AN ANALYSIS OF THE RELATIONSHIP BETWEEN AIRPORT SYSTEMS AND OPERATIONS AND THE IMPACT THE EFFICIENCY OF THIS CYCLE CAN HAVE ON ENVIRONMENTAL EMISSIONS.

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Acknowledgements

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Abstract

This thesis presents the analysis of the relationship between airport systems and operations and the impact the efficiency of this cycle can have on environmental emissions. Simulations of the existing and hypothetical relationships between the buildings existing services and operations are developed using the quantitative methodology, so allowing valid comparisons across the models. Although these systems and building efficiency techniques are well discussed in the literature in the light of different reduction techniques, this research has a different approach. The simulations allow analysis using a variety of hypothetical relationship patterns. The first simulation (Phase One) is the existing service and operations relationship. Results are analysed on a quantitative analysis technique basis to produce performance metrics. The performance metrics to be compared are the kWh and CO_2 emissions from the plants providing the comfort conditions. The first hypothetical relationship (Phase Two) manipulates the building service, to be provided only on operational demand. Results from the simulation are analysed on a comparative basis with the performance metrics from Phase One. The second hypothetical relationship (Phase Three) manipulates both the operation and service. The second simulation manipulates the buildings operation, and the service to be provided on the hypothetical operational demand in an attempt to reduce the CO_2 emissions. Results from the second simulation are analysed on a comparative basis with the performance metrics from Phase Two.

Manchester Airport has committed to be carbon neutral on airport energy use by 2015 (MAG, 2007). This is the point where the research can offer some help. Findings from the analysis will provide insight in measures to reduce not only Manchester's carbon emissions, but all airports within the UK. In addition, creation of the hypothetical relationship simulation models is shown to be a useful methodological tool for energy managers in making decisions concerning energy reduction policies.

1.0 OVERVIEW OF THE RESEARCH

This research demonstrates the effect that the relationship between airport building services systems and airfield operations can have on the buildings energy consumption and the subsequent carbon emissions.

Buildings electrical energy consumption is measured by kilowatt Hour (kWh) ("how much," n.d., para. 4) therefore the energy consumption of the building services equipment will be calculated and the subsequent CO_2 emissions released from these operations will be derived utilising the appropriate calculations.

The efficiency of this relationship could have a significant effect on the environmental impact, as the airport operates on a 24 hour 7 days a week basis; therefore the building services are also operating 24 hours providing passengers and staff with visual and thermal comfort conditions. The interaction between the operations and the systems, and the communication between the associated departments can play a significant part in energy management. If there is poor interaction or communication between the operations and services, this could lead to services or operations being provided in areas which are not required at that specific time period therefore contributing to energy wastage and unnecessary emissions.

Manchester Airport has a Master Plan prepared as do most airports in the UK; this follows the publication of the Government's White Paper; The Future of Airport Transport (Department for Transport. December 2003). Following detailed economic, capacity and environmental studies, Government policy is to support growth at Manchester up to the capacity of its two runways. But this is subject to dealing with the environmental challenges that growth will bring. By 2030, the Government believes the number of passengers travelling through the Airport could reach 50 million a year.

> The Master Plan sets out how we see our business developing through to 2030 and outlines our approach to important issues such as sustainable development, environmental impact and our economic and social effect on local communities and the wider North West. We are committed to the sustainable growth of our business. Our aim is to maximise the economic and social benefits that we bring while minimising the environmental and social harm caused by our activities. (Manchester Airport, 2007, p 3).

The Master Plan is supported by four detailed Action Plans that cover Community, Ground Transport, Land use and Environment; this research will be conducting a closer look at the Environment Plan.

In the Environmental Plan of 2007, Manchester Airport describes the intentions as:

- Set a clear framework to guide the environmental policy and management of the Airport up to 2030 in line with the Air Transport White Paper;
- Identify the key environmental issues that will influence the growth and development of the Airport;
- Set short, medium and long term targets and actions that will form part of the environmental programme.

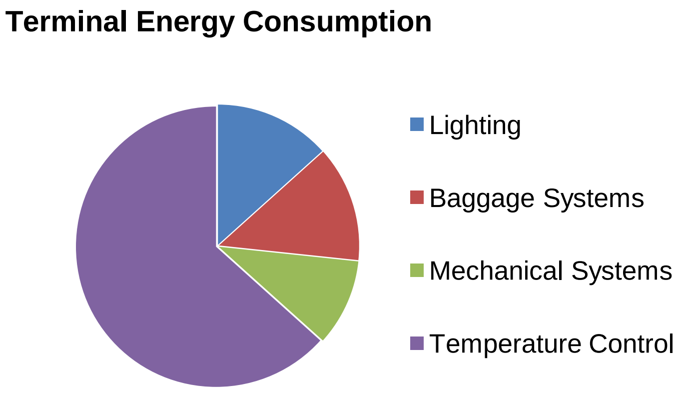
Manchester Airport use Environmental Performance Indicators to measure the level of impact and progress made towards their environmental goals. The obvious contributor is aircraft manoeuvres, but there are many operations contributing to the overall environmental impact, these include baggage handling, airfield lighting, passenger car parking, staff car parking, terminal lighting, car park lighting and air conditioning. Some of the operations are within direct control of the airport management teams but there are also operations that are under the control of third party companies who operate within the airport guidelines, who also have responsibility for environmental issues.

There are many systems that are involved in providing the airport's customer service including flight information, baggage reconciliation, baggage handling, travelators, lifts and many more, to cover all aspects of the airport systems is beyond the scope of this research therefore we have chosen to research the system which is arguably the largest energy user which is building services.

Building services covers a large envelope of systems including air conditioning, heating plant, cooling plant, lighting and hot water; which there is much literature available describing these systems in more detail, this particular research does not cover the whole building services umbrella, but does cover building services incorporated into the air conditioning plant providing comfort conditions to the reviewed area. These particular building services are explained in more details in following sections.

Chapter 4 – Climate Change of the Manchester Airport Environmental Plan (2007) states: About half of the energy used on-site is by our service partners. Energy use within our direct control includes:

- Heating and Ventilation plant;
- Electro-mechanical systems such as autowalks, escalators, lifts and baggage systems;
- Lighting in the terminals, other buildings, car parks and airfield.



Source: MAG Environmental Plan 2007

Depending on the conclusion of this particular research, additional research could be conducted incorporating other building services into the new efficient operational cycle to produce even greater emission reductions. The obvious building service to be incorporated would be terminal lighting as the terminal lighting and air conditioning run in conjunction to provide the required regulatory conditions required for that specifically utilised space.

The research is going to concentrate on the particular services and operations which provide a comfortable and safe environment for the passenger experience. Due to the size and complexity of the airport site, a specific area has been chosen to conduct the research within. One of the international piers has been chosen due to its 24 hour, 7 days a week schedule, therefore examining which operations and what systems are delivered on the passenger experience in this area.

There are Three Terminal Buildings incorporated within the Manchester Airport site, Figure 1.1 below displays an overview of Terminal 1 and highlights the chosen area of International C-Pier within which the research is to be conducted.

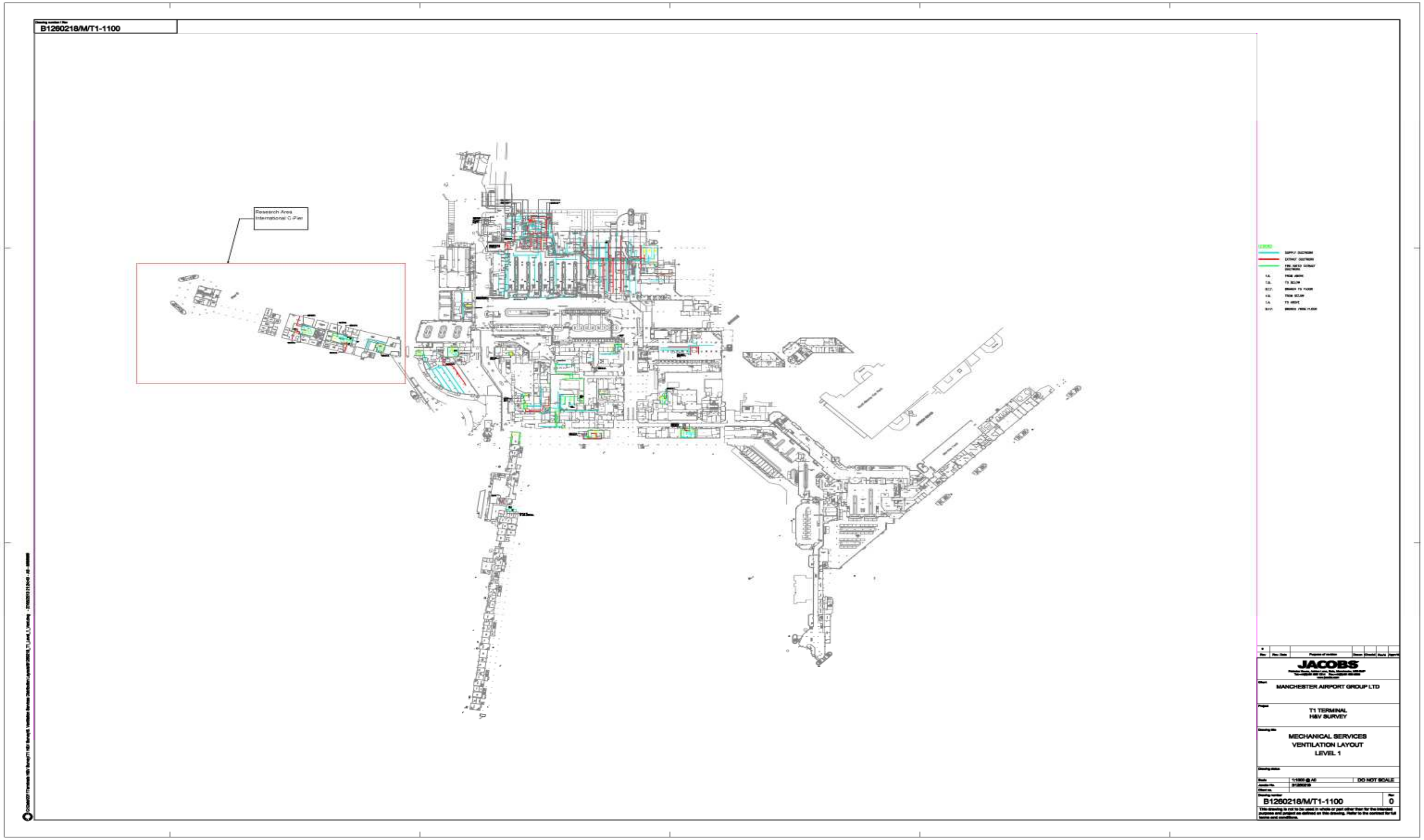


Figure 1-1 – Terminal 1 overview

Future research could incorporate the journey to and from the airport utilising public or private transport and also monitor occupant activity in other areas other than stand allocation routes.

Figure 1.2 graphically displays the relationship between the airport systems and operations and the effect this relationship can have on the environmental impact and also displays how the operational cycle can improve energy waste management.

There are many operations and systems which play integral parts in the operational cycle, and this only highlights the importance of the relationship between the two groups. The better the integration between the two groups, the greater the efficiency of the operational cycle will become.

The more efficient the operational cycle can operate, the greater the environmental impact and electrical energy consumption will improve.

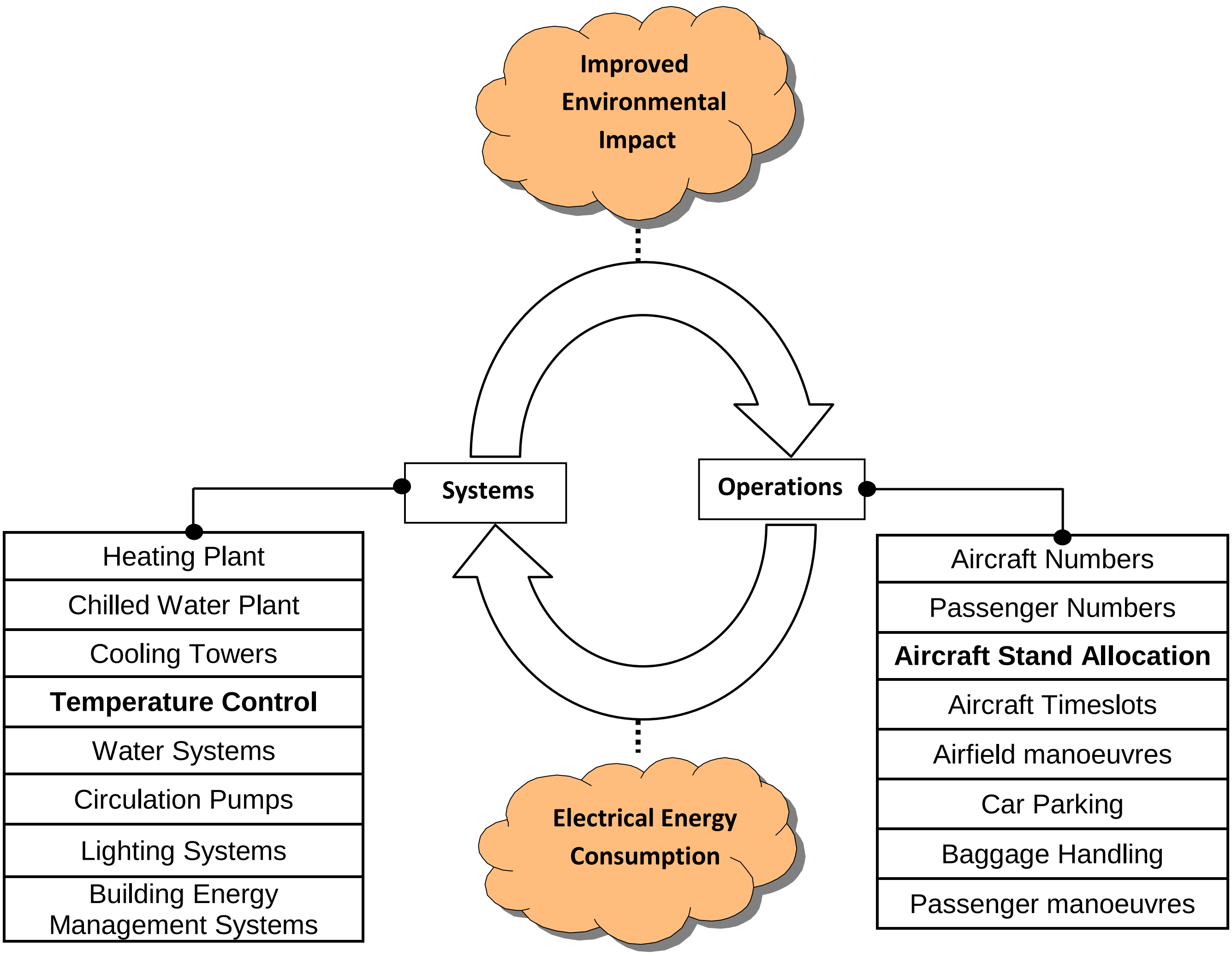


Figure 1-2 – operational cycle

1.1 MANCHESTER AIRPORT

The Manchester Airports Group (MAG) is the country's largest UK owned airport operator. Within the group there are four airports – Manchester, East Midlands, Bournemouth and Humberside which combined serve a total of more than 28 million passengers every year. ("Our Airports," n d,. para. 1)

The group support's the UK Government's commitment to the principles of sustainable development in the aviation industry, striking a balance between economic, social and environmental considerations.

Manchester Airport is the largest and busiest of the four airports, and in 2007/08 served more than 22 million passengers: 8.2 million on charter flights, 10.9 million on schedule flights and 3.5 million on domestic flights. By 2030 passenger numbers are expected to rise to 50 million. ("Manchester Airport," n.d., para 1)

The Airport is home to more than 100 airlines and 300 tour operators serving more than 220 destinations worldwide, more than any other UK airport. It is for this reason that the research is primarily undertaking at this site with the possibility of creating a working framework for the other airports within the group.

1.2 RESEARCH AIMS

The aim of this research is to examine the current environmental emissions and reduction methods and options available to the Airport Site and assess the relationship between the Airport Systems and operations in an endeavour to provide insights into whether the efficiency of this operational cycle has any effect on the environmental impact.

1.3 RESEARCH OBJECTIVES

The following research objectives aim to accomplish the research aims stated above:

1. Examine the current environmental emissions and available reduction methods.
2. Examine the current Airport operations and systems relationship.
3. Examine the current building services energy reduction methods.
4. Examine the energy usage and subsequent effect the operational cycle has on the environmental impact.
5. Collate data to analyse the existing energy use of the temperature control plant.
6. Collate actual data to analyse the existing aircraft stand allocations to determine the relationship of the operational cycle.
7. Analyse the data results to determine whether the operational cycle can become more efficiency and create a reduction on the environmental emissions.

8. Utilise the collated data to forecast emissions from the temperature control plant on the existing operational cycle pattern.

9. Utilise the research data to forecast emissions from the temperature control plant on a hypothetical operational cycle pattern.

1.4 RESEARCH QUESTIONS

The research objectives mentioned above constitute the following research questions:

1. What effect does the interaction within the operational cycle have on the environmental impact?

2. How provisions of building services are influenced by aircraft stand allocation?

3. Can data exchange and greater interaction between systems and operations influence environmental emissions?

1.5 IMPORTANCE OF THE RESEARCH

Based on issues discussed in section 1.0, it is clear that European Airports have to face challenges to improve their carbon emissions in order to fulfil their obligations to achieve their set government standards and current legislations, specifically the 2020 Climate and Energy Package.

The aviation industry has shown significant growth over the last few years and signs are the growth is going to continue in the future, (MAG n.d., para 2) therefore the research area is going to take on more significance as the aircraft and passenger numbers increase. ("Aviation Development," n.d., para 2)

There are many research ideas, including Multi agent systems, neural networks and holistic management procedures to optimise building services and energy management with ever increasing Intelligent Building Management Systems being developed, especially with the introduction of the open protocol BACnet which allows multi vendor hardware to be incorporated into a sites existing building management system providing an array of different energy management products.

However there is crucial need for improvement with the integration and passing of relevant data between the numerous information systems incorporated into the modern day building. Improved communication between the building management systems and operational information systems will lead to a more efficient operational cycle and reduce electrical consumption and subsequent emissions.

1.6 EXPECTED CONTRIBUTION TO KNOWLEDGE

This study aims to increase understanding of the effect, greater integration between systems and operations within the operational cycle may have on the environmental emission.

1.6.1 Benefits for theory

1. Demonstrating the quantitative analyses methodology as a beneficial tool for analysing operational system efficiency.
2. Manipulating the data under different operational and system patterns as a way of evaluating the performance of the operational cycle.
3. Offering further insight of the systems relationship under particular operational and system patterns and formulate policies to improve operational cycle efficiency.
4. Offering further insight into the importance of interoperability between multiple systems and operations to improve a buildings operational efficiency.

1.6.2 Benefits for practice

1. Produce a working framework to be introduced on different areas of the airport site.
2. Produce a working framework to be introduced across the Manchester Airports Group.

1.7 RESEARCH SCOPE

The research is concerned with the relationship between building systems and building operations; and the effect this cycle can have on a buildings carbon emissions. Manchester Airport site was chosen due to its complexity with multiple operations and systems already set in place which operate on a 24/7 basis, this could provide greater scope for future improvement. With this in mind, the initial research has had boundaries set which envelope a specific system and operation. The system selected is temperature control due to it being the largest energy consumer within the terminal building. The operation selected is Aircraft Stand Allocation due to its varying relationship with temperature control. The relationship is defined as varying due to the fact that temperature control in the specific gate area will only be required during set departure and arrival times.

1.8 METHODOLOGICAL SUMMARY

The research was largely formed using the Quantitative method (Saunders et al., 2011). Data was gathered from existing air conditioning plants located within the dedicated research area of the building, flight information for the month of April 2012 was also collated. The month of April was chosen as an average representation of the normal flight numbers allocated to the specific gates during a year. Quantitative analysis techniques were then performed on the data to produce the existing and hypothetical results for further analysis. A more in depth explanation of the methodology consideration are detailed within chapter 3.

