	28	32	39	44	49	53
0.258	900 x 300 650 x 400 550 x 500	m^3/s	0.394	0.524	0.656	0.788	0.920	1.050	1.310	1.580	1.840	2.100
	750 x 350 600 x 450	NC		12	18	24	29	33	40	45	50	54
0.289	1525 x 200 1000 x 300 750 x 400 600 x 500	m^3/s	0.441	0.586	0.734	0.883	1.030	1.180	1.470	1.760	2.050	2.350
	1225 x 250 900 x 350 650 x 450 550 x 550	NC		13	19	25	30	34	41	46	51	55
0.335	1825 x 200 1225 x 300 750 x 450	m^3/s	0.510	0.680	0.850	1.020	1.190	1.360	1.700	2.040	2.380	2.730
	1525 x 250 900 x 400 600 x 600	NC		13	19	25	30	34	41	46	51	55
0.399	1225 x 350 800 x 500	m^3/s	0.609	0.812	1.010	1.210	1.420	1.620	2.030	2.430	2.840	3.240
	900 x 450 700 x 600	NC		14	20	26	31	35	42	47	52	56
0.432	1825 x 250 900 x 500	m^3/s	0.661	0.878	1.100	1.320	1.540	1.760	2.200	2.630	3.070	3.510
	1225 x 400 750 x 600	NC		15	21	27	32	36	43	48	53	57
0.518	1825 x 300 1225 x 450	m^3/s	0.788	1.050	1.320	1.580	1.850	2.110	2.630	3.160	3.690	4.220
	1525 x 350 900 x 600	NC		16	22	28	33	37	44	49	54	58
0.581	1825 x 350 1225 x 500	m^3/s	0.887	1.180	1.470	1.770	2.070	2.360	2.950	3.540	4.130	4.720
	1525 x 400	NC	10	17	23	29	34	38	45	50	55	59

NC 40 NC 50

NC 20 NC 30 NC 40 NC 50

- Neg. SP is negative static pressure.
- NC values are based on room absorption of 10 db, re 10^{-12} watts.
- All pressures are in pascals.
- Heavy dividing lines denote ranges of NC values.

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H Appendix H

Energy Analysis Output

ERV – System 1

ACADS BSG Program

BEAVER SYSTEMS

Version Number 7.11.1

ACADS BSG advises that the program BEAVER is intended to be used only by persons who are proficient in its use and application and that these results should be verified independently. The results must not be used without acceptance of the ACADS-BSG's License Agreement for this program.

BEAVER has been successfully validated against BESTEST. The conclusions obtained are listed in the User Guide

CALCULATION BUILD NUMBER 7.11.1BU

Project Data

```
PROJECT NAME       Multi-Purpose Hall - ERV
PROJECT LOCATION
PROJECT NUMBER
BUILDING NAME      Multi-Purpose Hall - ERV
ADDRESS
LOADS RUN DESC.

SYSTEMS TITLE

SYSTEMS RUN DESC.
FIRM NAME
PROJECT ENGINEER
DATE                 2 SEP 2019
RATING SCHEME (LOADS)   :  BCA Class 9b School                               2010-2013
RATING SCHEME (SYSTEMS):  BCA Class 9b School                               2010-2012
 Weather Data Location
  Weather Station No. - 94294               Site No. -     1
  TOWNSVILLE                                TOWNSVILLE
 Weather file name: TOWNSVILLE1986_TRY.SWF

 Weather Data Period                       Energy Source
  Weather Year  - 1986                      Heating      - ELEC.M.METER
  Starting Date - JAN  1                    Radiation    - ELEC.M.METER
  Ending Date   - DEC 31                    Re-heat      - ELEC.M.METER
                                            Pre-Heating  - ELEC.M.METER

 Electric Heating Schedules                Electric Radiation
  Starting Date - JAN  1                    TURN ON Temp.  10.0
  Ending Date   - DEC 31
```

WARNING MESSAGES

```
 System 601 ERV
   Sub-metering - unitary sub-meter assignments not allowed for non unitary system
```

SUMMARY OF ENERGY

	kWhr	MJ	%
Lighting	61559	221613	16.8
Equipment	19683	70857	5.4
Unitary Cooling	220365	793312	60.2
Unitary Heating	63	226	0.0
Unitary Fans	64237	231253	17.6
TOTAL	**365902**	**1317246**	
per square metre	229	823	
project floor area (m2)	1600		
Condensate total (kl)	136		

Summary of Lighting, Equipment and Process Energy Use

Description	Energy kWhr	Energy Source
LIGHTING L1	61559	ELECTRICITY
EQUIPMENT E1	19683	ELECTRICITY

Master Meter Energy Report

	ELECTRICITY		GAS		STEAM		TOTAL
	Peak Hourly kW	Total Monthly kWhr	Peak Hourly Cub. m	Total Monthly Cub. m	Peak Hourly kgs	Total Monthly kgs	Monthly kWhr
JAN	198.	38219	0.	0	0.	0	38219
FEB	216.	34352	0.	0	0.	0	34352
MAR	174.	32676	0.	0	0.	0	32676
APR	170.	31541	0.	0	0.	0	31541
MAY	165.	28532	0.	0	0.	0	28532
JUN	145.	23152	0.	0	0.	0	23152
JUL	157.	25647	0.	0	0.	0	25647
AUG	153.	23142	0.	0	0.	0	23142
SEP	168.	27848	0.	0	0.	0	27848
OCT	173.	33451	0.	0	0.	0	33451
NOV	179.	29427	0.	0	0.	0	29427
DEC	208.	37914	0.	0	0.	0	37914
Total Energy		**365901**		**0**		**0**	**365902**
Per Sq.m.		**229**		**0**		**0**	**229**