1.9 STRUCTURE OF THE THESIS

The thesis consists of five chapters which can be categorized as; an introduction of the research in Chapter One, establishing the problem from the reviewed literature in Chapter two, describing the research methodology employed in Chapter three and research findings analysis in Chapter four. The final Chapter discusses the findings and contributions arising from this research.

Chapter one introduces the background to the research; its aims, objectives, questions to be answered, its importance, expected contribution and research scope. Finally, the methodology employed and structure of the thesis is described.

Chapter Two initially reviews building services literature which establishes the requirement for further reviews into current and previous research in improving building efficiency procedures in which system integration has been discussed.

Chapter Three describes the research methodology employed in order to undertake the research and to answer the research questions.

Chapter Four covers the analyses of the research findings, which includes a comparison of the energy used and subsequent emissions from the existing operational cycle, energy used and subsequent emissions from improved interoperability within the operational cycle and finally energy used and subsequent emissions from improving the operation (Stand Allocation) which forms part of the operational cycle.

Finally, in Chapter Five, the thesis concludes with a discussion of the findings, contributions and suggestions for future research.

2.0 INTRODUCTION

This chapter follows from the discussion in Chapter One to highlight the importance of the research, and is split into seven different sections. Section 2.1 describes the scope of the review detailing the review parameters. The following sections continue with reviews into energy use and a subsequent section on environmental emissions. Emissions are included in this review to demonstrate the importance of the research, due to growing concerns not only nationally, internationally but globally the impact on the way modern society lives today. This may affect the environment that future generations live in unless ongoing research into energy management and energy reductions methods are continued. The review continues with research into building services plant and the Building Management Systems implemented to control them. A small section on aircraft taxiing procedures is included to demonstrate the importance of discovering new methods and ideas to maximise operational efficiency and the impact that the operational efficiency of the systems and operations can have on the environmental impact. This discussion eventually leads to a description of the relationship between building services systems and aircraft allocation management in section 2.6. Finally the research gap in both building services energy management and aircraft allocation management is highlighted specifically the research gap in the relationship between the system and operation. This is to demonstrate the significance of the thesis in providing additional knowledge in those fields.

2.1 SCOPE OF REVIEW

The scope covered by the literature review involves energy reduction of building services plant, environmental emissions at Manchester Airport and research work in energy reduction procedures of building services. As discussed in Chapter One Building Services incorporates a large number of systems including lighting, drainage, Domestic hot water, heating, cooling which all can be monitored by many different manufacturers of building management systems, there are many books and journals not only focusing on these areas but also books and journals focusing on different control techniques for the different services and how they can interact, for this reason, the review is confined to a specific building service which is the air conditioning plants, the research structure is displayed in figure 2.1. Research work addressing energy management of the excluded building services is not included in this discussion, although future research into the additional building service systems deployed within the same area analysed within this research could be conducted and the findings discussed in conjunction with the research conclusions. The review of Air Conditioning Plant focuses on various energy management procedures including incorporating modern efficient system hardware and initiating a more energy efficient optimisation control strategy via the Building Management Systems software programs which is described in detail in section 2.2.

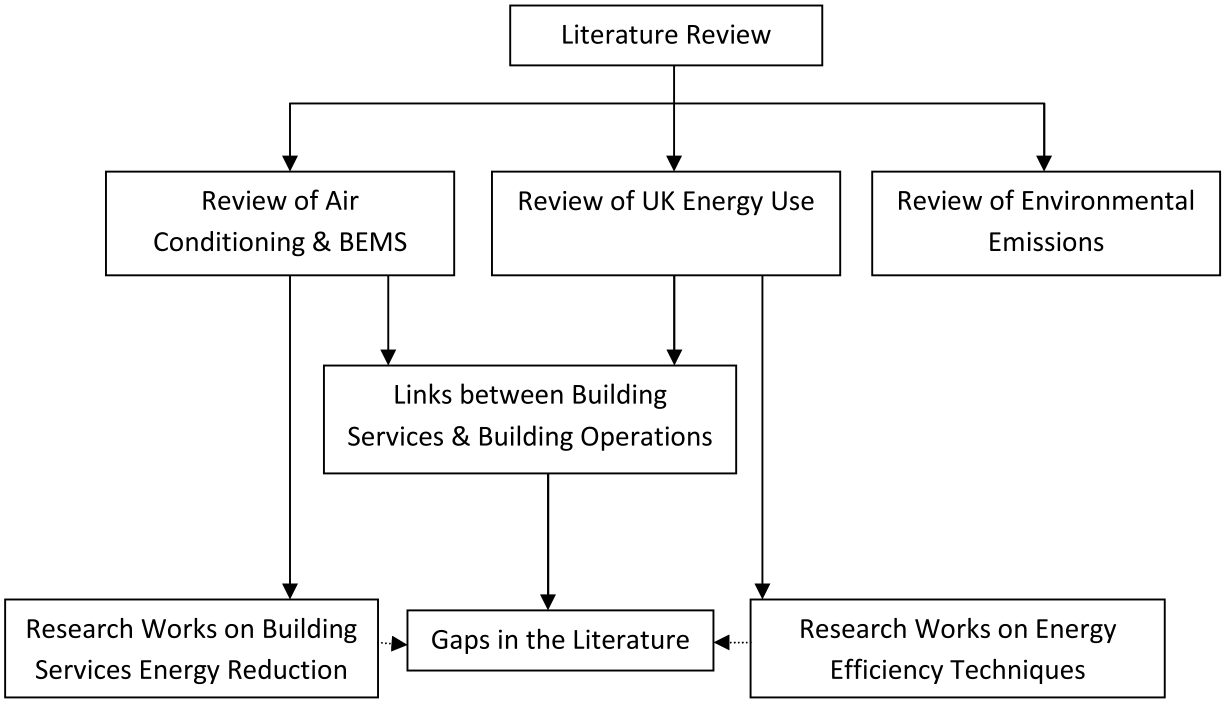


Figure 2.1 – Structure of the literature review

The review of Environmental Emissions initially focuses on the importance of general global emissions and the reason why it is of global importance that we reduce the emissions being generated by man. The review then looks closer at the emissions relating to Manchester Airport and its current operations that contribute to these emissions. Finally we take a look at the legislations set in place and the government incentives to encourage the reduction of CO_2 emissions.

The discussion on research work in Energy Efficiency Techniques highlights the available techniques being developed to assist in the global commitment of CO_2 reduction.

The literature discussed on the field of air conditioning and building energy management systems details the plants and their components. The review on BEMS describes the general attributes of a BEMS and the advantages of installing a BMS system to control and monitor air conditioning plants fro efficient operation.

The review on Building services Energy reduction follows on from the literature within the air conditioning and BEMS review. It discusses general energy reduction procedures available, with additional papers selected on alternative energy reduction procedures.

The review of links between building services and building operations discusses items that can affect both systems in an efficiency process. In particularly the relationship that can be formed between the two subjects.

Finally the gaps in the research are discussed. This is to demonstrate that both the system and the operation can be improved but more importantly the relationship between building systems, building operations and the building design can be integrated into a more efficient cycle to reduce the impact they have on the environment.

2.2 REVIEW OF UK ENERGY USE

The following section provides a brief overview of the energy consumption in the UK since 1970. The data has been produced and available from DECC's annual publication 'Energy consumption in the UK'.

Total final consumption of UK energy products can be divided into four sectors – transport, domestic, industrial and services sector – where consumption from the transport sector represents 36 per cent of consumption in 2012, the domestic sector 29 per cent, the industrial sector 17 per cent and the services sector 13 per cent; the remaining 5 per cent was used for non-energy purposes (ECUK 2013).

The Government Department for Energy and Climate Change (DECC) publish the "Energy Consumption in the UK (2013)" document which states,

> In 2012, total UK overall primary energy consumption in primary energy terms (that is, fuels obtained directly from natural sources) was 206.3 million tonnes of oil equivalent (mtoe), 2 per cent higher than in 2011, which – at 202.1 mtoe – had been the lowest level of UK primary energy consumption for over 25 years. The level of primary energy consumption in 2012 was similar to that last seen in 1985, and was 3 per cent lower than in 1990 and 2 per cent lower than in 1970. On a temperature corrected basis (to remove the impact a hot or cold year has on energy consumption) primary energy consumption in 2012 was at its lowest since 1985 at 206.1 mtoe; 2011 was a mild year, compared to 2010 and 2012. Between 1990 and 2012 primary energy consumption on a temperature correct basis fell by 7 per cent, and was 3 per cent lower than in 1970. There was a 1 per cent fall in consumption between 2011 and 2012.

Figure 2.2 shows the UK primary energy consumption since 1970 for both the unadjusted and temperature corrected series.

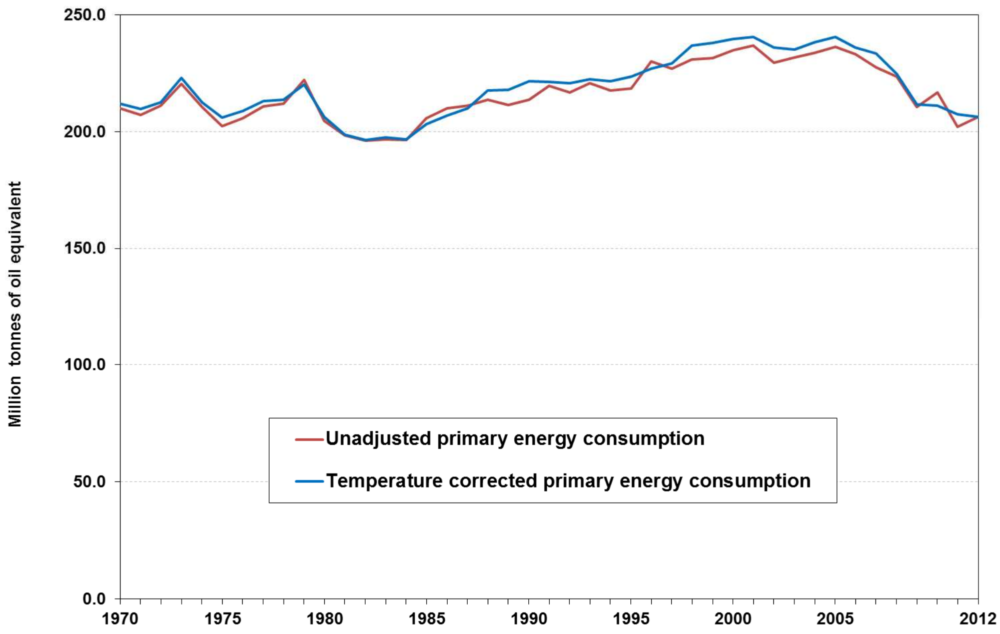


Figure 2.2 - Total primary energy consumption, unadjusted and temperature corrected, UK (1970 to 2012) source: ECUK 2013

In 1970, fuel consumption was dominated by solid fuel use (47 per cent of all energy consumption in the UK) and petroleum (44 per cent), with gas contributing a further 5 per cent and electricity 4 per cent, as can be seen in Figure 2.3 (ECUK 2013).

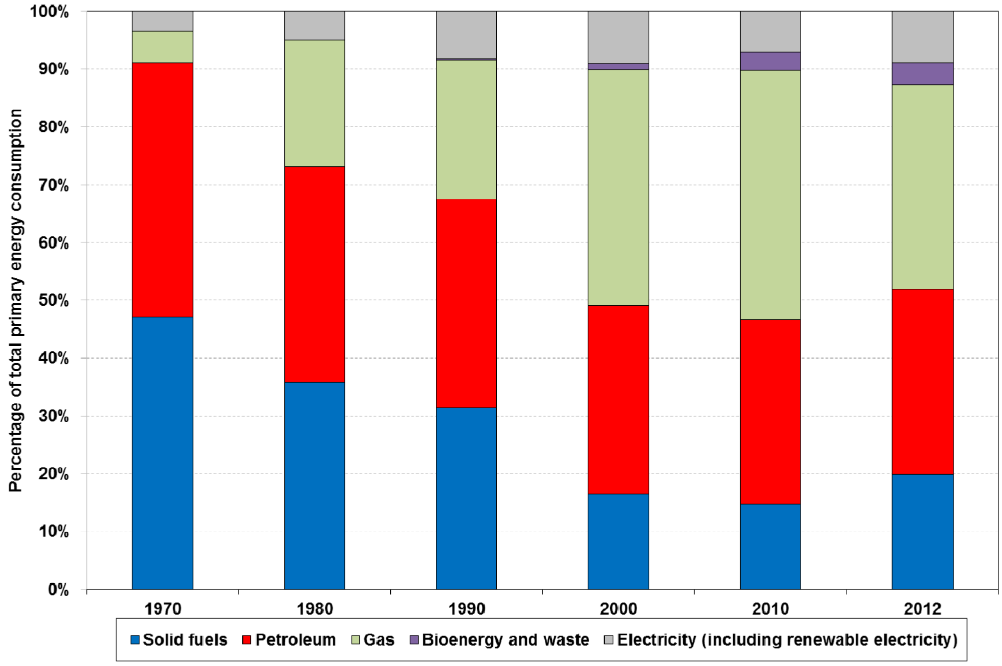


Figure 2.3 - Total primary energy consumption by fuel, UK, 1970 to 2012

Source: ECUK 2013

The most noticeable difference on the graph is that between 1900 and 2000.It clearly shows that Natural gas consumption had become the dominate fuel with 41% of all UK energy consumption, whilst solid fuels consumption had halved.

“By 2012 more renewable fuels had entered the energy mix for both electricity generation and bio energy consumption, and coal use for electricity generation had also increased. Around 11 per cent of electricity generated in 2012 came from renewable sources”. (ECUK 2013)

Figure 2.4 displays the final energy consumption by fuel in the UK for the same period. The graph is described by ECUK (2013) as:

> Final consumption of energy products in 2012 was 148.2 mtoe, of which 7.6 mtoe were used for non-energy purposes. The remaining 140.6 mtoe for energy purposes was 5 per cent lower than in 1990 and 4 per cent lower than in 1970.
> The most recent two years have shown the lowest level of final energy consumption in the UK since 1984. The decrease between 2010 and 2011 was mainly driven by the 17 per cent reduction in gas consumption, resulting from a milder winter in 2011 requiring less fuel for heating purposes compared with the cold winter in 2010. This was reversed between 2011 and 2012, when more gas was used in the winter heating season as temperatures were cooler.

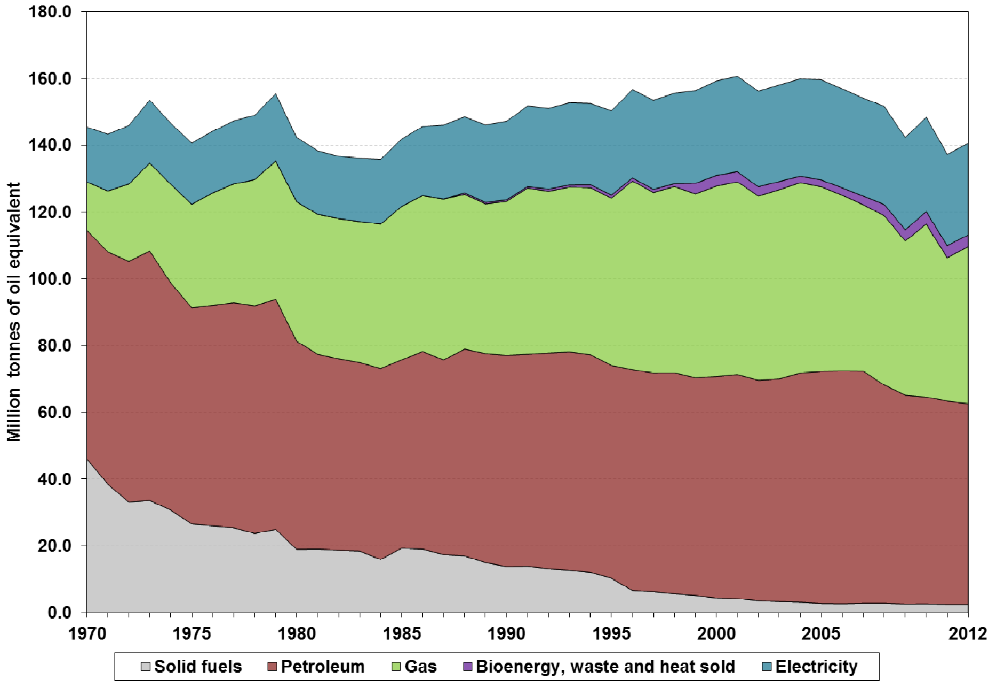


Figure 2.4 - Total primary energy consumption by fuel, UK, 1970 to 2012

Source: ECUK 2013

2.2.1 Manchester Airports Group (MAG) Energy Use

As part of its business strategy, Manchester Airport has set a target to be carbon neutral for its ground operations. This commitment includes the objectives to review energy supplies, selecting low carbon alternatives, encourage and promote energy efficiency, carbon reduction measures through service partners/staff and increase energy efficiency.

Below are some examples of progress that has already been undertaken which are detailed in MAG Sustainability Report 2010/11

MAG Progress report:

- Airport Carbon Accreditation – ACI Europe has upgraded Manchester Airports accreditation to level 3 (Optimisation).
- Two of four wind turbines have been installed at East Midlands Airport, which will supply 10% of the airports electricity.
- Design brief for the arrivals building at Bournemouth Airport included the requirement to deliver a low carbon building with 70% - 100% lower carbon consumption than a traditional building. Initiatives include photovoltaic panels on the roof.
- A collaborative Environmental Management Group was formed at Manchester Airport with the aim of creating procedures to improve CO_2 emissions.
- Introduction of an automatic Metering System for electricity at Manchester Airport at a capital expenditure cost of approximately £1.2m. (MAG, 2010/11)

Figure 2.5 displays the Direct and Indirect Energy Consumption for MAG between the years 2007 to 2010.

Direct and Indirect Energy Consumption

		2007	2008	2009	2010
Direct	*Vehicle fuel*				
	Diesel (litres)	1,605,695	1,498,716	1,548,521	1,693,753[1]
	Petrol (litres)	399	219	0	
	Gas oil (litres)	108,213	107,320	99,924	
	Buildings energy				
	Natural gas (MWh)	124,562	87,396	90,764	109,083
	Liquefied petroleum gas (litres)	58	66	54	2,909[2]
	Gas oil (litres)	471,693	12,013	123,972	877,386
Indirect	*Buildings energy*				
	Electricity (MWh)	176,120	187,335	182,217	168,630

Figure 2.5 – MAG Energy Consumption

Source: MAG Sustainability Report 2010/11

Figure 2.6 displays the Energy Consumption for each airport within the Group. Manchester Airport is by far the greater energy consumer with its electrical consumption being greater than 75% of the whole of the Groups energy consumption.

Direct and Indirect Energy Consumption Split by Airport

Source		Airport	
Direct	Gas (kWh)	Manchester Airport	102,496,737
		East Midlands Airport	6,586,751
		Bournemouth Airport	0
		Humberside Airport	0
		Total	**109,083,488**
	Gas oil (litres)	Manchester Airport	639,751
		East Midlands Airport	63,560
		Bournemouth Airport	135,597
		Humberside Airport	38,478
		Total	**877,386**
	Liquefied petroleum gas (litres)	Manchester Airport	0
		East Midlands Airport	0
		Bournemouth Airport	0
		Humberside Airport	2,909
		Total	**2,909**
	Vehicle fuel (litres)	Manchester Airport	1,498,516
		East Midlands Airport	108,890
		Bournemouth Airport	24,041
		Humberside Airport	62,306
		Total	**1,693,753**
Indirect	Electricity (kWh)	Manchester Airport	133,513,770
		East Midlands Airport	22,575,177
		Bournemouth Airport	9,809,121
		Humberside Airport	2,732,210
		Total	**168,630,278**

Figure 2.6 – Energy Consumption by Airport

Source: MAG Sustainability Report 2010/11

Around a half of the energy used on site is by the airports service partners, and is not under the airports direct control. Further research may be required to investigate the best way to encourage service partners to use non fossil fuel energy sources. Most service partners get their electricity through the airports supply network. The airport can create a green tariff supply on their network and encourage service partners to contract for this.

Energy used within the direct control of the airport includes lighting in the terminals, airfield, out buildings and car parks. Other energy use is by elecro-mechanical systems such as the baggage systems, autowalks, escalators and lifts. The largest energy user within the direct control of the airport is the heating and ventilation plant. Included within this plant is chillers, boilers and air handling units. Figure 2.7 below graphically displays the terminal energy consumption.

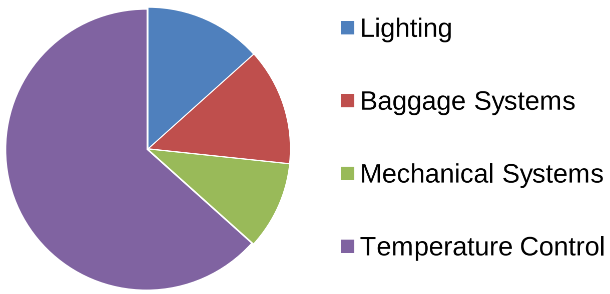


Figure 2.7 – Terminal Energy Consumption

Source: MAG Environmental Plan 2007

2.3 REVIEW OF ENVIRONMENTAL EMISSIONS

Most modern day societies are familiar with terminology like “Air pollution”, “Urban smog”, “Acid deposition” and “Global Warming” but natural air pollutions, including volcanoes, natural fires and desert dusts have been occurring since the earth began (Jacobson, 2012).

With more research literature being created on a daily basis and the advancement in technology to gather data, environmental issues have fast become an important global issue which we all agree must be addressed.

The earth is protected from the sun’s rays by several layers of gases, known as the atmosphere. The heat from the sun travels through these gases and warms the earth. Heat from the earth then travels back into the atmosphere. The gases that form the atmosphere prevent all the heat escaping and maintain a constant earth temperature for life to exist. This effect is known as the ‘Greenhouse Effect’, and the gases are referred to as greenhouse gases (GHG’s).

The most common greenhouse gases are water vapour, carbon dioxide, methane, nitrous oxide and ozone. Greenhouse gases occur naturally, nitrous oxide occurs when plants die, methane is produced by cattle whilst digesting and carbon dioxide is produced by people and animals breathing.

Some greenhouse gases are also man-made, Chlorofluorocarbons (CFC’s) was widely used in cooling systems and hairsprays. CFC’s are damaging because CFC molecules can damage ozone molecules and therefore upset the greenhouse gas balance. Carbon dioxide is also produced by burning fossil fuels, again being released into the atmosphere and adjusting the greenhouse gas balance.

The earth’s temperature can be altered by the imbalance of these greenhouse gases, causing the temperature to rise. This temperature rise is known as ‘Global Warming’.

Many scientific articles have been written around the greenhouse effect but one particular article describes it perfectly, therefore I shall not try to enhance it in any way, Fankhauser, (2013). states “While the general public has only recently become aware of the global warming problem, the scientific greenhouse debate covers a span of more than 150 years. In 1824 French scientist Jean Baptiste Fourier first described the natural greenhouse effect, drawing a parallel between the action of the atmosphere with the effect of glass covering a container. As is now well known, the natural greenhouse effect described by Fourier forms an important part of the earth’s energy balance system and is essential for life on earth: without it the average surface temperature on the planet would be a mere -18^{O}C, rather than the 15^{O}C observed today – too low for any sort of life. The possibility of an enhanced or man-made greenhouse effect was introduced some 70 years later by the Swedish scientist Svante Arrhenius published around the turn of the century (Arrhenius, 1896; 1903; 1908). Arrhenius hypothesized that the increased burning of coal, which had paralleled the process of industrialization, may lead to an increase in atmospheric CO_2 concentration and warm the earth”.

On some climate change issues (such as global warming), there is no disagreement among the scientists. The greenhouse effect is unquestionably real; it is essential for life on earth. Water vapour is the most important greenhouse gas (GHG); followed by CO_2.(Omer, 2013)

Average temperatures of the planet's surface have been documented and recorded over a large number of years. Ongoing scientific research into the global warming shows that the average temperature of the planet's surface - has risen by 0.89 °C from 1901 to 2012. (Met Office n.d). A less than 1 °C temperature rise doesn't appear to be a huge gain. Measure this on a global scale and it can appear to be a significant rise, with arguments being made as a possible contribution to the extreme weather conditions been experienced in the last few years.

Global warming grabs most of the headlines and is the term that most people are familiar with or think they are. Global warming provokes much discussion within non scientific circles, each with their own interpretation of the cause and solution. Within only a few years what was primarily of scientific interest has grown in to worldwide concern. Concerns are raised amongst the wider population when people are exposed to literature and scientific statements that are extremely thought provoking.

Athanasiou & Baer., (2011) states "that even if we move quickly to cap the emission of greenhouse pollutants, the consequences of global warming will soon become quite severe, and even murderous, particularly for the poor and the vulnerable. And in the more likely case where we move slowly, the impacts will verge on the catastrophic"

Such powerful descriptive terminology must raise awareness even in the most sceptical of audiences.

Survey evidence exists that there is agreement within scientific literature and climate scientists that the planet is warming up, and this climate change is being driven by humans. (Jacobs et al., 2013)

Climate change is perhaps the central challenge that faces humanity. The concept of green growth is needs to be more than a mere rebranding of the concept of sustainability.

An agreement on the best way to achieve a low-carbon society is very difficult to achieve due to the financial differences between the least and most wealthy, the scale and the potential effects of climate change make it imperative that one is reached. (Reilly, 2013)

Global emissions of carbon dioxide (CO_2) – the main cause of global warming – increased by 3% in 2011, reaching an all-time high of 34 billion tonnes in 2011.(Olivier et al., 2012)

Due to this fact CO_2 is going to be the greenhouse gas to be examined during this research as it is widely agreed to be a man-made problem, and one which we can all influence.

As discussed earlier carbon dioxide emissions are created by burning fossil fuels. Coal, petroleum (oil), and natural gas are all fossil fuels. They are called fossil fuels because they are created from the remains of plants and animals that lived millions of years ago in the form of concentrated biomass.

Once claimed the fossil fuels are converted to energy by the fossil fuel power stations situated around the world. Fossil fuel power stations could be situated virtually anywhere as long as it has access for large quantities of the fuel.

Burning of any fossil fuel during the energy process, produces carbon dioxide which is the major contributor to the green house effect and global warming.

The strategy of the European Union in the field of energy and climate change highlights three commitments to be met by 2020: to reduce greenhouse gas emissions by at least 20%, to ensure that 20% of final energy consumption is met with renewable sources, and to raise energy efficiency by 20%. This strategy is based on the scientific consensus drawn by the International Panel for Climate Change, and implements the EU political strategy to limit the anthropogenic temperature rise to no more than 2^{o}C. (da Graça Carvalho et al., 2011)

If we examine the long-term trend, a worrying result is discovered. Jarvis, A. J., Leedal, D. T., & Hewitt, C. N. (2012) interestingly pointed out that human produced carbon emissions data going back to the mid 19th century display an exponential curve. From the graph it is clear that regardless of all the global concern and implementation of legislations, the long term trend has not changed. The growth rate in total carbon emissions in the past decade, at around 2% a year, was the same as that of the 1850s.

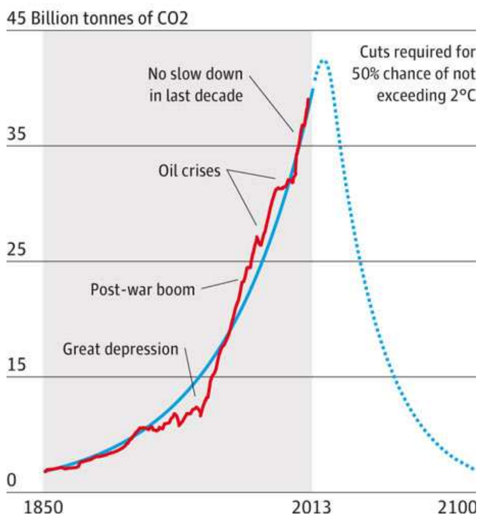


Figure 2.8 - CO_2 emissions since 1850 (red); exponential growth (blue); cuts to hit climate target (dashed).

Source: Guardian.co.uk

Ultimately the climate doesn't care what technology you are using, or how efficient you have got your plant to operate. It only cares about how much global warming pollutants you are emitting.

Due to the global carbon reduction commitments, alternative low carbon technologies are being explored.

Low carbon technologies such as renewable and nuclear, and reducing emissions through carbon capture and storage (CCS) will supposedly help reduce the emissions contributing towards the greenhouse effect and global warming.

2.3.1 MAG emissions

In the UK, aviation accounts for 5.5% f the total CO2 emissions by end user (0.1% of global emissions. (MAG, 2007). Figure 2.2 shows the aviation industry as a smaller contributor to emissions than domestic and transport. The UK aviation industry is forecasted to grow at between 4-6% per year to 2030 therefore defining the importance of the research.(MAG, 2007)

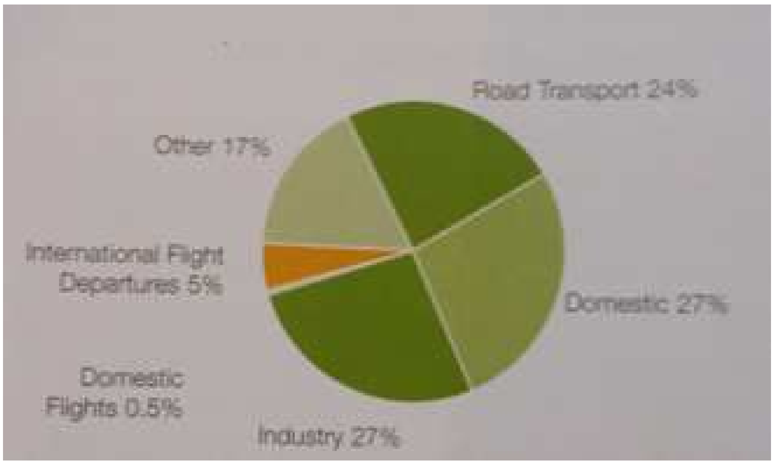


Figure 2.9 – UK carbon dioxide emissions by end user

Source: Environmental Plan MAG 2007

Carbon dioxide (CO_2) is the main greenhouse gas, accounting for about 83 per cent of total UK greenhouse gas emissions in 2011, the latest year for which final results are available. In 2012, UK net emissions of carbon dioxide were provisionally estimated to be 479.1 million tonnes (Mt). This was 4.5 per cent higher than the 2011 figure of 458.6 Mt. (DECC, 2013)

Climate Change Act 2008 clearly states that the UK government has committed to achieve a target to reduce carbon emissions by 80% lower than the 1990 baseline, it is the duty of the Secretary of State to ensure that the targets are achieved and they by order may amend the percentage specified or amend the appropriate section to provide a different year for the baseline. Carbon emissions from the UK's non domestic buildings which comprise of commercial offices, hotels, shops, schools, hospitals, factories and other buildings are responsible for 18% of the UK's total (Carbon Trust 2009).

"Buildings consume nearly half the energy used in the UK" (CIBSE F 2004, p1-1) therefore it is a collective responsibility to assist in the challenge of reducing carbon emissions for new and refurbished buildings, which include the building designers incorporating efficient designs and technologies to the building managers monitoring and adjusting building services to provide satisfactory operational and comfortable condition

The Manchester Airports Group Plc (M.A.G) is the country's largest UK-owned airport operator. Our four airports - Stansted, Bournemouth, East Midlands and Manchester – serve around 42 million passengers every year. ("About MAG,". n.d., para 1)

Total MAG Net CO_2 Emissions (tonnes)

Source	2007	2008	2009	2010
Gas	24,188	17,884	18,301	20,165
Electricity	75,790	70,619	54,024	47,256
Gas oil	1,289	294	332	2,392
Vehicle fuel	4,425	4,483	4,512	4,561
Liquefied petroleum gas	n/a	n/a	n/a	40
Total	**105,692**	**93,280**	**77,169**	**74,414**

Figure 2.10 - Total MAG Net CO2 Emissions

Source: Sustainability Report MAG 2007

Figure 2.4 details the Total MAG Net CO_2 emissions per source. The majority of MAG's carbon emissions occur as a result of energy consumption (MAG, 2007). Gas and electricity are the main energy source for the sites, with electricity following a reduction pattern year on year. This is due to the energy reduction procedures already in place, and the purchase of 50% renewable electricity (MAG, 2007). Gas consumption displays a rise in CO_2 emissions during the 2010/11 period. This would have been affected by the particular cold weather of that period. This demonstrates the effect and importance of weather data on energy use and subsequent CO emissions. Historical weather data can be used in the energy forecast management procedures.

Source		Airport	CO₂ (tonnes)
Direct	Gas	Manchester Airport	18,947
		East Midlands Airport	1,218
		Bournemouth Airport	0
		Humberside Airport	0
		Total	**20,165**
	Gas oil	Manchester Airport	1,770
		East Midlands Airport	184
		Bournemouth Airport	332
		Humberside Airport	106
		Total	**2,392**
	Vehicle fuel	Manchester Airport	4,025
		East Midlands Airport	287
		Bournemouth Airport	77
		Humberside Airport	172
		Total	**4,561**
	Liquefied petroleum gas	Humberside Airport	40
		Total	**40**
Indirect	Electricity	Manchester Airport	35,850
		East Midlands Airport	5,652
		Bournemouth Airport	4,905
		Humberside Airport	849
		Total	**47,256**
		TOTAL	**74,414**

Figure 2.11 - CO_2 Emissions by source per Airport.

Source: Sustainability Report MAG 2007

Figure 2.5 details the Direct/Indirect CO_2 emissions by source per airport within the group.

Manchester is clearly the largest CO_2 emitter of the group with both Gas and electricity being significantly larger than any other energy source. The table also shows that nearly half of the group CO_2 emissions are being produced from Manchester Airport electricity consumption.

There are many different activities within an airport that produce CO_2 emissions. The main activities that contribute are energy use, vehicles, staff and passenger journeys. Energy use incorporates heating, cooling, lighting and the mechanical systems like baggage handling systems within the Terminals. Vehicles include operational vehicles across the whole site, including service partner's vehicles. Staff and Passenger journeys to and from the airport, as detailed in figure 2.6 is a large contributor to CO_2 emissions. There is large commitment by Government and Manchester Airport to invest in this area in particular with passenger travellers. The existing Ground Transport Interchange, which is a transport hub of coaches, buses and trains is being developed to incorporate the local tram service. Manchester Airport also invests heavily in a company car share scheme. This is to encourage staff to reduce their individual car journeys by sharing or alternating the journey with other members of staff.

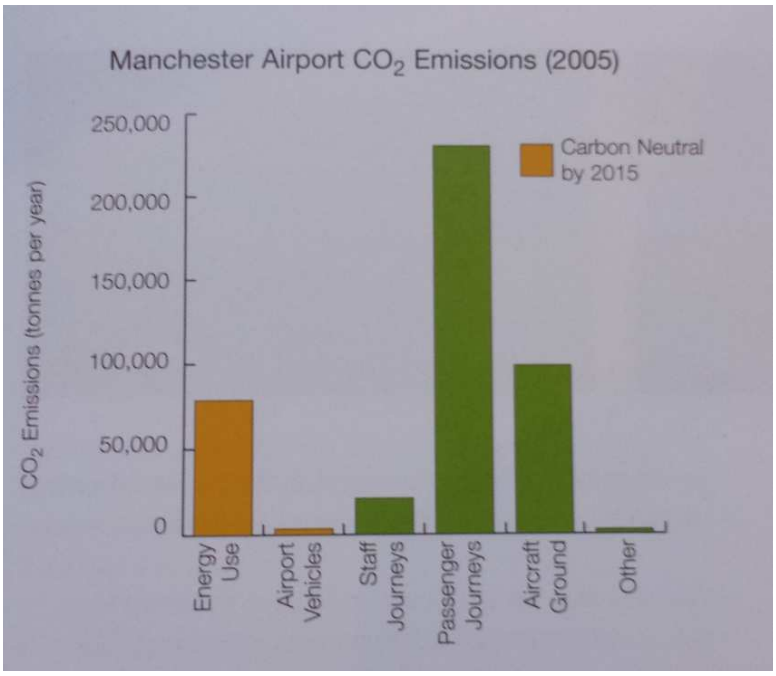


Figure 2.12 – Manchester Airport CO2 Emissions (2005)

Source: Environmental Plan MAG 2007

Figure 2.12 also details the commitment that Manchester Airport has made to be Carbon Neutral by 2015 in the areas of Energy use and Airport Vehicles

2.3.2 CO_2 Reduction incentives

Some of the key Government energy efficiency drivers are legislation, in particular the Carbon Reduction Commitment Energy Efficiency Scheme (CRC) and fiscal penalties or incentives which include the climate change levy and the enhanced capital allowance.

CRC Energy Efficiency Scheme (often referred to as simply ‘the CRC’) is a mandatory scheme aimed at improving energy efficiency and cutting emissions in large public and private sector organisations. These organisations are responsible for around 10% of the UK’s greenhouse gas emissions. (DECC 2013)

The CRC Energy Efficiency Scheme Order 2010 clearly states the Order is applicable over a period of seven phases which comprise:

a) A first phase of three years commencing on 1st April 2010
b) A second phase of seven years commencing on 1st April 2011
c) Subsequent phases of seven years commencing as shown in the following table:

	Commencement Date of Phase
Third Phase	1st April 2016
Fourth Phase	1st April 2021
Fifth Phase	1st April 2026
Sixth Phase	1st April 2031
Seventh Phase	1st April 2036

The CRC scheme is intended through incentives to encourage organisations to actively participate in exercising cost effective energy efficient opportunities within their organisation. It is compulsory for organisations that meet the schemes requirements have to take part. The CRC scheme applies to organisations whose total annual half hourly metered electricity use in 2008 was above the qualification threshold of 6,000 MWh. The qualifying organisations have to register as CRC scheme participants and then on an annual basis measure and report their carbon emissions.

Participants of the scheme are required to buy allowances for every tonne of carbon they emit. The participants are required to buy the allowances on each year they report, this means the organisation have the opportunity to lower their allowance costs by reducing the emissions they emit. Due to stakeholder feedback which included comments as " it is complex, administratively burdensome, overlaps with other regulatory mechanisms and forces organisations to participate in ways which do not readily align with their natural business structures and process" (Department of Energy and Climate Change IA No. DECC0066 2013) the Government has committed to simplify the scheme and release The CRC Energy Efficiency Scheme Order 2013. The main changes and timetable for their introduction can be viewed in the Environment Agency Document titled The simplification of the CRC energy scheme-An overview of the simplification of the CRC Energy Scheme 2013

The Climate Change Levy has two different rates of Levy, the Main rates of CCL is intended to change the behaviour of an organisations energy use by taxing the supply of specified energy products such as electricity, gas and coal for use as fuels , which includes to provide for lighting, heating and power by business consumers. The Main rate also encourages the business consumer to look at alternative energy sources such as wind farms, solar energy and hydro power.

The Climate Change Levy has a different rate which is the Carbon Price Support (CPS) which is a tax on energy products such as gas and coal used in electricity generation. This tax is to encourage the electricity generation industry to invest in low carbon emission technology.

The enhanced capital allowance is as the name states, instead of the standard capital allowance of 18% (in the first year); an organisation has the opportunity to claim the enhanced capital allowance of 100% tax relief as a one off payment. The qualifying criterion for the enhanced capital allowance is the technology purchased has to be listed on the official Energy Technology Product list.

All MAG airports adhere to the Governments mandatory CRC Energy Efficiency Scheme to cut CO_2 emissions in large public and private sector organisations

Manchester Airport set a Carbon Challenge aimed at engaging service partners and occupiers across the site to work together on environmental commitments. So far, eight businesses have signed up to the Carbon Challenge. (MAG, 2010-2011)

2.4 REVIEW OF AIR CONDITIONING PLANT & BEMS

2.4.1 Air Conditioning

Air Conditioning systems can be defined as full mechanical control of the internal environment to maintain specified conditions for a certain purpose. The objective may be to provide a thermally comfortable temperature, humidity, air cleanliness and freshness for the users of the building or it may be to satisfy operational conditions for machinery or processes. The term air conditioning may be used to describe an air-cooling system that reduces excessive temperatures but does not guarantee precise conditions, to minimize capital and operational costs. This is better described as comfort cooling (Chadderton, 1998).