Floor Area for kW/m2 = 1600. m2
Conditioned Floor Area = 1600. m2

Sub-Meters Energy Report

	METER NO 1 ELECTRIC UNITARY HEATING				METER NO 2 ELECTRIC UNITARY COOLING				METER NO 3 ELECTRIC UNITARY AUXILIARY			
	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr
JAN	0.00	0	0	0	143.47	15	12	25444	0.00	0	0	0
FEB	0.00	0	0	0	160.58	6	15	23204	0.00	0	0	0
MAR	0.00	0	0	0	119.49	5	12	20909	0.00	0	0	0
APR	0.00	0	0	0	115.06	25	12	19308	0.00	0	0	0
MAY	0.00	0	0	0	109.76	8	12	16260	0.00	0	0	0
JUN	84.00	16	8	1	90.12	9	12	11422	0.00	0	0	0
JUL	84.00	10	8	31	101.89	17	15	12841	0.00	0	0	0
AUG	84.00	6	8	31	97.54	26	12	11343	0.00	0	0	0
SEP	0.00	0	0	0	113.28	22	12	15615	0.00	0	0	0
OCT	0.00	0	0	0	117.56	22	12	20676	0.00	0	0	0
NOV	0.00	0	0	0	124.36	18	11	18202	0.00	0	0	0

DEC	0.00	0	0	0	152.94	23	12	25139	0.00	0	0	0
Total Energy				**63**				**220365**				**0**
Per Sq.m.				**0.0**				**137.7**				**0.0**

	METER NO 4 ELECTRIC UNITARY FAN				**METER NO 5 ELECTRIC AHU Fans**				**METER NO 6 ELECTRIC AHU Aux**			
	Peak Hourly Demand kWhr	**Day/Hr**		**Total Monthly kWhr**	**Peak Hourly Demand kWhr**	**Day/Hr**		**Total Monthly kWhr**	**Peak Hourly Demand kWhr**	**Day/Hr**		**Total Monthly kWhr**
JAN	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
FEB	24.61	3	8	4922	0.00	0	0	0	0.00	0	0	0
MAR	24.61	3	8	5168	0.00	0	0	0	0.00	0	0	0
APR	24.61	1	8	5414	0.00	0	0	0	0.00	0	0	0
MAY	24.61	1	8	5414	0.00	0	0	0	0.00	0	0	0
JUN	24.61	2	8	5168	0.00	0	0	0	0.00	0	0	0
JUL	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
AUG	24.61	1	8	5168	0.00	0	0	0	0.00	0	0	0
SEP	24.61	1	8	5414	0.00	0	0	0	0.00	0	0	0
OCT	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
NOV	24.61	3	8	4922	0.00	0	0	0	0.00	0	0	0
DEC	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
Total Energy				**64235**				**0**				**0**
Per Sq.m.				**40.2**				**0.0**				**0.0**

	METER NO 7 ELECTRIC All Lights				**METER NO 8 ELECTRIC All equipment**			
	Peak Hourly Demand kWhr	**Day/Hr**		**Total Monthly kWhr**	**Peak Hourly Demand kWhr**	**Day/Hr**		**Total Monthly kWhr**
JAN	22.80	1	10	5391	7.60	1	10	1723
FEB	22.80	3	10	4718	7.60	3	10	1509
MAR	22.80	3	10	5000	7.60	3	10	1599
APR	22.80	1	10	5166	7.60	1	10	1652
MAY	22.80	1	10	5195	7.60	1	10	1661
JUN	22.80	2	10	4971	7.60	2	10	1590
JUL	22.80	1	10	5391	7.60	1	10	1723
AUG	22.80	1	10	5000	7.60	1	10	1599
SEP	22.80	1	10	5166	7.60	1	10	1652
OCT	22.80	1	10	5391	7.60	1	10	1723
NOV	22.80	3	10	4775	7.60	3	10	1528
DEC	22.80	1	10	5391	7.60	1	10	1723
Total Energy				**61555**				**19683**
Per Sq.m.				**38.5**				**12.3**

Master Meter Energy Report

	ELECTRICITY		**GAS**		**STEAM**		**TOTAL**
	Peak Hourly kW	**Total Monthly kWhr**	**Peak Hourly Cub. m**	**Total Monthly Cub. m**	**Peak Hourly kgs**	**Total Monthly kgs**	**Monthly kWhr**
JAN	198.	38219	0.	0	0.	0	38219
FEB	216.	34352	0.	0	0.	0	34352
MAR	174.	32676	0.	0	0.	0	32676
APR	170.	31541	0.	0	0.	0	31541
MAY	165.	28532	0.	0	0.	0	28532
JUN	145.	23152	0.	0	0.	0	23152
JUL	157.	25647	0.	0	0.	0	25647
AUG	153.	23142	0.	0	0.	0	23142
SEP	168.	27848	0.	0	0.	0	27848
OCT	173.	33451	0.	0	0.	0	33451
NOV	179.	29427	0.	0	0.	0	29427
DEC	208.	37914	0.	0	0.	0	37914

Total Energy	**365901**	**0**	**0**	**365902**
Per Sq.m.	**229**	**0**	**0**	**229**

Floor Area for kW/m2 = 1600. m2
Conditioned Floor Area = 1600. m2

Sub-Meters Energy Report

	METER NO 1 ELECTRIC UNITARY HEATING				METER NO 2 ELECTRIC UNITARY COOLING				METER NO 3 ELECTRIC UNITARY AUXILIARY			
	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr
JAN	0.00	0	0	0	143.47	15	12	25444	0.00	0	0	0
FEB	0.00	0	0	0	160.58	6	15	23204	0.00	0	0	0
MAR	0.00	0	0	0	119.49	5	12	20909	0.00	0	0	0
APR	0.00	0	0	0	115.06	25	12	19308	0.00	0	0	0
MAY	0.00	0	0	0	109.76	8	12	16260	0.00	0	0	0
JUN	84.00	16	8	1	90.12	9	12	11422	0.00	0	0	0
JUL	84.00	10	8	31	101.89	17	15	12841	0.00	0	0	0
AUG	84.00	6	8	31	97.54	26	12	11343	0.00	0	0	0
SEP	0.00	0	0	0	113.28	22	12	15615	0.00	0	0	0
OCT	0.00	0	0	0	117.56	22	12	20676	0.00	0	0	0
NOV	0.00	0	0	0	124.36	18	11	18202	0.00	0	0	0
DEC	0.00	0	0	0	152.94	23	12	25139	0.00	0	0	0
Total Energy				**63**				**220365**				**0**
Per Sq.m.				**0.0**				**137.7**				**0.0**

	METER NO 4 ELECTRIC UNITARY FAN				METER NO 5 ELECTRIC AHU Fans				METER NO 6 ELECTRIC AHU Aux			
	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr
JAN	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
FEB	24.61	3	8	4922	0.00	0	0	0	0.00	0	0	0
MAR	24.61	3	8	5168	0.00	0	0	0	0.00	0	0	0
APR	24.61	1	8	5414	0.00	0	0	0	0.00	0	0	0
MAY	24.61	1	8	5414	0.00	0	0	0	0.00	0	0	0
JUN	24.61	2	8	5168	0.00	0	0	0	0.00	0	0	0
JUL	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
AUG	24.61	1	8	5168	0.00	0	0	0	0.00	0	0	0
SEP	24.61	1	8	5414	0.00	0	0	0	0.00	0	0	0
OCT	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
NOV	24.61	3	8	4922	0.00	0	0	0	0.00	0	0	0
DEC	24.61	1	8	5661	0.00	0	0	0	0.00	0	0	0
Total Energy				**64235**				**0**				**0**
Per Sq.m.				**40.2**				**0.0**				**0.0**

	METER NO 7 ELECTRIC All Lights				METER NO 8 ELECTRIC All equipment			
	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr
JAN	22.80	1	10	5391	7.60	1	10	1723
FEB	22.80	3	10	4718	7.60	3	10	1509
MAR	22.80	3	10	5000	7.60	3	10	1599
APR	22.80	1	10	5166	7.60	1	10	1652
MAY	22.80	1	10	5195	7.60	1	10	1661
JUN	22.80	2	10	4971	7.60	2	10	1590
JUL	22.80	1	10	5391	7.60	1	10	1723
AUG	22.80	1	10	5000	7.60	1	10	1599
SEP	22.80	1	10	5166	7.60	1	10	1652
OCT	22.80	1	10	5391	7.60	1	10	1723
NOV	22.80	3	10	4775	7.60	3	10	1528
DEC	22.80	1	10	5391	7.60	1	10	1723
Total Energy				**61555**				**19683**
Per Sq.m.				**38.5**				**12.3**

No ERV – System 2

ACADS BSG Program

BEAVER SYSTEMS

Version Number 7.11.1

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BEAVER has been successfully validated against BESTEST. The conclusions obtained are listed in the User Guide

CALCULATION BUILD NUMBER 7.11.1BU

Project Data

```
PROJECT NAME         Multi-Purpose Hall - ERV
PROJECT LOCATION
PROJECT NUMBER
BUILDING NAME        Multi-Purpose Hall - ERV
ADDRESS
LOADS RUN DESC.

SYSTEMS TITLE

SYSTEMS RUN DESC.
FIRM NAME
PROJECT ENGINEER
DATE                  1 SEP 2019
RATING SCHEME (LOADS)   :  BCA Class 9b School                            2010-2013
RATING SCHEME (SYSTEMS):   BCA Class 9b School                            2010-2012
 Weather Data Location
  Weather Station No. - 94294               Site No. -     1
  TOWNSVILLE                                TOWNSVILLE
 Weather file name: TOWNSVILLE1986_TRY.SWF

 Weather Data Period                       Energy Source
  Weather Year    - 1986                    Heating       - ELEC.M.METER
  Starting Date - JAN  1                    Radiation     - ELEC.M.METER
  Ending Date     - DEC 31                  Re-heat       - ELEC.M.METER
                                            Pre-Heating   - ELEC.M.METER

 Electric Heating Schedules                Electric Radiation
  Starting Date - JAN  1                    TURN ON Temp.   10.0
  Ending Date     - DEC 31
```

SUMMARY OF ENERGY

	kWhr	MJ	%
Lighting	61559	221613	15.5
Equipment	19683	70857	4.9
Unitary Cooling	284065	1022634	71.3
Unitary Heating	448	1613	0.1
Unitary Fans	32611	117401	8.2

TOTAL	**398364**	**1434110**
per square metre	249	896
project floor area (m2)	1600	
Condensate total (kl)	168	

Summary of Lighting, Equipment and Process Energy Use

Description	Energy kWhr	Energy Source
LIGHTING L1	61559	ELECTRICITY
EQUIPMENT E1	19683	ELECTRICITY

Maximum Loads Report

SYSTEM ID	Type	No Times Loads Not Met	Maximum Demand	Instal'd Capacity	Last Occurence Mo Day Hr	Outside Cond. DB(C)	WB(C)	Enth.	Cap Avail

Any difference between Cap Avail and Installed Capacity is due to scheduling, derating from insufficient chiller or heating plant capacity or re-rating for VRF units due to ambient and space conditions.