The ventilation of buildings has been a major design issue of recent years. The decision whether to ventilate naturally or mechanically, and the implications for comfort, health, productivity and energy use have been much debated. The traditional views that naturally ventilated buildings must be narrow in plan and that mechanically ventilated buildings are not energy-efficient have been countered by innovative design, both architectural and engineering. It is now generally accepted that there is not a preferred solution to ventilation design, whether mechanical or natural, and that appropriate ventilation design is needed, with the emphasis on design (CIBSE B2, 2001). This is also of importance in the design of retrofit areas of existing buildings particularly in the area of air tight design to maintain the efficient ventilation/infiltration of that space.

There are many types of air conditioning modes of operation including single-duct variable air temperature with 100% fresh air, single-duct variable air volume, single-duct with fan coil units and there are many books and journals detailing the different categories of the mode of operation of air conditioning systems and the advantages of each different system mode. Section 3.23.8 of the (CIBSE B2, 2001) provides an overview of guidelines of ventilation and air conditioning of Airport Terminals and states; Airports generally consist of one or more terminal buildings, connected by passageways to departure gates. Many terminals have telescoping loading bridges connecting the departure lounges to the aircraft. These eliminate heating and cooling problems associated with open doorways. The aim of any ventilation system should be to create a positive internal pressure that will prevent the odour and pollutants from entering the buildings. Terminal buildings have large open circulation areas, check-in facilities, retail outlets, offices and ancillary areas. As occupancy can vary considerably through the day, it is important that the ventilation/air conditioning system is able to respond to the changes in occupancy. However, due to the large volume of the circulation spaces it is possible to use the building volume to absorb the sudden changes and peak flows. Ventilation systems can be designed with recirculation (to provide heat reclaim), controlled by air quality detectors, thereby automatically reacting to passenger flows. The system design should also incorporate sufficient zone control to accommodate the widely varying occupancy levels in different parts of the building, or even between adjacent departure gates. If available, histograms on passenger movement for departure and arrival are useful in estimating the design occupancy.

Filtering of the outdoor air with activated carbon filters should be considered to reduce the presence of noxious fumes. However, the siting of air intakes away from the aircraft jet exhausts may obviate the need for filtration and will reduce operating costs. However, since it may be difficult to predict if fumes will affect the air intake location, supply systems should incorporate facilities to enable carbon filters to be added at a later stage, if necessary.

Figure 2.13 displays a typical layout of a single-duct variable air temperature air conditioning system with recirculation of room air (SDVATR) original form (Chadderton, 1998)

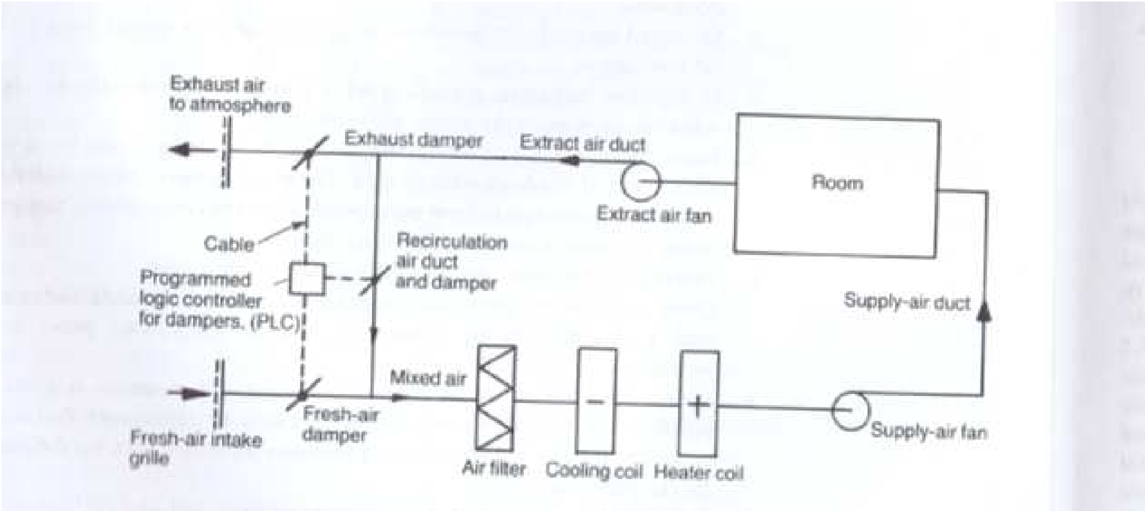


Figure 2.13 - Schematic layout of a single-duct variable air temperature air conditioning system with recirculation of room air (SDVATR) Source: David V. Chadderton 1998

2.4.2 BEMS

A key element for reducing carbon emissions and creating a sustainable future is the design and implementation of control systems for a specific function of a building or for building services to achieve comfort conditions for certain activities with minimum energy consumption (CIBSE H, 2009).

The primary goal of a building automation system is to solve the conflict that can occur between energy consumption and comfort conditions. What I mean by conflict is they usually work in opposite to each other. Greater comfort conditions as in more heating or cooling requires more energy consumption.

A large majority of earlier Building Management Systems (BMS) were not utilised to their full potential, partly through lack of training for end users and building managers but also through insufficient time and money allocated for design, installation and commissioning of the controls and the plant they are controlling. (Levermore, 2000). In more recent years building managers and energy managers are realising the potential of a utilising the BMS to monitor and forecast energy usage which has led to the development of Intelligent Building Control (IBC).

The BMS is a “stand alone” computer system that can calculate requirements of a building or specific area and control the connected plant to provide comfort conditions to meet those requirements. A hierarchy of programmable (Intelligent) and non programmable (Dummy or no intelligence) controllers forms the network which can communicate between each other, and these are located around the building, these controllers are often referred to as outstations.

The programmable field controllers require actual field data in which to process and include within the controller program to calculate what action to take, this data is collated from inputs and the calculated actions are performed by outputs. Inputs fall mainly into two different groups, analogue inputs and digital inputs. Analogue inputs include items such as temperature, air quality and velocity sensors, analogue inputs can also provide feedback signals such as actual fan or pump speed. Digital inputs include items like fan or pump differential pressure switch, damper end switch and alarm indicators such frost protection.

Outputs again fall into two main groups, analogue and digital outputs. Analogue outputs include items such as calculated fan or pump speed, valve and damper positions. Digital outputs include items such as fan or pump enable signal.

The BMS can also be configured to alarm on conditions that don’t meet a certain criteria, or can be configured to warn responsible personnel of critical plan failure, via raising an alarm or e-mailing the appropriate department to perform corrective action. The alarm procedure can play a significant role in plant efficiency by highlighting individual equipment or plant which is faulty and causing the plant to operate in an in-efficient manner.

Most modern BMS have the facility to incorporate web browser applications into the network which provides the function of accessing the system remotely for occasional users or to monitor different sites from one main control area. This can be useful for a building manager to have the site monitored by external energy consultants to ensure efficient plant operation is being maintained.

This function also provides the system administrator/building manager to give restricted access to clients/tenants to view the actual comfort conditions and energy use within their operating area, which can reduce reactive calls for a maintenance department.

Another facility provided by the BMS is the option of configuring occupancy times such that the plant is brought on and off to meet the client/tenant requirements. Modern BMS incorporate optimum start; this means that the heating plant is enabled, at a varying pre-determined time, which is calculated by the optimum start function to ensure that the heated space is at the set desired temperature for the start of the day. The BMS therefore, based on the outside air temperature the space temperature and the building structure, calculates the optimum plant start time.

Figure 2.14 below displays a typical BMS structure showing the four different levels of hardware architecture. Figure 2.14 displays a DELTA controls system layout, and DELTA define the AREA level controllers as primarily to break up a large segments of a WAN, SYSTEM level controllers are used to distribute networks into manageable building segments, and are I/O controllers for equipment such Air Handling Units and these controllers can have a subnet of controllers beneath it. (DELTA 2008)

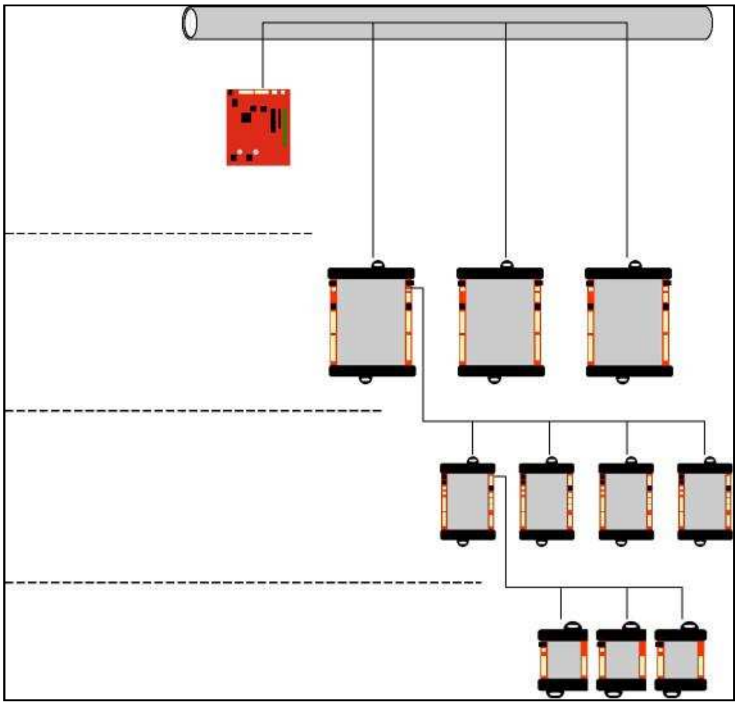


Figure 2.14 - Typical BMS hardware Architecture

Source: DELTA Control

In a modern commercial building there are several other services being provided in addition to the common known services of lighting and heating and ventilation plant. These services can include closed circuit television (CCTV), fire control, lift control, security and access and large companies contain a large infrastructure of information technology networks which are necessary for the business operation. All of the systems above require networks to communicate and there are major benefits in trying to reduce the number of compatible networks or introducing a common network protocol so systems can communicate and exchange data between each other. The more compatible systems there are the more data can be passed between each system and greater interaction between the systems and the services these systems provide. There are different levels of integration from different manufacturers being able to communicate over the same network, in which manufactures produce their products to a certified standard therefore irrespective of the manufacturer the device chosen for that a specific task will communicate to its peers on the same network. BACnet is fast becoming the number one open protocol for building control as “BACnet is an American national standard, a European standard, a national standard in more than 30 countries, and an ISO global standard”. (“BACnet” n.d., para 1)

At its most advanced level all systems communicate over the same network and exchange data between systems as and when required, this is controlled and monitored via a central supervisor station. (I have doubts over this statement as it’s difficult to find a user who is competent with all multi disciplines to monitor effectively). This full integration approach is referred to as the Intelligent Building Concept. (CIBSE H, 2009). Figure 2.15 displays a typical intelligent control architecture clearly showing the different services including building management, life safety, security and access all communicating on the same network.

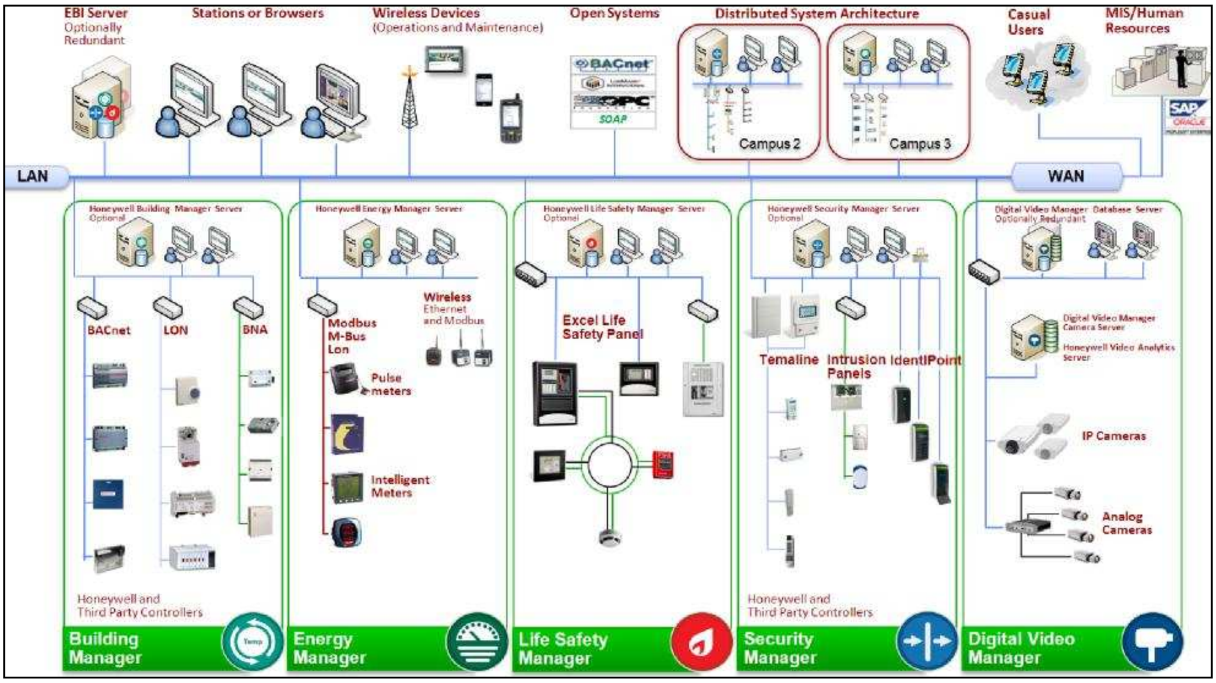


Figure 2.15 - A Typical Intelligent Building Control Architecture

Source: Honeywell Control Ltd

There is an important relationship between the control system and human interaction as this can play a positive or negative role in the energy management of a building. The positive role of this relationship is by the building services control system being monitored by a competent person for any system malfunctions which could cause inefficient operation and reporting to the appropriate department for corrective measures to be performed. The negative role of this relationship is by elements of the building control system being adjusted by unauthorised personnel to achieve a condition they would prefer rather than the control systems calculated condition i.e. somebody adjusting a room thermostat to its maximum (or minimum) position creating a greater load on the system which requires more energy. Sabotage of equipment can also create a situation where more energy is being consumed then would actually be desired by the system, i.e. thermostatic actuators on radiators being removed.

Staff and tenant training on using the building controls in an efficient manner (or restricting their use altogether) can play a significant part in energy reduction plans within a large commercial building.

Energy and comfort management is the major task for a building automation system. Energy efficiency and occupants comfort are two primary concerns for evaluating the performance of a building control system. It is important for occupants well being and productivity where required to create a comfortable environment. Two main factors in providing this comfortable environment is thermal comfort and air quality. Air quality sensors measure the CO_2 content (usually within the return air ductwork) in parts per million.

These factors are mainly controlled from the HVAC system. Therefore the buildings energy efficiency and occupancy comfort can be improved by adequate control of the system.

Occupant comfort is related to the occupant's preference. To determine satisfactory levels, certain parameters have to be identified and set points for these parameters are what the control system aims to maintain. These parameters can be altered for different occupancy activity, or levels. Different occupancy levels can be controlled in an efficient manner by having different parameter se points for the different occupancy levels. In the case of low occupancy a larger deadband can be incorporated in to the control strategy to allow a reduction in heating or cooling demand. Indoor temperature, CO_2 and lux levels are the predominant parameters to be used to measure the required conditions against.

There are many papers written on the different control methods available to determine occupant's activities such as Fuzzy Logic, neural networks all of which are discussed in later sections.

One such paper on multi-agent systems by Yang & Wang, (2013) states: "One of the major challenges in determining occupant's activities is the construction of the sensor networks"

They go on to mention different types of sensors including acoustic and motion sensors. This statement is important when building accurate data analysis models. Occupant activity to the level of whether the occupant is asleep or not which is also discussed in their paper , is taking the control to its extreme and does not have a major effect on the comfort conditions provided. The comfort conditions provided are more on an 'if required or not' basis.

2.5 LINKS BETWEEN BUILDING SERVICES AND BUILDING OPERATIONS

2.5.1 Chroma Airport Suite

Manchester Airport, like most modern commercial buildings in today's technological world incorporates a large network infrastructure within its terminal buildings. This infrastructure is utilised to create numerous local area networks (LAN) and virtual local area networks (VLAN) for the airports many different information systems. Due to the physical size of the airport and the number of plant it utilises within its building services. The airport's BMS uses a dedicated VLAN's for communication between its plants and systems.

One of the information systems installed within Manchester Airport is Chroma Airport Suite.

Chroma Airport Suite is a product of The Amor Group who state that Chroma is:

> The world's only truly integrated set of airport operational solutions; the Chroma Airport Suite® delivers a common technology platform that establishes a commitment to airport-wide collaboration and integration. It enables operators to establish and monitor service levels to drive an increase in performance across the airport.
>
> The Chroma Airport Suite facilitates Airport-wide Collaboration via an integrated set of products that include ACDB, AODB, FIDS, RMS, CDM, Demand Forecasting, in-depth Business Intelligence and Billing solutions that is helping customers including Dubai Airports, London Heathrow, Oslo and Manchester Airport Group deliver the Next Generation Airport, today. (Chroma, n.d., para 1)

Amongst the integrated products within the Chroma suite is a product called ChromaAODB - Multi Airport Operational Database. The Amor group describes ChromaAODB as :

> ChromaAODB, alongside ChromaACDB, is the core module within the Chroma Airport Suite®; storing, managing and disseminating data relative to traditional operational activities around the airport for both airside and terminal operations, enhancing end-to-end stakeholder collaboration. (Chroma, n.d.para 3)

Chroma AODB provides a number of interfaces that could provide information to other applications that may require flight information. One of these interfaces at Manchester Airport could be a BMS interface which could then provide flight information to the Building Management System allowing the system to know which aircraft stands are being used and at what time of day.

Once the interface has been established this information can then be incorporated into the BMS schedules to enable and disable plants in a more efficient manner. The schedule will still allow the systems to maintain comfort conditions within the appropriate areas, but only on passenger demand which will be determined by the flight information interface.

2.5.2 Building Innovations

The Low Carbon Innovation Co-ordination Group (LCICG), is the coordination vehicle for the UK's major public sector backed organisations in the area of 'low carbon innovation'. Its core members are the Department of Energy and Climate Change (DECC), the Department for Business, Innovation and Skills (BIS), the Engineering and Physical Sciences Research Council (EPSRC), the Energy Technologies Institute (ETI), the Technology Strategy Board (TSB), the Scottish Government, Scottish Enterprise, and the Carbon Trust (TINA 2012). The group publish a report of Technology Innovation Needs Assessments for Non domestic buildings annually and alo produce a summary report.

The innovative measures in the TINA summary are additional to existing commercial measures. The aim of the TINAs is to identify and value the key innovation needs of specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. Additional barriers and opportunities in planning, the supply chain, related infrastructure and finance are not explicitly considered in the TINA's conclusion since they are the focus of other Government initiatives, in particular those from the Office of Renewable Energy Deployment in DECC and from BIS (TINA, 2012).

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Innovations have a major part to play in the UK commitment to reducing its GHG emissions. Carbon Trust research has revealed a significant opportunity from existing commercial measures – a 35% carbon saving is possible with a net benefit of at least £4bn by 2020. A carbon saving of 75% by 2050 is achievable at no net cost, however these savings, and additional savings from new technologies, will be difficult to realise without innovation (Carbon Trust 2010)

Innovations for non-domestic buildings can be split into four major technology areas: integrated design; build process; management and operation, and materials and components. TINA explains each section in more detail as:

Integrated design innovations include:

modelling and software tools, which could become faster and more accurate in using passive design to minimise the need for building services;

design tools and services, knowledge tools that could be used to close the gap between design intent and actual performance by addressing the wide variety of buildings and incorporating feedback from operational buildings.

Build process innovations include:

smart manufacturing processes, e.g. off-site construction, where individual modules are pre-manufactured and assembled on-site, and modern on-site construction, including products such as. tunnel-form concrete and tighter supply chain integration;

industrialised retrofit techniques, new construction methods to reduce the cost of refurbishing existing buildings and improve the performance of refurbished buildings;

commissioning building services, ensuring that services (heating, cooling, lighting, and ventilation) are put to use efficiently.

Management and operation innovations include:

smart controls and systems diagnostics, predictive, intelligent user-oriented building management systems and diagnostic applications that optimise performance of building services;

carbon management services, integrating landlord-tenant building management through new investment and leasing models to overcome split responsibility and identified lack of action. While these are not technology innovations, they are necessary process innovations;

Assisting **behavioural change** by providing users with clear information and incentives.