SYSTEM ID	Type	No Times Loads Not Met	Maximum Demand	Instal'd Capacity	Last Occurence Mo Day Hr	DB(C)	WB(C)	Enth.
Cooling Coil			**(kW)**	**(kW)**				
1	2	0	621.7	722.0	2/ 6/15	31.1	28.2	91.12
Heating Coil			**(kW)**	**(kW)**				
1	2	0	89.0	155.0	8/ 6/ 8	15.1	7.6	23.76

Component Peak Hourly and Total Monthly Loads for:

SYSTEM No. 1 Title - AHU1 - NO ERV - No Off 1 Package

Type 2 Constant Volume Single Zone Heating and Cooling

	Cooling Peak kW	Cooling Total kWhrs	Heating Peak kW	Heating Total kWhrs	Radiation Peak kW	Radiation Total kWhrs	Re-Heat Peak kW	Re-Heat Total kWhrs	Condensate Peak l/hr	Condensate Total kl
JAN	522.5	76260	0.0	0	0.0	0	0.0	0	377	42.247
FEB	621.7	73286	0.0	0	0.0	0	0.0	0	526	44.146
MAR	399.1	52813	0.0	0	0.0	0	0.0	0	298	17.484
APR	345.8	42641	0.0	0	0.0	0	0.0	0	265	9.887
MAY	312.7	33553	0.0	0	0.0	0	0.0	0	180	6.563
JUN	173.8	19643	42.4	114	0.0	0	0.0	0	16	0.016
JUL	236.4	21815	78.3	139	0.0	0	0.0	0	88	1.348
AUG	214.4	19071	89.0	194	0.0	0	0.0	0	71	0.515
SEP	293.1	31196	0.0	0	0.0	0	0.0	0	137	1.387
OCT	372.2	47041	0.0	0	0.0	0	0.0	0	210	11.474
NOV	410.3	41317	0.0	0	0.0	0	0.0	0	256	4.566
DEC	545.0	69335	0.0	0	0.0	0	0.0	0	398	28.862
Total		**527971**		**448**		**0**		**0**		**168.495**

	Pre-heating Peak kW	Pre-heating Total kWhrs	Humidification Peak kW	Humidification Total kWhrs	Fan Peak kW	Fan Total kWhrs	Auxiliary Peak kW	Auxiliary Total kWhrs	Total Peak kW	Total Total kWhrs
JAN	0.0	0	0.0	0	12.5	2874	0.0	0	535.0	79134
FEB	0.0	0	0.0	0	12.5	2499	0.0	0	634.2	75785
MAR	0.0	0	0.0	0	12.5	2624	0.0	0	411.6	55437
APR	0.0	0	0.0	0	12.5	2749	0.0	0	358.3	45390
MAY	0.0	0	0.0	0	12.5	2749	0.0	0	325.2	36302
JUN	0.0	0	0.0	0	12.5	2624	0.0	0	186.3	22381
JUL	0.0	0	0.0	0	12.5	2874	0.0	0	248.9	24828
AUG	0.0	0	0.0	0	12.5	2624	0.0	0	226.9	21889
SEP	0.0	0	0.0	0	12.5	2749	0.0	0	305.6	33945
OCT	0.0	0	0.0	0	12.5	2874	0.0	0	384.7	49915
NOV	0.0	0	0.0	0	12.5	2499	0.0	0	422.8	43816
DEC	0.0	0	0.0	0	12.5	2874	0.0	0	557.5	72208
Total		**0**		**0**		**32612**		**0**		**561031**

Hours of operation 2610

Date and Time of Peak Hourly Load

SYSTEM No. 1 Title - AHU1 - NO ERV - No Off 1 Package
Type 2 Constant Volume Single Zone Heating and Cooling

	Cooling		Heating		Radiation		Re-Heat		Condensate	
	Day	Hour	Day	Hour	Day	Hour	Day	Hour	Day	Hour
JAN	15	12	0	0	0	0	0	0	15	12
FEB	6	15	0	0	0	0	0	0	6	15
MAR	27	12	0	0	0	0	0	0	27	12
APR	29	12	0	0	0	0	0	0	29	12
MAY	8	15	0	0	0	0	0	0	8	15
JUN	9	12	26	8	0	0	0	0	16	15
JUL	17	15	30	8	0	0	0	0	3	12
AUG	26	12	6	8	0	0	0	0	26	10
SEP	22	12	0	0	0	0	0	0	30	15
OCT	28	15	0	0	0	0	0	0	28	15
NOV	18	11	0	0	0	0	0	0	18	11
DEC	23	12	0	0	0	0	0	0	23	13

	Pre-heating		Humidification		Fan		Auxiliary		Total	
	Day	Hour	Day	Hour	Day	Hour	Day	Hour	Day	Hour
JAN	0	0	0	0	1	8	0	0	15	12
FEB	0	0	0	0	3	8	0	0	6	15
MAR	0	0	0	0	3	8	0	0	27	12
APR	0	0	0	0	1	8	0	0	29	12
MAY	0	0	0	0	1	8	0	0	8	15
JUN	0	0	0	0	2	8	0	0	9	12
JUL	0	0	0	0	1	8	0	0	17	15
AUG	0	0	0	0	1	8	0	0	26	12
SEP	0	0	0	0	1	8	0	0	22	12
OCT	0	0	0	0	1	8	0	0	28	15
NOV	0	0	0	0	3	8	0	0	18	11
DEC	0	0	0	0	1	8	0	0	23	12

Max and Min Temperatures

During Occupied Period

	HIGHEST Temperatures Temp. (C)	Date Mo/Day/Hr	No.of Occur	LOWEST Temperatures Temp. (C)	Date Mo/Day/Hr	No.Of Occur	
SYSTEM No. 1 Title - AHU1 - NO ERV - No Off 1 (Op. Hours 2610)							
Space 1	23.7	11 14 12	0	21.0	7 10 8	0	Room No 1

Space Temperature Distribution Report

(Number of temperature occurences)

During Occupied Period

SPACE ID	Degree classes BELOW thermostat low temp >3.0	3.0	2.0	1.0	Low TStat Temp.	Set Point (C)	High TStat Temp.	Degree classes ABOVE thermostat high temp 1.0	2.0	3.0	>3.0	% In T'stat Range	% In Range 18-26
SYSTEM No. 1 Title - AHU1 - NO ERV - No Off 1 (Op. Hours 2610)													
1	0	0	0	0	27	22.0	2583	0	0	0	0	100	100