Materials and components innovations include:

advanced façade materials and integration, improving the functional performance of façades to provide light, insulation, shading and ventilation whilst reducing the need for cooling;

advanced daylight technologies, harvesting daylight from roofs and façades through skylights, fibre optics or other means;

advanced natural ventilation systems, using ventilation stacks, atria and automatic openings combined with automatic control systems, passive cooling such as breathable walls, and the effective thermal mass of buildings to reduce cooling and ventilation energy;

low carbon cooling, a range of technologies combined with building thermal mass and phase change materials to moderate temperature fluctuations.

The reason for the extensive review on the TINA summary is because I wanted to pay particular attention to two specific innovation technology areas. The first area is the integrated design innovations, where the TINA summary tables existing measures alongside the innovative needs and secondly the build process technology area.

Within the integrated design area the existing measures were listed as simplified energy modelling used for new build and dynamic modelling applied to selection of new build and refurbishment projects, where as the needs assessment was more advanced modelling to improve accuracy and to incorporate building performance data into design tools.

The tables listing for the building process area’s existing and needs assessment was predominantly traditional construction, sample details and manual inspection with the needs assessment to be moves to off-site construction, automated surveying and inspection tools, improved process for commissioning and handover and lastly tools allowing correct sizing of building services.

Both Integrated design and Build process technology areas have what I consider to be realistic and essential need assessments. Both assessments would be a significant step in the right direction of the commitment of commercial GHG emission reduction. The concerning element of the report is the actual results or market failures of the UK contribution to the assessment needs.

Integrated design, specifically the modelling and software sub areas result on the market failure was “Critical Failure”, with building process achieving “significant failure” with the industrial retrofit techniques sub section.

These results go to highlight the significance of this particular research in analysing what effect greater integration between systems and operations can have on CO_2 emissions. Also the analysis of the existing relationship in the current build design highlighted potential improvements with greater interaction and knowledge passed between designers and building services engineers on the retrofit projects.

2.5.3 Retrofit Designs

Figure 2.16 below displays the existing ductwork layout providing the conditioned air into the designated zone space. It was noted during analysis that with greater knowledge of the operation associated with that space, and correct zoning of the air handling unit plants, energy reduction may have been possible. The more efficient procedure could have occurred with greater zoning of air handling units, or a minor alteration to AHU 34. AHU 34 ductwork could have been increase to accommodate the departure flights for stand 25. Figure 2.17 displays the created AHU/stand schedule for specific departure routes, currently both, AHU 34 & 38 are required to provide passenger comfort for their route to depart from stand 25. With improved relationships between operation and services, particular during design stage, the procedure may have been designed that just AHU 34 would have been sufficient to provide the comfort condition required.

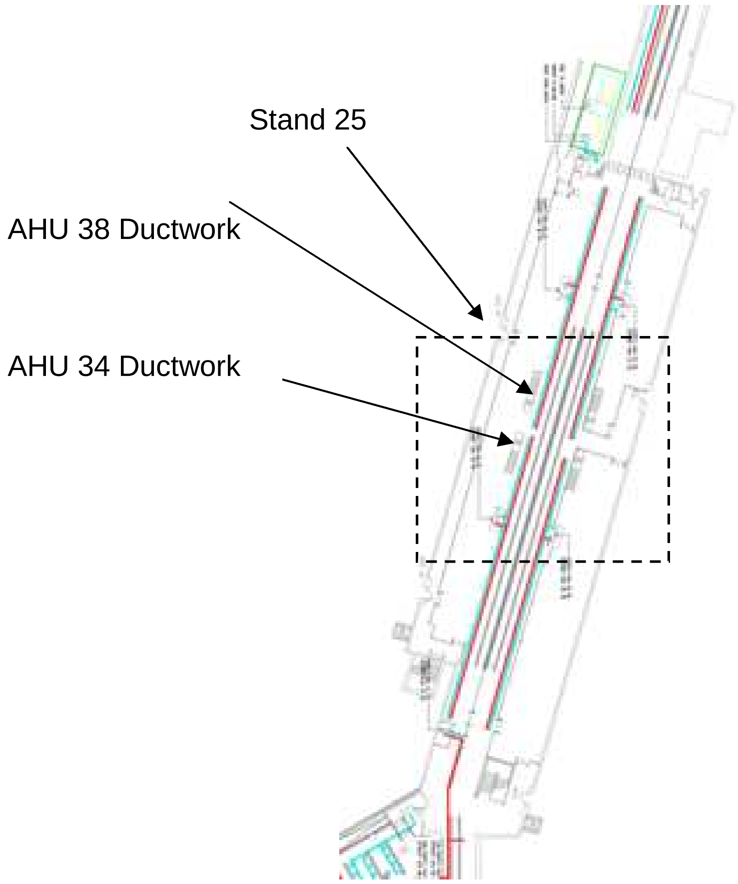


Figure 2.16 - Ductwork Arrangement for AHU 34

Stand	AHU required for Departure Comfort Conditions						
22	34	35					
23	34						
24	34		37	38			
25	34			38			
26	34		37	38			
27	34			38			
28	34			38	43	44	45
29	34			38	43	44	45
31	34			38	43	44	45
32	34			38	43	44	45

Figure 2.17 - Departure AHU/Stand Schedule

In phase three the primary consideration was to analyse the efficiency of the relationship between operation and service with emphasis on the operation. The aircraft stand management was examined and adjusted accordingly to allocate aircraft closer to the main terminal building to attempt to reduce the areas that would require comfort conditioning. This proved successful as the energy usage and subsequent emissions was reduced from phase two results. During this analysis the importance of the building design and building use, and the effect this can have on the efficiency was also highlighted. This became more apparent when the analysis of phase three stand allocation was performed. The main criteria for the stand allocation adjustment within the hypothetical phase three relationship, was to allocate the aircraft closer, where feasible to the main terminal to reduce the area or route the passengers embark to reduce the requirement of comfort conditioning.

Flight LS876 was re-allocated from stand 27 to stand 24 in phase three to reduce the distance from the aircraft to the main terminal. The distance from the aircraft to the terminal was reduced but due to the design and use of the area, the actual passenger route had increased. The increase was due to the design of the build and the different requirement for the departing and arrival routes. Stand 27 currently does not require any comfort conditions due to the route the passengers have to take, but stand 24 has a requirement to enable AHU 35 producing a greater provision for comfort conditioning. Figures 2.17 to 2.19 detail the additional requirements for AHU 35 for the Arrival route and AHU 37 for the Departure route for flight LS876.

This result has obvious implications on the energy usage of the units but highlights the potential for even greater savings with a better knowledge of the buildings use in addition to the services and operations relationship. Further research into the AHU schedule to determine which plants are required or are already enabled for existing flights could become a major factor in the operational adjustment for allocating flight stands. The closer stand to the terminal may not be the most efficient stand to allocate an aircraft to if an available stand further from the terminal already has the comfort conditions enabled within the same time frame and meets the aircraft size criteria.

The above results again highlight the importance of this research. Not only the relationship between the operation of the building and the services provided can affect the energy consumption, but this relationship can also be made more efficient with greater knowledge and interaction of data between the building design, operation and services being provided.

Flight No	Aircraft Reg	Aircraft Type	Aircraft Size	ATA	Original Stand	Proposed Stand
LS876	GGDFJ	738	5	15:07:	27	24

Figure 2.18 - Flight LS76 Phase Three Stand Allocation

Aircraft Stand/AHU Schedule - Arrivals 8th April 2012 Phase 3															
flight No	Aicraft type	Aircraft Reg.	Origin	STA	ETA	ATA	stand		Air Handling Unit (AHU) Required						
LS876	738	GGDFJ	FAO	15:00:	15:00:	15:07:	24	Phase 3		35					
LS876	738	GGDFJ	FAO	15:00:	15:00:	15:07:	27	Phase 2							

Figure 2.19 - Flight LS876 AHU Arrival Schedule

Aircraft Stand/AHU Schedule - Departures 8th April 2012 Phase 3															
flight No	Aicraft type	Aircraft Reg.	Origin	STD	ETD	ATD	stand		Air Handling Unit (AHU) Required						
LS887	738	GGDFJ	PRG	16:00:	16:10:	16:11:	24	Phase 3	34		37	38			
LS887	738	GGDFJ	PRG	16:00:	16:10:	16:11:	27	Phase 2	34			38			

Figure 2.20 - Flight LS876 AHU Departure Schedule

There is definitely a gap within the research topic particularly in the reviewed literature on the relationship and interaction between systems and operations. Many of the reviewed literature detailed efficiency procedures for certain plant and system components with a minority discussing system optimisation. The relationship between building design, building operation and the services provided during that operation is certainly a topic that requires more research. Further research is required to highlight the importance of the system and operation relationship but also research to further enhance the knowledge of providing the services (within the systems) in an efficient manner to match the actual operational demands restricted by the building design.

2.6 RESEARCH WORK ON BUILDING SERVICES ENERGY REDUCTION

A major factor can that sometimes be overlooked for efficient operation of plant is the deployment of operation and maintenance programs. These programs targeting energy efficiency can save between 5% and 20% on energy bills. (NREL, 2011). Within these inspections experienced maintenance engineers can make general observations on actuators, dampers and perform periodically re-commissioning on the units. It is the modern day approach to have highly skilled white collar engineers monitoring plant operations and alarms on the BMS workstations whilst located in a modern office. A very interesting article by Aune, M et al., (2009) titled “The missing link which was already there” argues the fact that experienced building operators can improve energy efficiency with or without advanced technological systems. I feel the importance of the maintenance can sometimes be dismissed when a building manager believes their plant is being controlled by a highly technical Building Management System. The BMS system and white collar worker can monitor the system and alarms, but what does the system and worker do when they identify a problem? Until that problem can be physically resolved the plant will be working in an in-efficient manner.

There are many energy efficiency procedures that can be implemented into HVAC systems. These are obviously dependant on the finances available and whether the building is in design stage or existing. The practicality to implement the procedures into older systems and buildings would have to be a consideration when looking into energy efficient projects.

Some of the larger projects that could be undertaken would be to replace old inefficient cooling equipment with high efficiency equipment that has a higher coefficient of performance (COP) rating. Replacement of large air cooled cooling equipment with water cooled chillers and cooling towers. Maintenance programs again have to be strictly adhered to when incorporating cooling towers into the HVAC system to prevent legionella disease. Water cooled chilled water plants have a COP rating that are approximately twice that of air cooled equipment. (NREL 2011)

Heat recovery systems should also be considered; these can include thermal wheels and run around coils. Both systems recovery the energy from the exhaust air within the plant and replenish it into the delivered air. This can reduce the cooling energy required.

Energy efficiency of Air Handling Units as they are the main equipment associated with this research has also been investigated. Once again maintenance is the major efficiency tool for air handling units. During the program the engineer must check proper operation of all dampers, driving them in percentage changes to prove correct modulation in proportion to the controller output. Correct seating of the dampers is also an important check to ensure there are no leakages when fully closed (fresh air damper) which would produce an increase in energy use.

A similar process is required for the heating and cooling valves. Examine correct operation on a percentage change in proportion with the controller output. Additional checks utilising the ductwork air temperature sensors. If installed check the pre-coil temperature and discharge temperature sensors when the heating valve is closed. This can determine if the valve is seating correctly or whether the valve is passing. The same process can be performed on the cooling valve again preventing any unnecessary energy use.

Visual inspection of the actual heating and cooling coils should also be incorporated within the maintenance program. If the coils are becoming clogged due to insufficient filtering (filters damaged or even removed) the static pressure across the coil will increase. This pressure increase will result in reducing heat transfer across the coils. This would result in an increase in energy use, having to provide more (or for longer periods) heating or cooling than should be necessarily required

As discussed filters are usually installed prior to the coils and can include panel filter and bag filters. Carbon filter which absorb contaminants from the air (smells) are installed after the coils and should also be included in the maintenance inspection. If heat recovery systems including thermal wheel are incorporated into the plant then filters should also be installed within the extract ductwork prior to the thermal wheel. Differential pressure switches are installed to measure the static pressure across the pre and bag filters. The readings are usually displayed on the side of the unit via dials to be recorded on inspection or if connect to a BMS system they can be set to alarm at a pre determined level. Once the filter has reached the determined static pressure reading the filter must be replaced with new filters. Unusually this arrangement does not appear to be followed for the heating and cooling coils, if static pressure sensors were to be installed across the coils, again readings or alarms could indicate when the coils require cleaning, and also determines that further investigation is required as to why the filters are being by-passed.

2.6.1 Hardware

As the “energy conservation” concept has been widely accepted by most engineers and building professionals, the power electronics variable speed drives have been very popular in the building industry, in particular, in the area of heating, ventilation and air-conditioning (HVAC) applications because this is the area where substantial energy consumption exists in a modern commercial building. (Chan et al., 1997).

Variable Speed Drives (VSD’s) provide a greater opportunity for the building managers to achieve their goal, which is to provide services only when demand is required. VSD’s can also save energy on existing air handling units by reducing the supply and extract fan speeds. Existing air handling units would have been designed to provide a calculated flow of air to satisfy the correct comfort for the activity being performed within that space. Once the air flow had been determined the motors would have been sized for the project. Typically these motors would have been selected on the larger rather than smaller process to provide the air flows. With the existing motor control methods the motor would have been enabled and controlling at a speed of 50Hertz. Once the VSD has been installed the motor speed can be reduced to provide the adequate air flow required. Additional control methods could then be applied to the air handling unit sequence once the VSD had been installed (see Software).

Manchester Airport Utilities department in partnership with ABB embarked on a project to replace existing motor control methods with a more energy efficient method.

This particular project was aimed at energy reductions on the airport air handling units installed within Terminal 1. The project developed from the idea of utilising a new energy efficient air filter product that had been developed by Vokes Air. There are over 200 air handlings units located on the Manchester Airport site, with each unit having panel, bag and carbon filters installed within the unit to filter the air from dust and smells, therefore significant improvements on filter efficiency could play a major role in improving plant efficiency across the site particularly with the inclusion of the VSD units. The reduced pressure drop across the efficient filter allows the VSD to reduce the fan speed and still maintain adequate flow rates.

Vokes have developed a new bag filter (Revo II) which it claims not only improves filter efficiency through its aerodynamic design which reduces pressure drop, but also provides cost savings on filter layout as the synthetic media incorporating nanofibres eliminates the need for panel filters to be installed in the units prior to the bag filter. (Vokes n.d., para 3)

The Revo II meets the requirements of EN 779:2012 which is the European filter standard.

Figure 2.21 - Revo II Bag Filter (Vokes Air)

Source: http://www.vokesair.com/

The new motor control method selected was the ABB ACH Variable speed drive, which is a dedicated HVAC inverter. To compliment the Inverter installation and to overcome the existing unit design, ABB IE2 motors replaced the existing motors. The ABB IE2 motors were resized to maintain the desired air flow rates but achieve greater running efficiency. Manchester Airport Utilities group stated a five percent saving can be realised. (ABB., n.b., para, 3)

Figure 2.22 – ABB ACH550 Variable Speed Drive

Source: http://www.abb.co.uk/energy

Manchester Airport Utilities are aiming to push the project out across the entire site which would provide even greater savings than that currently reported, ABB claim "A project to upgrade the Air Handling Units (AHUs) at Manchester Airport with ABB low voltage drives and ABB high-efficiency IE2 motors is saving annually 4,000 MWh, as well as cutting CO_2 emissions by over 2,000 metric tons a year". (ABB., n.b., para, 2) particularly as the project falls within the government incentive schemes.

Variable speed drives when installed on pump systems, can be utilised to match flow rates to actual demand on cooling coils of air handling units or fan coil units systems rather than providing full capacity on a constant basis.

A survey of the existing chilled systems would have to undertaken and if the results revealed a constant volume system and 3 port configurations on the coils, energy reduction would be possible. The procedure would involve replacing the 3 port valves on each coil (remembering to provide a pressure relief point or leave the last coil on the circuit as a 3 port configuration) with 2 port valves. Once the VSD are installed and operating to the correct static pressure point, the VSD will reduce the pumps speed as demand on the coil reduces. The 2 port valves will begin to close creating a static pressure rise which will cause the VSD to reduce the pump speed to match the systems current static pressure set point.

VSD's should also be installed on cooling tower fans to control the condense water temperature. If the condense circuit has multiple cooling towers installed, the control strategy should not bring on an additional tower on demand until the first tower has ramped up to a pre determined frequency of around 50Hz. In conjunction with additional software alterations (discussed in software) this could reduce chilled water system energy consumption considerably.

2.6.2 Software/System Optimisation

"One of the most important functions of a building control system is time control, ensuring that plant is switched off when not needed. Substantial energy savings may be made by intermittent heating or cooling of a building compared with continuous operation" (CIBSE H 2009). Optimum start controller is an additional control available in most modern BMS programs. A simple time switch or time schedule configure within the BMS controller, would enable and disable a plant at the designated times allocated within the schedule. The schedule start up time would have been derived from working out how long the plant has taken to achieve the desired conditions within the dedicated space. The problem with this arrangement is that the start up schedule does not take into account that if the outside air is higher than when the initial commissioning was taking place, the system could have reached the desired temperature in a much shorter period culminating in energy use when not required. The opposite problem may also arise if the system was left inactive for an unusually longer period than normal with cold outside air temperatures, the system would not reach the desired temperature in the time allocated.

The optimum start controller incorporates an algorithm that calculates the optimum start up time required to achieve the desired conditions. The controller takes into account different operating conditions such as outside air temperature and local indoor air temperature sensors when calculating the time period required.

Optimum stop functions are also available which calculate the time period that the plant can be switched off but still maintain the desired comfort conditions within the space with occupancy. Optimum stop functions are not as popular as optimum start functions and are not often included in energy strategies. This is particularly the case with air handling unit systems. CIBSE H (2009) states that the zone air temperature will approach the building fabric temperature within 15 minutes after switch off. It argues that this may not maintain the desired comfort conditions. I feel this procedure, particularly within the environment of this research study, is that energy saving opportunities out way the passenger comfort conditions for that time period. If the actual zone temperature falls below the desired comfort conditions within a small time period due to severe outside temperatures. The actual number of arriving passengers who will be exposed to that specific condition will be small and the length they would be expose would also be minimum as they pass through into the next zone.

Another important energy reducing control loop is the Compensator loop. The loop is a function available in most BMS controllers. The compensator loop can alter a set point in relation to the outside temperature. An example would be to reduce the heating flow set point on a radiator circuit in relation to a rise in outside air temperature.

There are a great number of different methodologies that describe the design of controllers for the exact purpose of operating HVAC systems including genetic algorithms, fuzzy logic, neural networks and the more conventional PID.

There has been many articles written on the theory of genetic algorithms and their application to HVAC optimisation including works by (Huang & Lam, 1997; Asiedu et al., 2000; Chow et al., 2002; Lu et al.,2005; Atthajariyakul & Leephakpreeda, 2005).

This may be due to the fact that genetic algorithms have very favourable characteristics and the wide range of problems they cover. (Chambers,1998).

Congradac & Kulic, (2009) conducted an experiment on a HVAC system incorporating fresh air and recirculation dampers, 3 port valve controlling the flow into a cooling coil, chiller and a supply fan. They developed an optimisation program using genetic algorithms to determine optimum positions for the dampers and 3 port valves at specific conditions. The results concluded that the energy reduction possibilities should not be disregarded. As with many genetic algorithm simulations, the several functional components of a air handling unit are examined and not the complete system as a whole. Congradac, V., & Kulic, F. determined their results with a constant 7^{o}C chilled water set point and a constant pump speed. If the HVAC system was a large commercial system incorporating a large capacity single or multiple chillers there could be the possibility of greater energy savings by increasing the chilled water temperature and condensing water set points in relation to outside air temperatures. In conjunction with raising the temperature set points on low demand, as explained in earlier sections the chilled water pump sets and cooling tower fans could also be reduced via VSD's to match the actual system demand.

There has been many articles written on Fuzzy logic and their application to HVAC systems, works from (Gacto et al., 2012; Alcalá et al., 2009; Alcalá et al.,2005).

Fuzzy controllers have been developed for HVAC systems and it has been found that they offer advantages of robustness, energy saving and fast response, compared with conventional PID control (Wang, 1999).

I feel the big advantages of fuzzy logic control is that it does not require a model of the process to be controlled and that it is possible to incorporate the results of operational experience into the set of rules. With knowledge of the system the fuzzy control can be implemented and additional rules can be applied to facilitate any changes or operational requirements.

Again there has been many articles written on the theory of neural networks and their application to HVAC systems including works by (Kusiak & Xu., 2012; Guo et al., 2007), (Hosoz et al., 2007).

Neural networks attempt to reproduce the way the human brain learns by experience. In brief, a neural network device accepts data from a number of inputs processes the data, using a series of non-linear processing elements and produces a set of output data. What

distinguishes a neural network from other types of processor is that it does not depend on a model or even an understanding of the process, but is capable of learning by experience.
I feel this as a huge advantage for analysis of a system as the operation of a complete HVAC system is highly non-linear, making it difficult to optimise performance under a range of different load conditions. A neural network can be applied to learn the system behaviour and then used off-line to investigate optimum control strategy without having any effect on the existing operational conditions.
Neural networks are applicable where a high degree of non-linearity exists and there is a large amount of data available for training the network. A complete HVAC system with BMS control meets both these criteria.

There are other energy efficient software alterations that are applicable to any HVAC system being controlled by a BMS system. Some may require additional hardware components mentioned in previous sections, and other systems may already have the hardware available and not require any additional investment but could benefit from software alteration on its existing system.

Chilled water supply temperature can be determined by examining the valve position on the cooling coils of the system. If demand on the system is low and the majority of the valves are closed or closing, the chilled water temperature could be raised. This would have to be discussed in conjunction with the chillers manufacturer to maintain safe efficient operation of the chiller. If the system has multiple distribution circuits, the system can be monitored for static pressure across the coils and reduce the pump speed via a VSD accordingly to demand. Additionally on the chilled system , resetting the condenser water temperature based on outside air wet bulb temperature can improve efficiency of the chillers by reducing the temperature lift between the condenser and evaporator within the chiller. Previously mentioned in the hardware section, inverters installed on the cooling towers can adjust the motor speed accordingly within a cooling tower sequence which would match system demand.

2.7 RESEARCH WORK ON ENERGY EFFICIENCY TECHNIQUES

Sustainable development can be broadly defined as living, producing and consuming in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs.(Twidell & Weir., 2012). One of the major attributes to this vision is “Renewable energy”.

The term renewable energy comes from the fact that the energy source is naturally replenished when used. The main source of renewable energy is:

- energy from sunlight
- heat from the earth, the air or water sources
- plan
- ts grown for fuel (biomass or biofuels)
- waste
- the movement of water (known as hydro) and wind

Renewable energy sources are becoming increasingly popular in the modern day society. They are being produced to reduce the dependency on the non-renewable energies like fossil fuels. Developing or using new and additional renewable energy sources ensures that no net greenhouse gases are released during energy production and is one way a business can help to reduce their contribution to climate change.

The use of renewable energy can not only save business money and improve the corporate image but in certain applications can produce an income.

The total installed capacity of sites generating electricity from renewable energy sources in the UK at the end of 2011 was just over 10 GW; around 9% of the total electricity generation. (REN 2011).

On a larger scale, by the end of 2010, the EU 27 renewable energy generating capacity was 265GW, with total global generation capacity reaching an estimated 1,320,000MW. These capacity figures cover generation from wind, biomass, solar PV, geothermal power, solar thermal and tidal. A total of $211 billion had been invested globally in renewable energy. (DECC 2011)

As with CO_2 reduction, a driver behind the use of renewable energy is Government incentives. Businesses that can demonstrate their energy supply comes from renewable sources will also be exempt from the Climate Change Levy (CCL) for that element of their energy use.

More recently, in April 2010, the UK Government introduced the Feed-in Tariff (FIT) to incentivise smaller-scale renewable generation within the commercial, industrial and residential sectors. Also in March 2011, the UK Government announced the details of the Renewable Heat Incentive (RHI) aimed at providing a similar incentive to the FIT, but for renewable technologies that generate heat rather than electricity.

Renewable technologies include items such as:

Wind turbines produce electricity by capturing the natural power of the wind to drive a generator. Careful consideration is required when locating the ideal site position for the turbine.

Biomass boilers generate heat by burning organic material such as wood, straw and specific crops. Biomass boilers can also be utilised to generate electricity if connect to a combined heating and power plant.

Solar thermal systems use solar collectors to absorb energy from the sun and transfer it, using heat exchangers, to heat water. Solar thermal systems can be used to provide hot `water at temperatures of between 55ºC and 65ºC.

Solar Photovoltaic (PV) installations convert sunlight into electricity. PV electricity generation uses the energy in the light from the sun to causes an electrical current to flow between different atomic energy levels in specially processed materials. PV, like solar thermal, is a truly intermittent renewable energy technology and requires the user to obtain electricity from an alternative source during the night when it cannot generate electricity, or to utilise a battery back-up system where some of the energy generated can be stored during the day, for use at night.

Heat pumps and geothermal power provide a means to access and utilize the thermal energy that is contained naturally in air, water or the ground. Ground-source heat pumps take low-level heat from solar energy stored in the ground and convert it to high-grade heat by using a heat exchanger. Air-source heat pumps work on a similar principle to the ground source heat pumps, but source the low-level heat from the air, using an air-source collector, located outside of the building.

Hydro-electric power (hydropower) uses water flowing through a turbine to drive a generator that produces electricity. Obviously this technology is very site specific and could not be used at the majority of commercial buildings etc.

Careful consideration and planning is required to determine not only which technology is best suited for a given site, but as to whether any of the technology available is feasible to that site. Other considerations need to be taken into account when discussing renewable energies and whether they are reducing the emissions as much as you think. That is issues like secondary emissions. Biomass boilers require a steady influx of organic material for combustion, which if not locally sourced will require a regular delivery by multiple vehicles. The vehicles themselves will be producing CO_2 emissions on the various site visits. Supply chain issues are a real discussion point when considering renewable energy sources.

3.0 METHODOLOGICAL CONSIDERATIONS

The first stage of the research is to identify the issues relating to building efficiency and carbon emissions and is based on the extensive and ongoing discussion in the literature.

To assess what specific plant would be included within the research, site visits were arranged to survey the specific research area and the equipment providing comfort conditions within these areas.

The research was largely performed by the quantitative methodology (Saunders et al., 2011). The initial process involved gathering actual electrical consumption data from the dedicated air handling units. The quantifiable data collated from the supply and extract fan motors for all associated air handling units allowed the data to be formulated into separate air handling unit tables using the quantitative analysis technique (Cooper & Schindler, 2003). This data was now available for manipulation into energy consumption figures for 24 hour and annual periods.

Using similar techniques the additional data required could now be included into the analysis to calculate the CO_2 emissions for the same time periods.

Access was gained to quantifiable data on aircraft schedules which was produced by Manchester Airport Airfield operations from their flight information suite (Chroma). The data was filtered to produce a full 24 hour schedule of flights for the 8th April 2012.

A simulation model was created from the data to provide a graphical representation of the existing relationship between the services provided and the existing building operation. The simulation was created to compliment the accumulated data. (The simulation provides a greater insight into the relationship for non-technical personnel)

Information gathered from the initial site surveys including copies of “As Built” drawings of the existing air conditioning ductwork layouts provided by Airport Utilities, allowed for an AHU/Stand schedule to be produced. The schedule indicated which air handling unit provided the comfort conditions for the dedicated areas around the departure gates. This determined which AHU was required to provide comfort conditions for the passenger route to every departure gate.

The previous data analysis techniques could now be performed but with an additional added variable of the model boundaries. The variable is the enable and disable time frame of the plant to provide comfort conditions for flight demands only.

This analysis provided the hypothetical power consumption and CO_2 emissions from the hypothetical relationship between services and operations created.

A second simulation model was created from the data to provide a graphical representation of the hypothetical relationship between the hypothetical services provided and the existing building operation. The simulation was created to compliment the calculated data. (The simulation provides a greater insight into the relationship for non-technical personnel)

Quantifiable data on aircraft and stand sizes was produced by Manchester Airfield Operations and I was given access to a copy of the data. This data was examined to determine which specific stands could facilitate which specific aircraft on that particular day.

The existing operation was then hypothetically adjusted to re-allocate aircraft onto different stands to see if the efficiency of the relationship would be affected.

To calculate the hypothetical relationship of the new operation, a new AHU/Stand schedule had to be created.

The same data analysis as the two previous phases could now be performed. This provided a second hypothetical relationship between the services and operations.

A third simulation model was created from the data to provide a graphical representation of the second hypothetical relationship between the hypothetical services provided and the hypothetical building operation. The simulation was created to compliment the calculated data. (The simulation provides a greater insight into the relationship for non-technical personnel)

To visual analyse the data created from all 3 relationships, multi bar charts (Saunders et al., 2003) were created displaying energy consumption and CO_2 emissions simultaneously.

4.0 FINDINGS AND ANALYSIS

4.1 INTRODUCTION

The focus of this chapter is on the results generated by analysing three different system/operation relationships which will form part of the operational cycle.

Phase one is to examine the existing relationship between the temperature control services being provided for passengers associated with aircraft stand allocation operations. The energy consumption of the temperature control plant during this relationship will be calculated from the kWh rating of the electrical motors. The subsequent CO_2 emissions due to the electrical consumption of these services can be derived by using the emissions factor published by DEFRA which are updated annually and can be accessed via the DEFRA website. (http://www.ukconversionfactorscarbonsmart.co.uk/)

Phase two will be to examine the system/operation cycle whilst creating a hypothetical relationship between the temperature control system and the stand allocation operation. The results will then be compared to the findings during phase one analysis. The efficiency of the hypothetical relationship will be judged by comparing the results of the energy consumption of the temperature control units, and the subsequent carbon emissions with the results calculated from phase one operation. The service level provided to passengers provided by the temperature control units has to be maintained during the operational cycle and cannot have any adverse effects on the comfort conditions provided to the customer.

This will be achieved by analysing the flight information data provided by the Chroma Fusion airport system. Chroma Fusion details flight information including the type of aircraft and to which stand the aircraft has been allocated. Chroma Fusion provides flight departure and arrival times for all 3 Manchester Airport Terminals. The data can be filtered to provide the actual departure and arrival times of aircraft for the specific aircraft stands situated on International C-Pier. The efficiency of the relationship between the temperature control services provided and the stand allocation can be examined. The efficiency can be described as providing temperature control to the passenger occupied areas during aircraft embarkation/disembarkation timeslots only.

Phase three will be to see if system/operation efficiency can be improved even further from phase 2 results whilst maintaining safe stand allocation management. Simulation of actual departure/arrival stand allocation time slots over a 24 hour time period will be performed. The simulation will be analysed to determine if stand allocation management can be improved to reduce energy consumption even further, whilst maintaining both safe stand management and temperature control during passenger occupied periods.

Figure 4.1 – Overview of International C-Pier

Source: Adapted "C-Pier." 53° 21'43.78"N 2° 16'40.00" W Google Earth June 6 2009. June 17 2013.

Figure 4.1 is an aerial view of International C-Pier displaying the surrounding airfield apron along with the aircraft stand configuration. The image provides the viewer with a greater understanding of the complexity of the apron and stand management required to allocate the correct size aircraft for the appropriate stand.

International C-pier has been designed with three different operational levels. A site survey was undertaken to determine what type and size of plant is providing the temperature control services within the different levels of C-Pier. The ground level consists of staff areas which operate on a 24 hour 7 days a week basis. Level 1 runs the entire length of C-pier and consists of segmented areas allocated to departure and arrival zones. Level 2 consists of a building services plant room and exists in the furthest point of the pier away from the main building and is known as the satellite area.

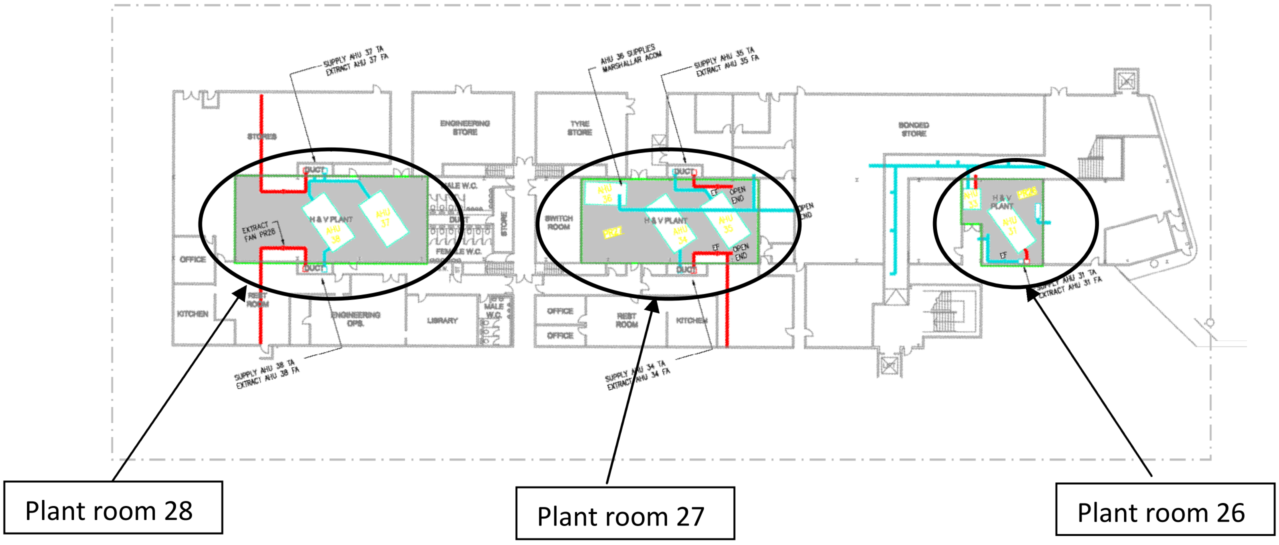
The following sections describe the different levels in more detail with actual building management system screenshots of the temperature control plant associated with each level.

4.2 PHASE ONE

4.2.1 Ground level

Figure 4.2 provides an overview of the ground level structure of International C-Pier. Figure 4.3 is an enlarged section of the highlighted area of figure 4.2 which houses the building services plant

Figure 4.2 – Ground level structure (Courtesy Airport Utilities)



[redacted]

Ground level consists of staff accommodation and building services plant rooms which house the air handling units and ancillary equipment. There are 3 plant rooms on ground level, containing 8 separate air conditioning plants which serve the departure, arrival areas on level 1 and staff accommodation on the ground level. The plant rooms are labelled plant rooms 26, 27 & 28 and details of the air conditioning plant associated with each plant room are described in the following sections.

4.2.2 Plant room 26

Plant room 26 consists of 3 air conditioning plants, Air Handling Unit's (AHU) 31, 32 & 33. Figure 4.4 details the power ratings of the existing plant, including nominal rating and actual running load rating of the motor. The particular type of starting method currently controlling each motor has also been documented for further discussion. The kWh usage has been calculated for a 24 hour period and yearly figures from the actual kW reading taken whilst the unit was in operation.

Plant Room	AHU No.	Fan	motor rating (kW)	Existing motor control	actual (kW)	kWh/24hrs	kWh/year
26	AHU 31	Supply	11	Inverter - Jaguar	8.1	194.4	70,956.0
26	AHU 31	Extract	1.1	DOL*	1.1	26.4	9,636.0
26	AHU 32	Supply	3	DOL*	3.0	72.0	26,280.0
26	AHU 32	Extract	3	DOL*	3.0	72.0	26,280.0
26	AHU 33	Supply	1.5	DOL*	2.1	50.4	18,396.0
26	AHU 33	Extract	1.5	DOL*	1.4	33.6	12,264.0
* DOL= Direct On Line					**Totals**	**448.8**	**163,812.0**

Figure 4.4 - Plant room 26 AHU electrical motor consumption

The Building Management System (BMS) monitors the operation of each plant and a graphical display can be viewed on a front end workstation. This can be a valuable tool to maintain efficient plant operation. When monitored by a skilled operator any malfunction with equipment that could cause inefficient operation, for example a faulty actuator on a heating valve which operates to satisfy heating demand can be identified and rectified swiftly by maintenance personnel.

Figure 4.5 below is the actual screenshot from the front end workstation monitoring the air conditioning plants located within plant room 26. It details 3 Air Handling Units (AHU) 31, 32 & 33 with their associated control hardware.

This particular screenshot highlights the importance of the BMS system as a monitoring tool as currently there are obvious issues with the plants hardware particularly with fan status and heating valve values which would require further investigation.

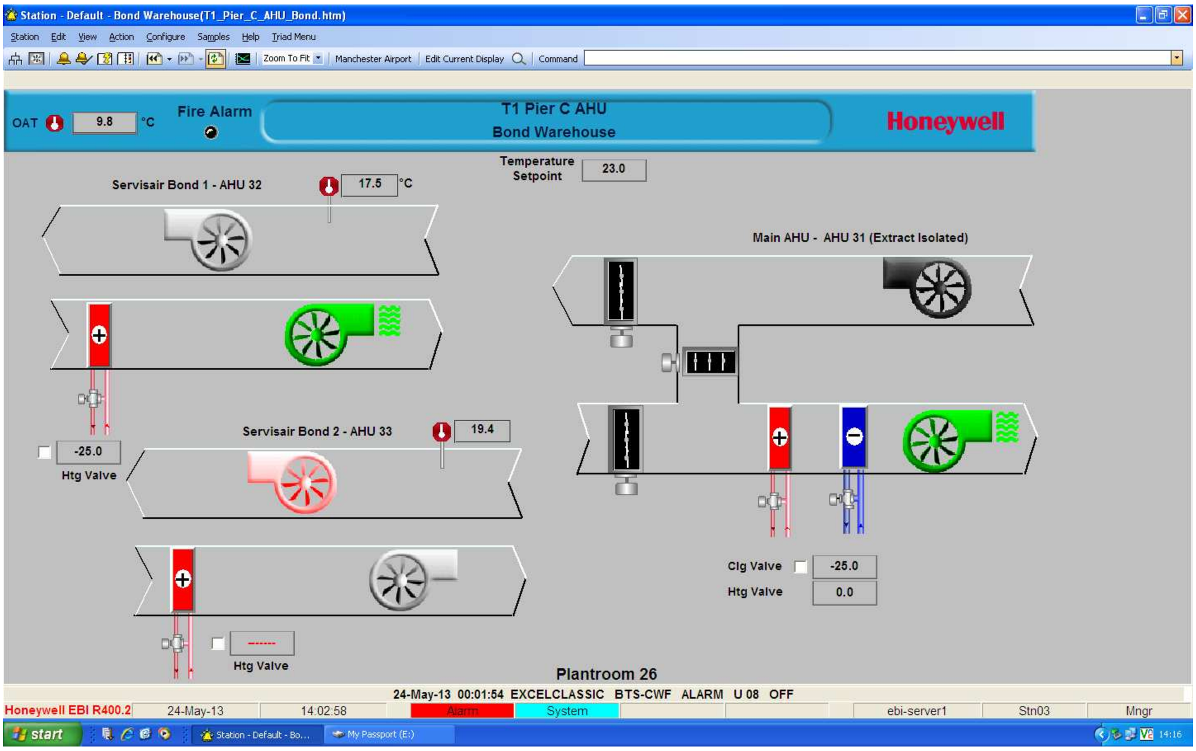


Figure 4.5 - Plant room 26 Air Handling Units (Courtesy Airport Utilities)

4.2.3 Plant room 27

Plant room 27 consists of 3 air conditioning plants, Air Handling Unit (AHU) 34, 35 & 36. Figure 4.6 details the power ratings of the existing plant, including nominal rating and actual running load rating of the motor. The particular type of starting method currently controlling each motor has also been documented for further discussion.. The kWh rating has been calculated for a 24 hour period and yearly figures from the actual kW reading taken whilst the unit was in operation.

Plant Room	AHU No.	Fan	motor rating kW	Existing motor control	actual (kW)	kWh/24hrs	kWh/year
27	AHU 34	Supply	11	Inverter - Jaguar	7.4	177.6	64,824.00
27	AHU 34	Extract	1.1	DOL*	1.1	26.4	9,636.00
27	AHU 35	Supply	11	Inverter - Jaguar	7.3	175.2	63,948.00
27	AHU 35	Extract	1.1	DOL*	1.1	26.4	9,636.00
27	AHU 36	Supply	3	DOL*	3.1	74.4	27,156.00
* DOL= Direct On Line					**Totals**	**480.0**	**175,200.00**

Figure 4.6 - Plant room 27 AHU electrical motor consumption

Figures 4.7 & 8 below are actual screenshots from the front end workstation monitoring the air conditioning plants located within plant room 27. It displays 2 air handling units with their associated control hardware.