Master Meter Energy Report

	ELECTRICITY Peak Hourly kW	Total Monthly kWhr	GAS Peak Hourly Cub. m	Total Monthly Cub. m	STEAM Peak Hourly kgs	Total Monthly kgs	TOTAL Monthly kWhr
JAN	262.	45336	0.	0	0.	0	45336
FEB	285.	42002	0.	0	0.	0	42002

MAR	209.	36878	0.	0	0.	0	36878
APR	199.	33648	0.	0	0.	0	33649
MAY	190.	29161	0.	0	0.	0	29161
JUN	177.	22498	0.	0	0.	0	22498
JUL	195.	24528	0.	0	0.	0	24528
AUG	177.	22716	0.	0	0.	0	22716
SEP	206.	28920	0.	0	0.	0	28920
OCT	204.	36065	0.	0	0.	0	36065
NOV	219.	32435	0.	0	0.	0	32435
DEC	270.	44175	0.	0	0.	0	44175
Total Energy		**398363**		**0**		**0**	**398364**
Per Sq.m.		**249**		**0**		**0**	**249**

Floor Area for kW/m2 = 1600. m2
Conditioned Floor Area = 1600. m2

Sub-Meters Energy Report

	METER NO 1 ELECTRIC UNITARY HEATING				METER NO 2 ELECTRIC UNITARY COOLING				METER NO 3 ELECTRIC UNITARY AUXILIARY			
	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr
JAN	0.00	0	0	0	218.81	15	12	35348	0.00	0	0	0
FEB	0.00	0	0	0	242.25	26	12	33277	0.00	0	0	0
MAR	0.00	0	0	0	166.34	27	15	27655	0.00	0	0	0
APR	0.00	0	0	0	155.92	25	12	24081	0.00	0	0	0
MAY	0.00	0	0	0	147.55	8	12	19555	0.00	0	0	0
JUN	155.00	25	8	114	101.56	9	12	13199	0.00	0	0	0
JUL	155.00	10	8	139	123.59	8	12	14401	0.00	0	0	0
AUG	155.00	5	8	194	116.33	26	12	13299	0.00	0	0	0
SEP	0.00	0	0	0	163.51	22	12	19353	0.00	0	0	0
OCT	0.00	0	0	0	161.05	28	15	26077	0.00	0	0	0
NOV	0.00	0	0	0	176.20	18	11	23633	0.00	0	0	0
DEC	0.00	0	0	0	227.14	23	12	34187	0.00	0	0	0
Total Energy				**448**				**284065**				**0**
Per Sq.m.				**0.3**				**177.6**				**0.0**

	METER NO 4 ELECTRIC UNITARY FAN				METER NO 5 ELECTRIC AHU Fans				METER NO 6 ELECTRIC AHU Aux			
	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr
JAN	12.49	1	8	2874	0.00	0	0	0	0.00	0	0	0
FEB	12.49	3	8	2499	0.00	0	0	0	0.00	0	0	0
MAR	12.49	3	8	2624	0.00	0	0	0	0.00	0	0	0
APR	12.49	1	8	2749	0.00	0	0	0	0.00	0	0	0
MAY	12.49	1	8	2749	0.00	0	0	0	0.00	0	0	0
JUN	12.49	2	8	2624	0.00	0	0	0	0.00	0	0	0
JUL	12.49	1	8	2874	0.00	0	0	0	0.00	0	0	0
AUG	12.49	1	8	2624	0.00	0	0	0	0.00	0	0	0
SEP	12.49	1	8	2749	0.00	0	0	0	0.00	0	0	0
OCT	12.49	1	8	2874	0.00	0	0	0	0.00	0	0	0
NOV	12.49	3	8	2499	0.00	0	0	0	0.00	0	0	0
DEC	12.49	1	8	2874	0.00	0	0	0	0.00	0	0	0
Total Energy				**32612**				**0**				**0**
Per Sq.m.				**20.4**				**0.0**				**0.0**

	METER NO 7 ELECTRIC All Lights				METER NO 8 ELECTRIC All equipment			
	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr	Peak Hourly Demand kWhr	Day	Hr	Total Monthly kWhr
JAN	22.80	1	10	5391	7.60	1	10	1723
FEB	22.80	3	10	4718	7.60	3	10	1509
MAR	22.80	3	10	5000	7.60	3	10	1599
APR	22.80	1	10	5166	7.60	1	10	1652
MAY	22.80	1	10	5195	7.60	1	10	1661
JUN	22.80	2	10	4971	7.60	2	10	1590

JUL	22.80	1	10	5391	7.60	1	10	1723
AUG	22.80	1	10	5000	7.60	1	10	1599
SEP	22.80	1	10	5166	7.60	1	10	1652
OCT	22.80	1	10	5391	7.60	1	10	1723
NOV	22.80	3	10	4775	7.60	3	10	1528
DEC	22.80	1	10	5391	7.60	1	10	1723
Total Energy				**61555**				**19683**
Per Sq.m.				**38.5**				**12.3**

Hours of Operation

Sched No.	Total Hrs	Title
1	2610	BCA Cl 9b (School) AH Plant

Equivalent Full Load Hrs for LOADS Operating Schedules

NOTE: Values are for total period for which LOADS program has been run.