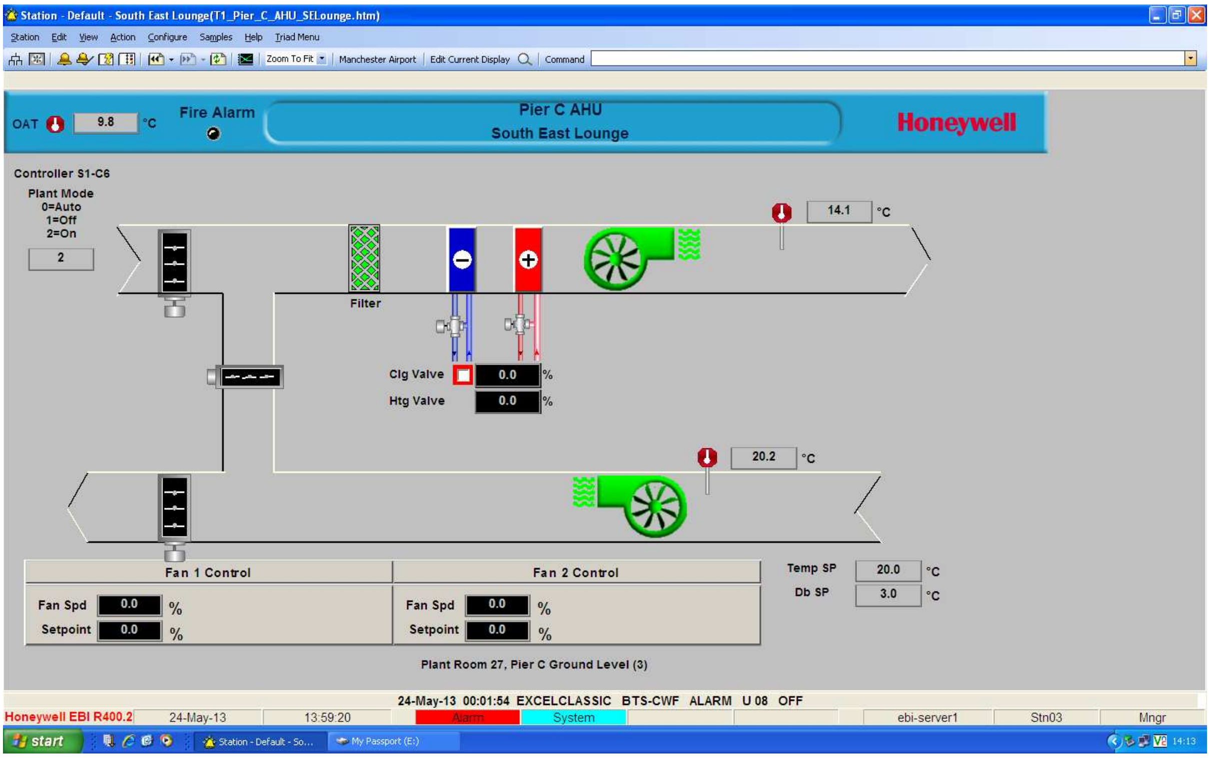


Figure 4.7 - Plant room 27 Air Handling Unit (AHU 34) (Courtesy Airport Utilities)

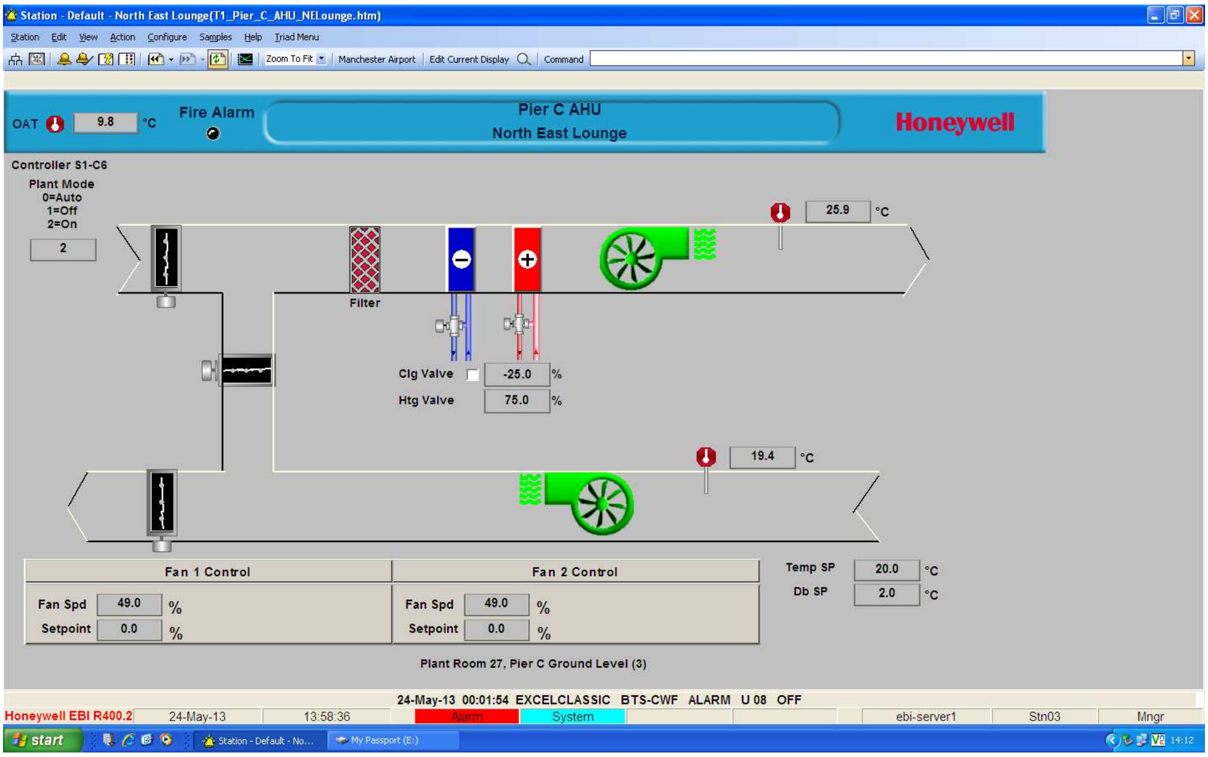


Figure 4.8 - Plant room 27 Air Handling Unit - AHU 35 (Courtesy Airport Utilities)

4.2.4 Plant room 28

Plant room 28 consists of 2 air conditioning plants, Air Handling Unit (AHU) 37 & 38. Figure 4.9 details the power ratings of the existing plant, including nominal rating and actual running load rating of the motor. The particular type of starting method currently controlling each motor has also been documented for further discussion.. The kWh rating has been calculated for a 24 hour period and yearly figures from the actual kW reading taken whilst the unit was in operation.

Plant Room	AHU No.	Fan	motor rating kW	Existing motor control	actual kW	kWh/24hrs	kWh/year
28	AHU 37	Supply	11	Inverter ABB - Sami	7.4	177.6	64,824.0
28	AHU 37	Extract	1.1	DOL*	1.1	26.4	9,636.0
28	AHU 38	Supply	11	Inverter ABB - Sami	7.4	177.6	64,824.0
28	AHU 38	Extract	1.1	DOL*	1.1	26.4	9,636.0
* DOL= Direct On Line					**Totals**	**408.0**	**148,920.0**

Figure 4.9 – plant room 28 AHU electrical motor consumption

Figures 4.10 & 11 below are actual screenshots from the front end workstation monitoring the air conditioning plants located within plant room 28. It displays 2 air handling units with their associated control hardware.

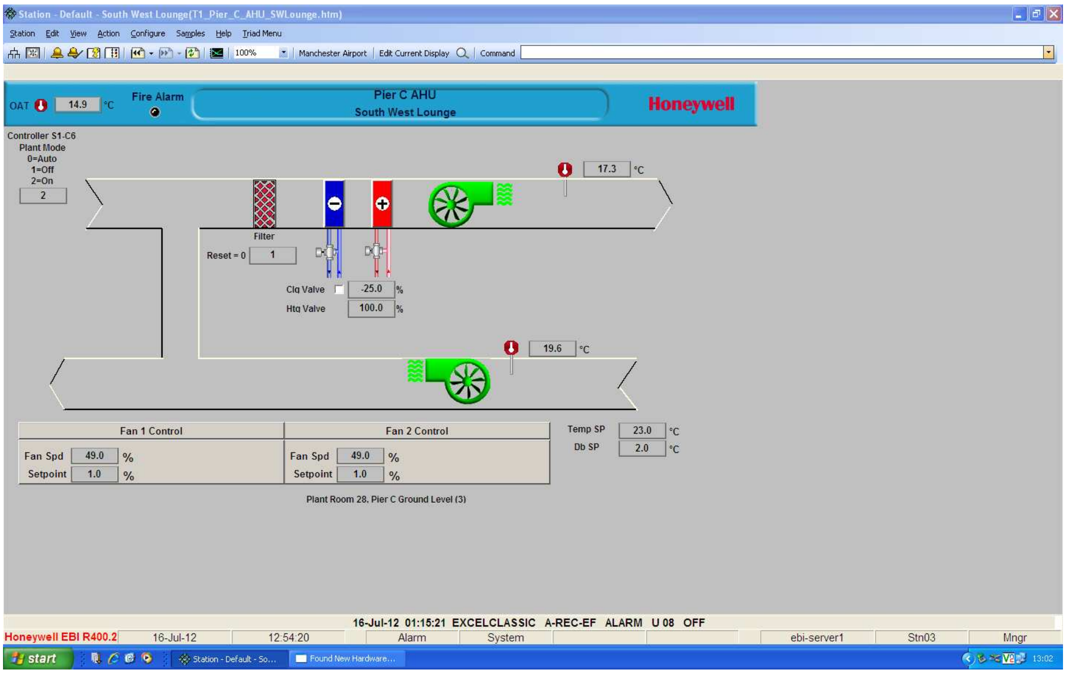


Figure 4.10 – plant room 28 air handling unit (AHU 37) (Courtesy airport utilities)

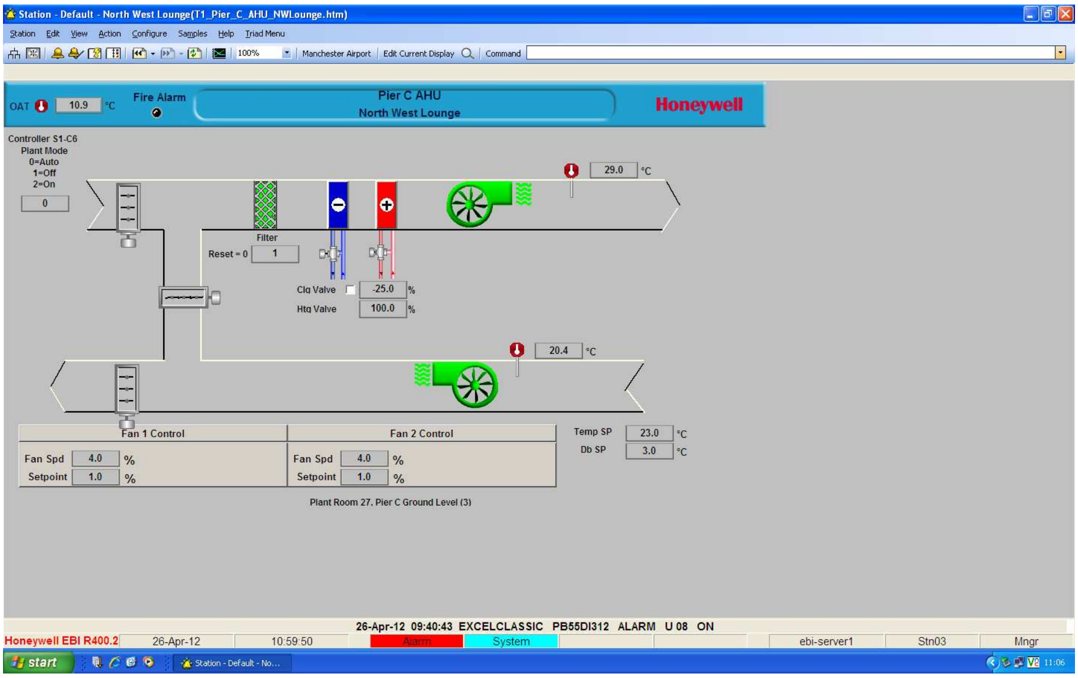


Figure 4.11 – plant room 28 air handling unit (AHU 38) (Courtesy airport utilities)

4.2.5 Level 1

Level 1 is a continuation from the main departure lounge and extends the full length of the pier giving access to all departure gates. Level 1 also provides access for arriving passengers to reach the main immigration hall via specific routes. Due to the date of construction of the pier and current security legislations, the area has been retrofitted by partition zones to ensure departing and arriving passengers cannot interact. The zones have security coded access to facilitate staff. Figures 4.9 & 4.10 define the separate departure and arrival zones of level

4.2.6 Level 2

Figure 4.12 provides an overview of the level 2 structure of International C-Pier. Level 2 only exists in the satellite area of the pier, and is a purpose built plant room (Plant room 29). Figure 4.13 is an enlarged section of the highlighted area of figure 4.12 and details the plant room and air handling units.

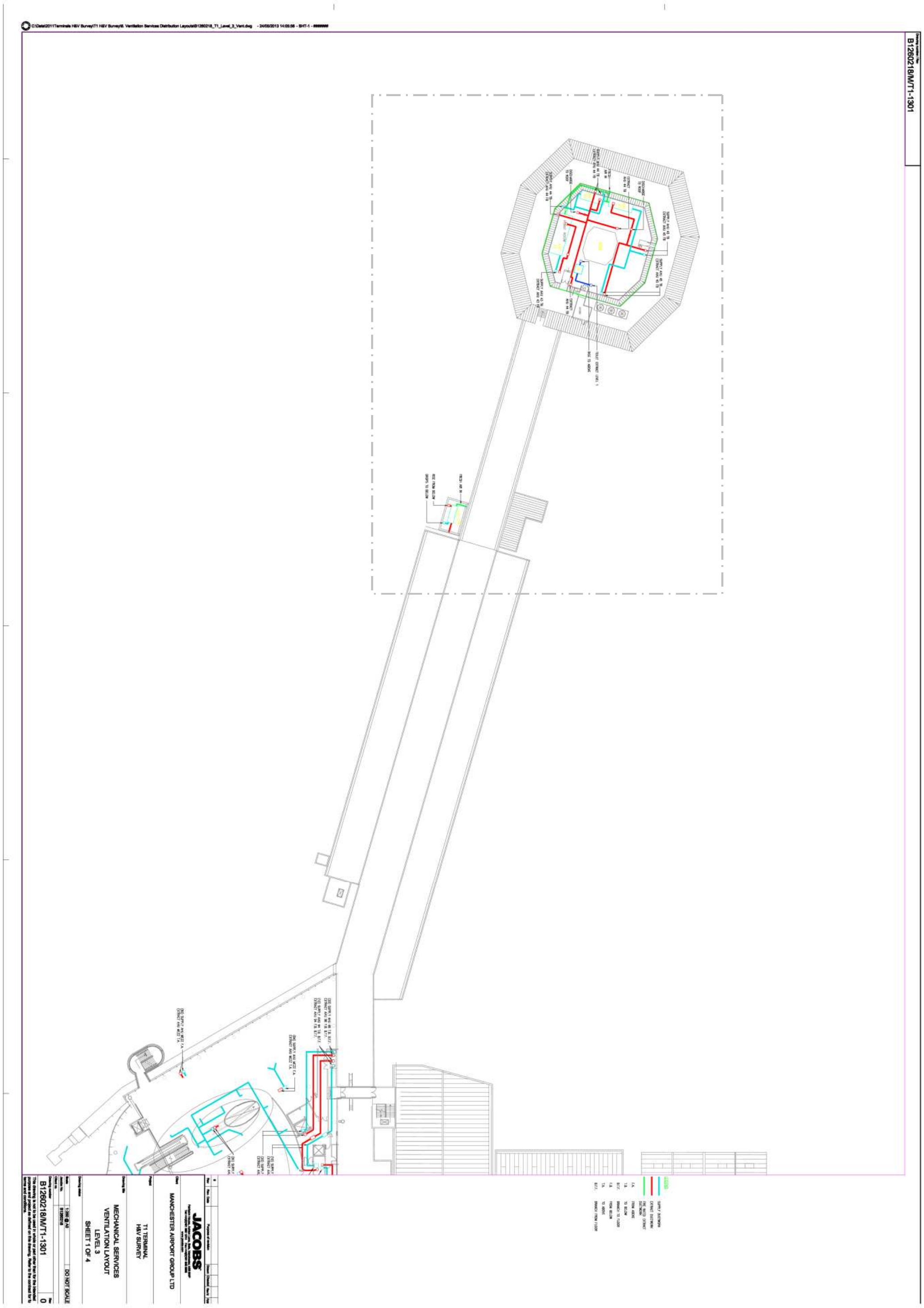


Figure 4.12 – Level 2 structure (Courtesy Airport Utilities)

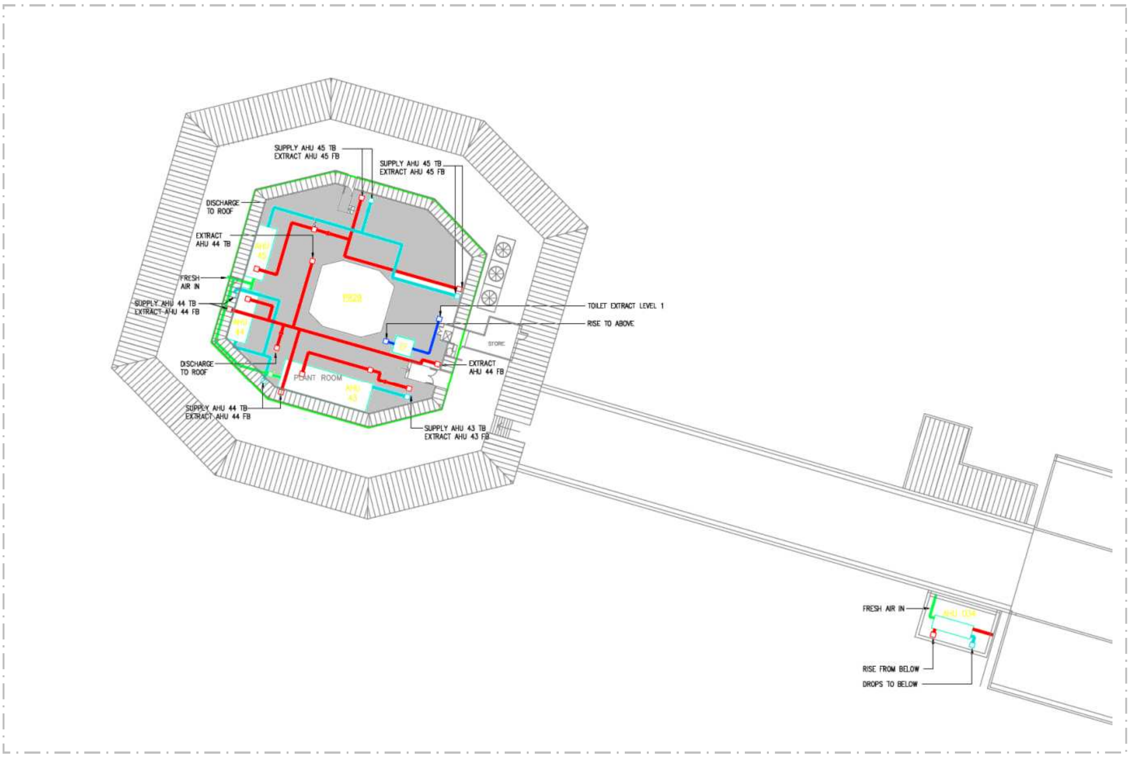


Figure 4.13 – Satellite plant room 29

4.2.7 Plant room 29

Plant room 29 consists of 3 air conditioning plants, Air Handling Unit's (AHU) 43, 44 & 45. Figure 4.17 details the power ratings of the existing plant, including nominal rating and actual running load rating of the motor. The particular type of starting method currently controlling each motor has also been documented for further discussion. The kWh usage has been calculated for a 24 hour period and yearly figures from the actual kW reading taken whilst the unit was in operation.