Sched No.	Equiv'nt Full Load Hrs	Title
1	1944.5	Class 9b (School) Occupancy
2	2565.2	Class 9b (School) Lighting
3	2460.8	Class 9b (School) Equipment
5	2610.0	Class 9b (School) Ventilation Plant Hrs

Plant ON/OFF Schedules

Sch No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Description	Hrs /day
1																									2g Plant Off	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2g 24HR	24
3								1	1	1	1	1	1	1	1	1	1								2g Mon-Frit	10
41									1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	Time of day	16

(1=ON or IN-USE, Blank=OFF or NOT-IN-USE, Mod=user modified, User=user entered)

Operating Schedules by Period and Day

No.	SUN	MON	TUE	WED	THU	FRI	SAT	HOL	End Date mth/day	
1	1	3	3	3	3	3	1	1	12/31	BCA Cl 9b (School) AH Plant

LOADS Internal load profiles

Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
No Load 24 hours																								
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Full Load 24 hours																								
2	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL
2g Occup Mon-Fri																								
3	0	0	0	0	0	0	0	5	75	90	90	90	50	50	90	70	50	20	20	20	10	5	5	5
2g Lights Mon-Fri																								
4	5	5	5	5	5	5	5	30	85	95	95	95	80	80	95	90	70	20	20	20	10	5	5	5
2g Lights Sat-Sun																								
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
2g Equip Mon-Fri																								
6	5	5	5	5	5	5	5	30	85	95	95	95	70	70	95	80	60	20	20	20	10	5	5	5
2g Equip Sat-Sun																								
7	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
DHW Mon-Fri																								

8	90	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
Ventilation Mon-Fri																								
9	0	0	0	0	0	0	0	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	0	0	0	0	0	0	0
Sample Lifts Mon-Fri																								
10	0	0	0	0	0	0	0	10	80	60	10	10	60	10	10	40	60	30	10	10	30	30	0	0

Note: FL (Full Load) means 100%

LOADS Operating Schedules by Period and Day

No.	Load Profile Index S U N	M O N	T U E	W E D	T H U	F R I	S A T	H O L	End Date mth/day	
1	1	3	3	3	3	3	1	3	12/31	Class 9b (School) Occupancy
2	5	4	4	4	4	4	5	5	12/31	Class 9b (School) Lighting
3	7	6	6	6	6	6	7	7	12/31	Class 9b (School) Equipment
5	1	9	9	9	9	9	1	9	12/31	Class 9b (School) Ventilation Plant Hrs

Space Relative Humidity Occurences Report

(Number of relative humidity occurences)

SPACE ID	Relative Humidity Range % 0:10	>10:20	>20:30	>30:40	>40:50	>50:60	>60:70	>70:80	>80:90	>90:100
SYSTEM No. 1 Title - AHU1 - NO ERV -					**No Off 1 (Op. Hours 2610)**					
1	0	14	105	60	69	136	362	1275	587	2

Master Meter Energy Report

	ELECTRICITY Peak Hourly kW	Total Monthly kWhr	GAS Peak Hourly Cub. m	Total Monthly Cub. m	STEAM Peak Hourly kgs	Total Monthly kgs	TOTAL Monthly kWhr
JAN	262.	45336	0.	0	0.	0	45336
FEB	285.	42002	0.	0	0.	0	42002
MAR	209.	36878	0.	0	0.	0	36878
APR	199.	33648	0.	0	0.	0	33649
MAY	190.	29161	0.	0	0.	0	29161
JUN	177.	22498	0.	0	0.	0	22498
JUL	195.	24528	0.	0	0.	0	24528
AUG	177.	22716	0.	0	0.	0	22716
SEP	206.	28920	0.	0	0.	0	28920
OCT	204.	36065	0.	0	0.	0	36065
NOV	219.	32435	0.	0	0.	0	32435
DEC	270.	44175	0.	0	0.	0	44175
Total Energy		**398363**		**0**		**0**	**398364**
Per Sq.m.		**249**		**0**		**0**	**249**

Floor Area for kW/m2 = 1600. m2
Conditioned Floor Area = 1600. m2

Sub-Meters Energy Report

METER NO 1 ELECTRIC UNITARY HEATING Peak Hourly Demand	Total Monthly	METER NO 2 ELECTRIC UNITARY COOLING Peak Hourly Demand	Total Monthly	METER NO 3 ELECTRIC UNITARY AUXILIARY Peak Hourly Demand	Total Monthly

	kWhr	Day/Hr	kWhr	kWhr	Day/Hr	kWhr	kWhr	Day/Hr	kWhr
JAN	0.00	0 0	0	218.81	15 12	35348	0.00	0 0	0
FEB	0.00	0 0	0	242.25	26 12	33277	0.00	0 0	0
MAR	0.00	0 0	0	166.34	27 15	27655	0.00	0 0	0
APR	0.00	0 0	0	155.92	25 12	24081	0.00	0 0	0
MAY	0.00	0 0	0	147.55	8 12	19555	0.00	0 0	0
JUN	155.00	25 8	114	101.56	9 12	13199	0.00	0 0	0
JUL	155.00	10 8	139	123.59	8 12	14401	0.00	0 0	0
AUG	155.00	5 8	194	116.33	26 12	13299	0.00	0 0	0
SEP	0.00	0 0	0	163.51	22 12	19353	0.00	0 0	0
OCT	0.00	0 0	0	161.05	28 15	26077	0.00	0 0	0
NOV	0.00	0 0	0	176.20	18 11	23633	0.00	0 0	0
DEC	0.00	0 0	0	227.14	23 12	34187	0.00	0 0	0
Total Energy			**448**			**284065**			**0**
Per Sq.m.			**0.3**			**177.6**			**0.0**

	METER NO 4 UNITARY	**ELECTRIC FAN**		**METER NO 5 AHU Fans**	**ELECTRIC**		**METER NO 6 AHU Aux**	**ELECTRIC**	
	Peak Hourly Demand kWhr	**Day/Hr**	**Total Monthly kWhr**	**Peak Hourly Demand kWhr**	**Day/Hr**	**Total Monthly kWhr**	**Peak Hourly Demand kWhr**	**Day/Hr**	**Total Monthly kWhr**
JAN	12.49	1 8	2874	0.00	0 0	0	0.00	0 0	0
FEB	12.49	3 8	2499	0.00	0 0	0	0.00	0 0	0
MAR	12.49	3 8	2624	0.00	0 0	0	0.00	0 0	0
APR	12.49	1 8	2749	0.00	0 0	0	0.00	0 0	0
MAY	12.49	1 8	2749	0.00	0 0	0	0.00	0 0	0
JUN	12.49	2 8	2624	0.00	0 0	0	0.00	0 0	0
JUL	12.49	1 8	2874	0.00	0 0	0	0.00	0 0	0
AUG	12.49	1 8	2624	0.00	0 0	0	0.00	0 0	0
SEP	12.49	1 8	2749	0.00	0 0	0	0.00	0 0	0
OCT	12.49	1 8	2874	0.00	0 0	0	0.00	0 0	0
NOV	12.49	3 8	2499	0.00	0 0	0	0.00	0 0	0
DEC	12.49	1 8	2874	0.00	0 0	0	0.00	0 0	0
Total Energy			**32612**			**0**			**0**
Per Sq.m.			**20.4**			**0.0**			**0.0**

	METER NO 7 All Lights	**ELECTRIC**		**METER NO 8 All equipment**	**ELECTRIC**	
	Peak Hourly Demand kWhr	**Day/Hr**	**Total Monthly kWhr**	**Peak Hourly Demand kWhr**	**Day/Hr**	**Total Monthly kWhr**
JAN	22.80	1 10	5391	7.60	1 10	1723
FEB	22.80	3 10	4718	7.60	3 10	1509
MAR	22.80	3 10	5000	7.60	3 10	1599
APR	22.80	1 10	5166	7.60	1 10	1652
MAY	22.80	1 10	5195	7.60	1 10	1661
JUN	22.80	2 10	4971	7.60	2 10	1590
JUL	22.80	1 10	5391	7.60	1 10	1723
AUG	22.80	1 10	5000	7.60	1 10	1599
SEP	22.80	1 10	5166	7.60	1 10	1652
OCT	22.80	1 10	5391	7.60	1 10	1723
NOV	22.80	3 10	4775	7.60	3 10	1528
DEC	22.80	1 10	5391	7.60	1 10	1723
Total Energy			**61555**			**19683**
Per Sq.m.			**38.5**			**12.3**

Hours of Operation

Sched No.	**Total Hrs**	**Title**
1	2610	BCA Cl 9b (School) AH Plant

Equivalent Full Load Hrs for LOADS Operating Schedules

NOTE: Values are for total period for which LOADS program has been run.

Sched No.	**Equiv'nt Full Load Hrs**	**Title**

1	1944.5	Class 9b (School) Occupancy
2	2565.2	Class 9b (School) Lighting
3	2460.8	Class 9b (School) Equipment
5	2610.0	Class 9b (School) Ventilation Plant Hrs

Plant ON/OFF Schedules

Sch No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Description	Hrs /day
1																									2g Plant Off	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2g 24HR	24
3								1	1	1	1	1	1	1	1	1	1								2g Mon-Frit	10
41									1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	Time of day	16

(1=ON or IN-USE, Blank=OFF or NOT-IN-USE, Mod=user modified, User=user entered)

Operating Schedules by Period and Day

No.	On/Off Schedule SUN	MON	TUE	WED	THU	FRI	SAT	HOL	End Date mth/day	
1	1	3	3	3	3	3	1	1	12/31	BCA Cl 9b (School) AH Plant

LOADS Internal load profiles

Index	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
No Load 24 hours																								
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Full Load 24 hours																								
2	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL
2g Occup Mon-Fri																								
3	0	0	0	0	0	0	0	5	75	90	90	90	50	50	90	70	50	20	20	20	10	5	5	5
2g Lights Mon-Fri																								
4	5	5	5	5	5	5	5	30	85	95	95	95	80	80	95	90	70	20	20	20	10	5	5	5
2g Lights Sat-Sun																								
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
2g Equip Mon-Fri																								
6	5	5	5	5	5	5	5	30	85	95	95	95	70	70	95	80	60	20	20	20	10	5	5	5
2g Equip Sat-Sun																								
7	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
DHW Mon-Fri																								
8	90	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
Ventilation Mon-Fri																								
9	0	0	0	0	0	0	0	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	0	0	0	0	0	0	0
Sample Lifts Mon-Fri																								
10	0	0	0	0	0	0	0	10	80	60	10	10	60	10	10	40	60	30	10	10	30	30	0	0

Note: FL (Full Load) means 100%

LOADS Operating Schedules by Period and Day

No.	Load Profile Index SUN	MON	TUE	WED	THU	FRI	SAT	HOL	End Date mth/day	
1	1	3	3	3	3	3	1	3	12/31	Class 9b (School) Occupancy
2	5	4	4	4	4	4	5	5	12/31	Class 9b (School) Lighting
3	7	6	6	6	6	6	7	7	12/31	Class 9b (School) Equipment
5	1	9	9	9	9	9	1	9	12/31	Class 9b (School) Ventilation Plant Hrs

I Appendix I

Life Cycle Cost Spreadsheet

System 1 – ERV Packaged Unit

PACKAGED ERV

Table I-1: System 1 - Life Cycle Breakdown

Year	Capital Costs	Electricity Costs	Maintenance Costs	Total
0	$ 409,603.00	$ 98,793.27	$ 16,320.00	$ 524,716.27
1	$ -	$ 103,732.93	$ 16,646.40	$ 645,095.60
2	$ -	$ 108,919.58	$ 16,979.33	$ 770,994.51
3	$ -	$ 114,365.56	$ 17,318.91	$ 902,678.99
4	$ -	$ 120,083.84	$ 17,665.29	$ 1,040,428.12
5	$ -	$ 126,088.03	$ 18,018.60	$ 1,184,534.74
6	$ -	$ 132,392.43	$ 18,378.97	$ 1,335,306.14
7	$ -	$ 139,012.05	$ 18,746.55	$ 1,493,064.75
8	$ -	$ 145,962.65	$ 19,121.48	$ 1,658,148.88
9	$ -	$ 153,260.79	$ 19,503.91	$ 1,830,913.58
10	$ -	$ 160,923.83	$ 19,893.99	$ 2,011,731.40
11	$ -	$ 168,970.02	$ 20,291.87	$ 2,200,993.28
12	$ -	$ 177,418.52	$ 20,697.71	$ 2,399,109.51
13	$ -	$ 186,289.44	$ 21,111.66	$ 2,606,510.61
14	$ -	$ 195,603.92	$ 21,533.89	$ 2,823,648.42
15	$ -	$ 205,384.11	$ 21,964.57	$ 3,050,997.11
16	$ -	$ 215,653.32	$ 22,403.86	$ 3,289,054.29
17	$ -	$ 226,435.98	$ 22,851.94	$ 3,538,342.21
18	$ -	$ 237,757.78	$ 23,308.98	$ 3,799,408.98
19	$ -	$ 249,645.67	$ 23,775.16	$ 4,072,829.81
20	$ -	$ 262,127.96	$ 24,250.66	$ 4,359,208.42
21	$ -	$ 275,234.35	$ 24,735.67	$ 4,659,178.45
22	$ -	$ 288,996.07	$ 25,230.39	$ 4,973,404.91
23	$ -	$ 303,445.88	$ 25,735.00	$ 5,302,585.79
24	$ -	$ 318,618.17	$ 26,249.70	$ 5,647,453.65
25	$ -	$ 334,549.08	$ 26,774.69	$ 6,008,777.42

System 2 – No ERV

PACKAGED AHU

Table I-2: System 2 - Life Cycle Breakdown

Year	Capital Costs	Electricity Costs	Maintenance Costs	Total
0	$ 330,708.00	$ 107,558.01	$ 16,320.00	$ 454,586.01
1	$ -	$ 112,935.91	$ 16,646.40	$ 584,168.32
2	$ -	$ 118,582.71	$ 16,979.33	$ 719,730.35
3	$ -	$ 124,511.84	$ 17,318.91	$ 861,561.11
4	$ -	$ 130,737.43	$ 17,665.29	$ 1,009,963.84
5	$ -	$ 137,274.31	$ 18,018.60	$ 1,165,256.74
6	$ -	$ 144,138.02	$ 18,378.97	$ 1,327,773.73
7	$ -	$ 151,344.92	$ 18,746.55	$ 1,497,865.20
8	$ -	$ 158,912.17	$ 19,121.48	$ 1,675,898.85
9	$ -	$ 166,857.78	$ 19,503.91	$ 1,862,260.54
10	$ -	$ 175,200.66	$ 19,893.99	$ 2,057,355.19
11	$ -	$ 183,960.70	$ 20,291.87	$ 2,261,607.76
12	$ -	$ 193,158.73	$ 20,697.71	$ 2,475,464.20
13	$ -	$ 202,816.67	$ 21,111.66	$ 2,699,392.53
14	$ -	$ 212,957.50	$ 21,533.89	$ 2,933,883.92
15	$ -	$ 223,605.38	$ 21,964.57	$ 3,179,453.87
16	$ -	$ 234,785.65	$ 22,403.86	$ 3,436,643.38
17	$ -	$ 246,524.93	$ 22,851.94	$ 3,706,020.25
18	$ -	$ 258,851.18	$ 23,308.98	$ 3,988,180.40
19	$ -	$ 271,793.73	$ 23,775.16	$ 4,283,749.30
20	$ -	$ 285,383.42	$ 24,250.66	$ 4,593,383.38
21	$ -	$ 299,652.59	$ 24,735.67	$ 4,917,771.65
22	$ -	$ 314,635.22	$ 25,230.39	$ 5,257,637.26
23	$ -	$ 330,366.98	$ 25,735.00	$ 5,613,739.24
24	$ -	$ 346,885.33	$ 26,249.70	$ 5,986,874.26
25	$ -	$ 364,229.60	$ 26,774.69	$ 6,377,878.55

Deficit

Table I-3: System Comparison - Cost Deficit

Year	System 1 - ERV	System 2 - No ERV	Deficit
0	$ 524,716.27	$ 454,586.01	-$ 70,130.26
1	$ 645,095.60	$ 584,168.32	-$ 60,927.28
2	$ 770,994.51	$ 719,730.35	-$ 51,264.16
3	$ 902,678.99	$ 861,561.11	-$ 41,117.88
4	$ 1,040,428.12	$ 1,009,963.84	-$ 30,464.28
5	$ 1,184,534.74	$ 1,165,256.74	-$ 19,278.00
6	$ 1,335,306.14	$ 1,327,773.73	-$ 7,532.41
7	$ 1,493,064.75	$ 1,497,865.20	$ 4,800.46
8	$ 1,658,148.88	$ 1,675,898.85	$ 17,749.97
9	$ 1,830,913.58	$ 1,862,260.54	$ 31,346.96
10	$ 2,011,731.40	$ 2,057,355.19	$ 45,623.80
11	$ 2,200,993.28	$ 2,261,607.76	$ 60,614.48
12	$ 2,399,109.51	$ 2,475,464.20	$ 76,354.69
13	$ 2,606,510.61	$ 2,699,392.53	$ 92,881.91
14	$ 2,823,648.42	$ 2,933,883.92	$110,235.50
15	$ 3,050,997.11	$ 3,179,453.87	$128,456.76
16	$ 3,289,054.29	$ 3,436,643.38	$147,589.09
17	$ 3,538,342.21	$ 3,706,020.25	$167,678.04
18	$ 3,799,408.98	$ 3,988,180.40	$188,771.43
19	$ 4,072,829.81	$ 4,283,749.30	$210,919.49
20	$ 4,359,208.42	$ 4,593,383.38	$234,174.96
21	$ 4,659,178.45	$ 4,917,771.65	$258,593.19
22	$ 4,973,404.91	$ 5,257,637.26	$284,232.34
23	$ 5,302,585.79	$ 5,613,739.24	$311,153.45
24	$ 5,647,453.65	$ 5,986,874.26	$339,420.61
25	$ 6,008,777.42	$ 6,377,878.55	$369,101.13