Plant Room	AHU No.	Fan	motor rating kW	Existing motor control	actual kW	kWh/24hrs	kWh/year
29	AHU 43	Supply	3	ABB-Sami ministar	1.3	31.2	11,388.0
29	AHU 43	Extract	3	Jaguar - Bypassed	3.4	81.6	29,784.0
29	AHU 44	Supply	15	Jaguar	10.0	240.0	87,600.0
29	AHU 44	Extract	7.5/1.9	ABB - ACS600	5.0	120.0	43,800.0
29	AHU 45	Supply	15	ABB - ACS600	10.0	240.0	87,600.0
29	AHU 45	Extract	7.5/1.9	Watt Drive - I200	8.8	211.2	77,088.0
* DOL= Direct On Line					**Totals**	**924.0**	**337,260.0**

Figure 4.14 – Plant room 29 AHU electrical motor consumption

Figures 4.18, 19 & 20 below are actual screenshots from the front end workstation monitoring the air conditioning plants located within plant room 98. It displays 3 air handling units with their associated control hardware.

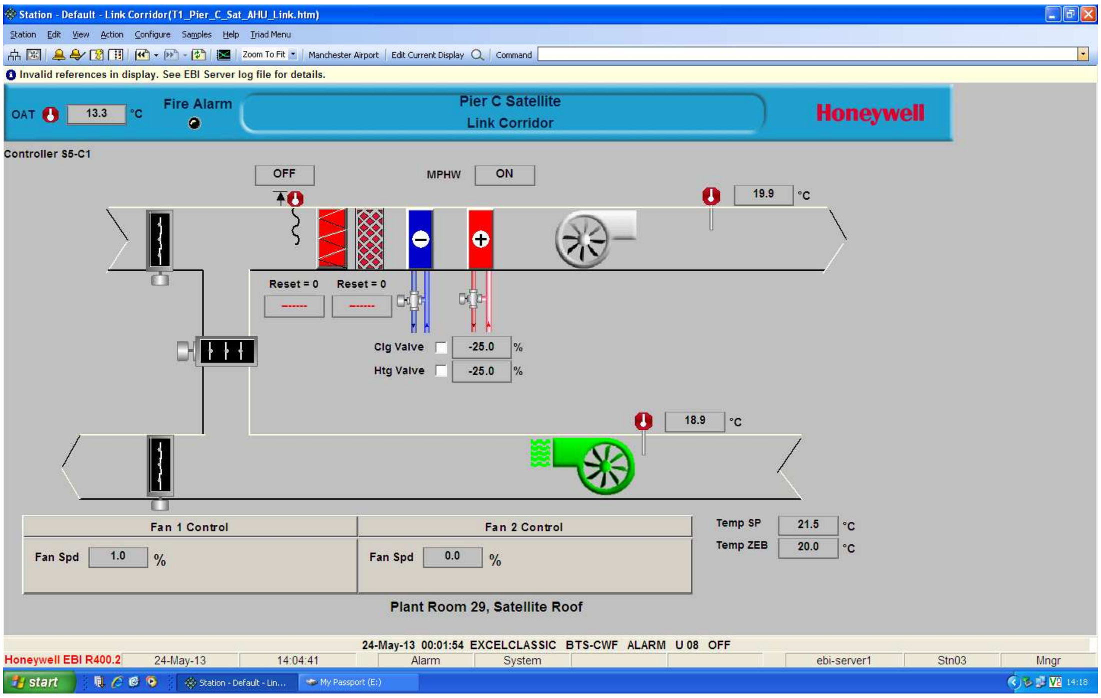


Figure 4.15 – Plant room 29 air handling unit - AHU 43 (Courtesy Airport Utilities)

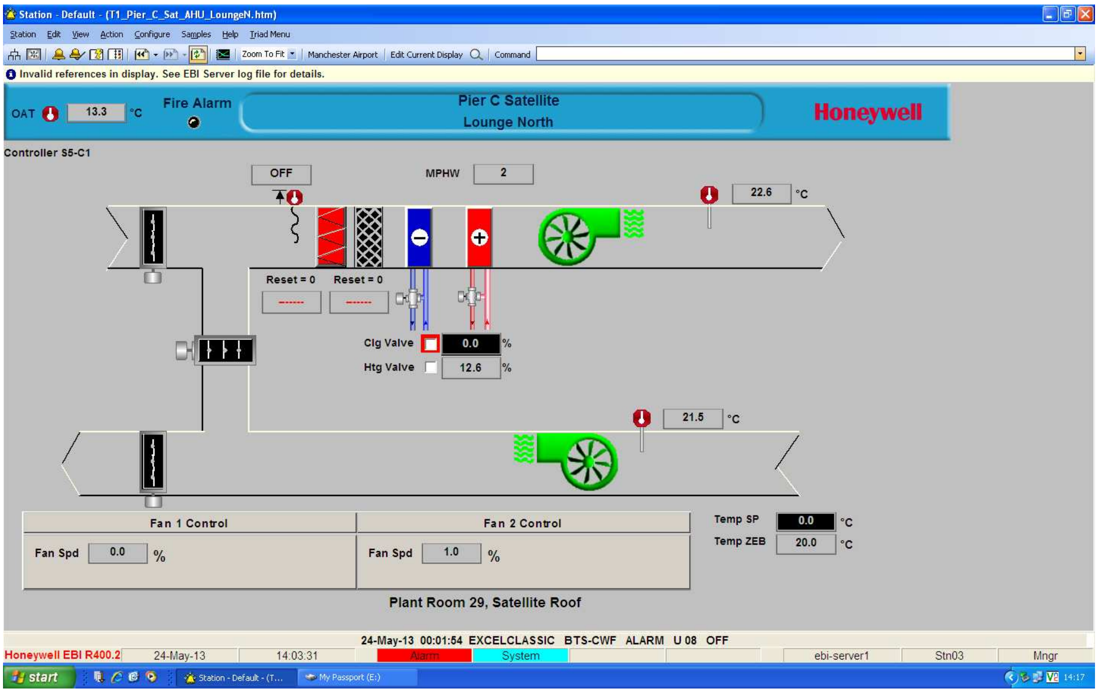


Figure 4.16 – Plant room 29 air handling unit - AHU 44 (Courtesy Airport Utilities)

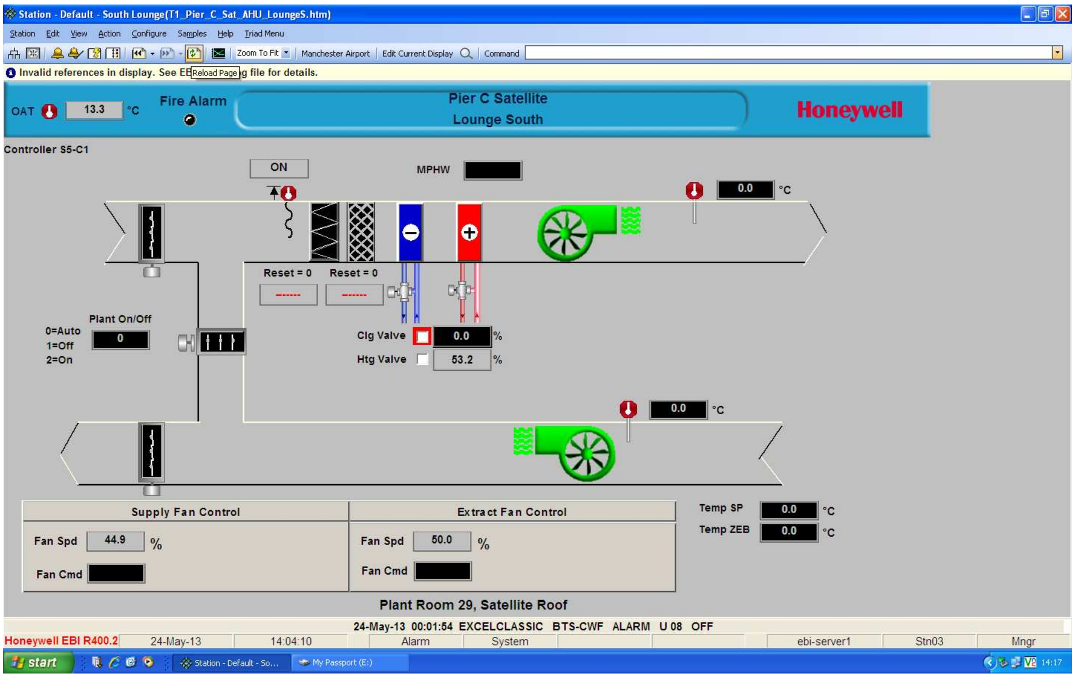


Figure 4.17 – Plant room 29 air handling unit - AHU 45 (Courtesy Airport Utilities)

4.3 PHASE 0NE - CO_2 EMISSIONS

In order to evaluate the gas emissions from the electricity used by the temperature control plant, the derived data has to be converted into CO_2 emissions. The Department for Environment Food & Rural

Affairs (DEFRA) publish conversion factors for organisations to report their emissions from different sources.

Organisations are required to report the electricity used on sites that are under their control. These reports are classified as scope 2 indirect emissions. DEFRA also publish factors for scope 3 emissions which are not directly under the organisations control. DEFRA advise organisations to include the scope 3 results which are *transmission and distribution* (T&D) losses of electricity they purchase, which occur between the power station and their particular site. The separate *transmission and distribution* losses are usually reported separate from the scope 2 results.

The conversion factors cover individual GHG including CO_2, CH_4 & N_2O and a combined factor of CO_2e. For the purpose of graphical representation of emissions throughout the research, the kg CO_2 factor within the scope 2 *Electricity generated* will be calculated and displayed only. Figures 4.18 & 4.19 display the conversion tables published from DEFRA.

Activity	Country	Unit	Year	kg CO_2e	**kg CO_2**	kg CH_4	kg N_2O
Electricity generated	Electricity: UK	kWh	2013	0.44548	**0.44238**	0.00029	0.00281

Figure 4.18 – DEFRA Scope 2 electricity generated factor

Source: www.ukconversionfactorscarbonsmart.co.uk June 22nd 2013

Activity	Type	Unit	Year	kg CO_2e	kg CO_2	kg CH_4	kg N_2O
T&D- UK electricity	Electricity: UK	kWh	2013	0.03809	0.03783	0.00002	0.00024

Figure 4.19 – DEFRA Scope 3 Transmission & Distribution factor

Source: www.ukconversionfactorscarbonsmart.co.uk June 22nd 2013

The existing relationship between the temperature control and stand allocation management has been examined and the results of the emissions from the individual plant can be calculated. In the current relationship between services and operations there is no interaction and both systems are working independently. The temperature control being provided operates on a 24 hour 7 days a week schedule and the plants continuously provide tempered air to the required set point. Emissions have been calculated for the individual air conditioning plants for inclusion in the phase two analysis.

4.3.1 Plant room 26

4.3.1.1 AHU 31 Emissions

AHU No.	Fan	motor rating (kW)	actual (kW)	kWh/24hrs	kWh/year	kg CO2/24hrs	kg CO2/year
AHU 31	Supply	11	8.1	194.4	70956.0	86.0	31,389.5
AHU 31	Extract	1.1	1.1	26.4	9636.0	11.7	4,262.8
					Totals	**97.7**	**35,652.3**

Figure 4.20 – AHU 31 emissions

4.3.1.2 AHU 32 Emissions

AHU No.	Fan	motor rating (kW)	actual (kW)	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 32	Supply	3	3.0	72.0	26280.0	31.9	11,625.7
AHU 32	Extract	3	3.0	72.0	26280.0	31.9	11,625.7
					Totals	**63.7**	**23,251.5**

Figure 4.21 – AHU 32 emissions

4.3.1.3 AHU 33 Emissions

AHU No.	Fan	motor rating (kW)	actual (kW)	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 33	Supply	1.5	2.1	50.4	18396.0	22.3	8,138.02
AHU 33	Extract	1.5	1.4	33.6	12264.0	14.9	5,425.35
					Totals	**37.2**	**13,563.37**

Figure 4.22 - AHU 33 emissions

4.3.2 Plant room 27

4.3.2.1 AHU 34 Emissions

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 34	Supply	11	7.4	177.6	64824.0	78.6	28,676.8
AHU 34	Extract	1.1	1.1	26.4	9636.0	11.7	4,262.8
					Totals	**90.2**	**32,939.6**

Figure 4.23 - AHU 34 emissions

4.3.2.2 AHU 35 Emissions

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 35	Supply	11	7.3	175.2	63948.0	77.5	28,289.3
AHU 35	Extract	1.1	1.1	26.4	9636.0	11.7	4,262.8
					Totals	**89.2**	**32,552.1**

Figure 4.24 - AHU 35 emissions

4.3.2.3 AHU 36 Emissions

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 36	Supply	3	3.1	74.4	27156.0	32.9	12,013.3
					Totals	**32.9**	**12,013.3**

Figure 4.25 -AHU 36 emissions

4.3.3 Plant room 28

4.3.3.1 AHU 37 Emissions

`	Fan	motor rating kW	actual kW	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 37	Supply	11	7.4	177.6	64824.0	78.6	28,676.8
AHU 37	Extract	1.1	1.1	26.4	9636.0	11.7	4,262.8
					Totals	**90.2**	**32,939.6**

Figure 4.26 - AHU 37 emissions

4.3.3.2 AHU 38 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 38	Supply	11	7.4	177.6	64824.0	78.6	28,676.8
AHU 38	Extract	1.1	1.1	26.4	9636.0	11.7	4,262.8
					Totals	**90.2**	**32,939.6**

Figure 4.27 - AHU 38 emissions

4.3.4 Plant room 29

4.3.4.1 AHU 43 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 43	Supply	3	1.3	31.2	11388.0	13.8	5,037.8
AHU 43	Extract	3	3.4	81.6	29784.0	36.1	13,175.8
					Totals	**49.9**	**18,213.7**

Figure 4.28 - AHU 43 emissions

4.3.4.2 AHU 44 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 44	Supply	15	10.0	240.0	87600.0	106.2	38,752.5
AHU 44	Extract	7.5/1.9	5.0	120.0	43800.0	53.1	19,376.2
					Totals	**159.3**	**58,128.7**

Figure 4.29 - AHU 44 emissions

4.3.4.3 AHU 45 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs	kWh/year	kg CO_2/24hrs	kg CO_2/year
AHU 45	Supply	15	10.0	240.0	87600.0	106.2	38,752.5
AHU 45	Extract	7.5/1.9	8.8	211.2	77088.0	93.4	34,102.2
					Totals	**199.6**	**72,854.7**

Figure 4.30 - AHU 45 emissions

4.3.5 Phase one Relationship simulation

A simulation model was created from the data to provide a graphical representation of the existing relationship between the services provided and the existing building operation. The simulation was created to compliment the accumulated data. (The simulation provides a greater insight into the relationship for non-technical personnel). The simulation is an exact replication of the flight activity associated with the 24 hour period of the 8th April 2012. The simulation incorporates the colour coding associated with each individual air handling unit zone which is detailed in figure 4.33 to clearly display when a specific zone is being comfort conditioned.

The simulation model has a time frame of 24 minutes which relates to the timescale of 1min simulation is the equivalent of 1 hour actual activity.(1 second/1 minute). The full simulation is available and can be viewed on the accompanying compact disc located within Appendix A

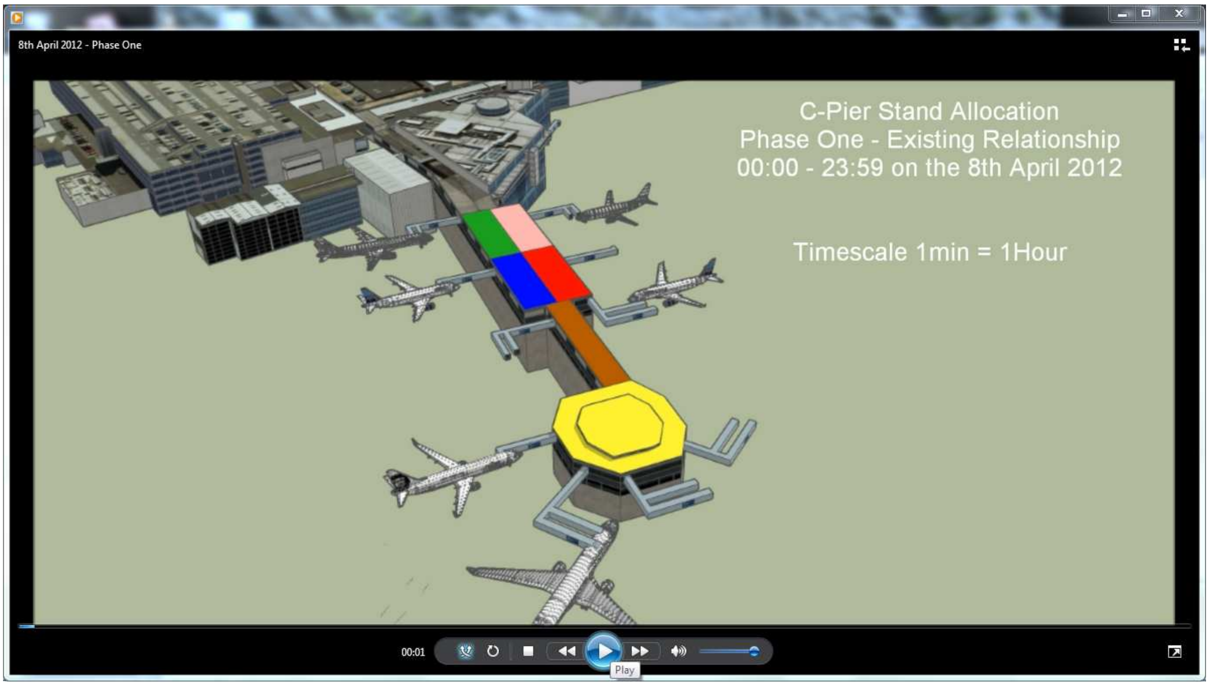


Figure 4.31 – Phase One simulation Screenshot

4.4 PHASE TWO

Phase two incorporates hypothetical interaction between the temperature control services and stand allocation operation. The interaction will be created by incorporating the available data from the Chroma flight information system into the schedule operation of the air handling plants. This information can then be used to control the time schedule of the air handling units operation. The units could be enabled for operation only when required to provide comfort conditions for specific passenger routes to allocated departure gates. Comparison of phase one results to the hypothetical results of phase two can be performed to examine the efficiency of the relationship. To provide accurate data regarding the temperature control plants, the area's being served by the individual air handling units will have to be identified. Phase one identified the air handling units associated with the specific area of interest. Figure 4.32 details the air conditioning ductwork layout within the area, therefore the area associated with individual departure gates can be identified and paired to the associated air handling unit.

4.4.1 Departing Passenger Areas

Figure 4.33 graphically displays the identified areas that have been divided into specific zones conditioned by individual temperature control units. The actual air handling unit serving the conditioned space has been identified and each area has been colour coded for analysis purposes. The same colour coding will be utilised throughout the whole analysis process. Over a period of time the design of the area has changed to facilitate the requirement of maintaining separation between departing and arriving passengers. The departure routes to each terminal gate have also been identified to associate individual air handling units to the specific departure routes. Figure 4.34 displays the departure areas which passengers will travel through for all gates associated with C-Pier.

4.4.2 Arriving Passenger Areas

The arrival routes from each terminal gate have been identified to associate individual air handling units to the specific arrival route. Figure 4.35 displays the arrival areas which passengers will travel through from all gates associated with C-Pier.

4.4.3 Passenger routes for individual gates

Analysis of actual passenger routes for Departing and arriving flights has been examined to determine what areas are required to be comfort conditioned for individual aircraft stands.

This data can be utilised to create an air handling unit schedule for departing and arrival flights to determine which air handling unit is required to perform the passenger comfort conditions for all flights associated with international c-pier. Figures 4.36 to 3.45 detail the departing and arrival routes associated with individual gates.

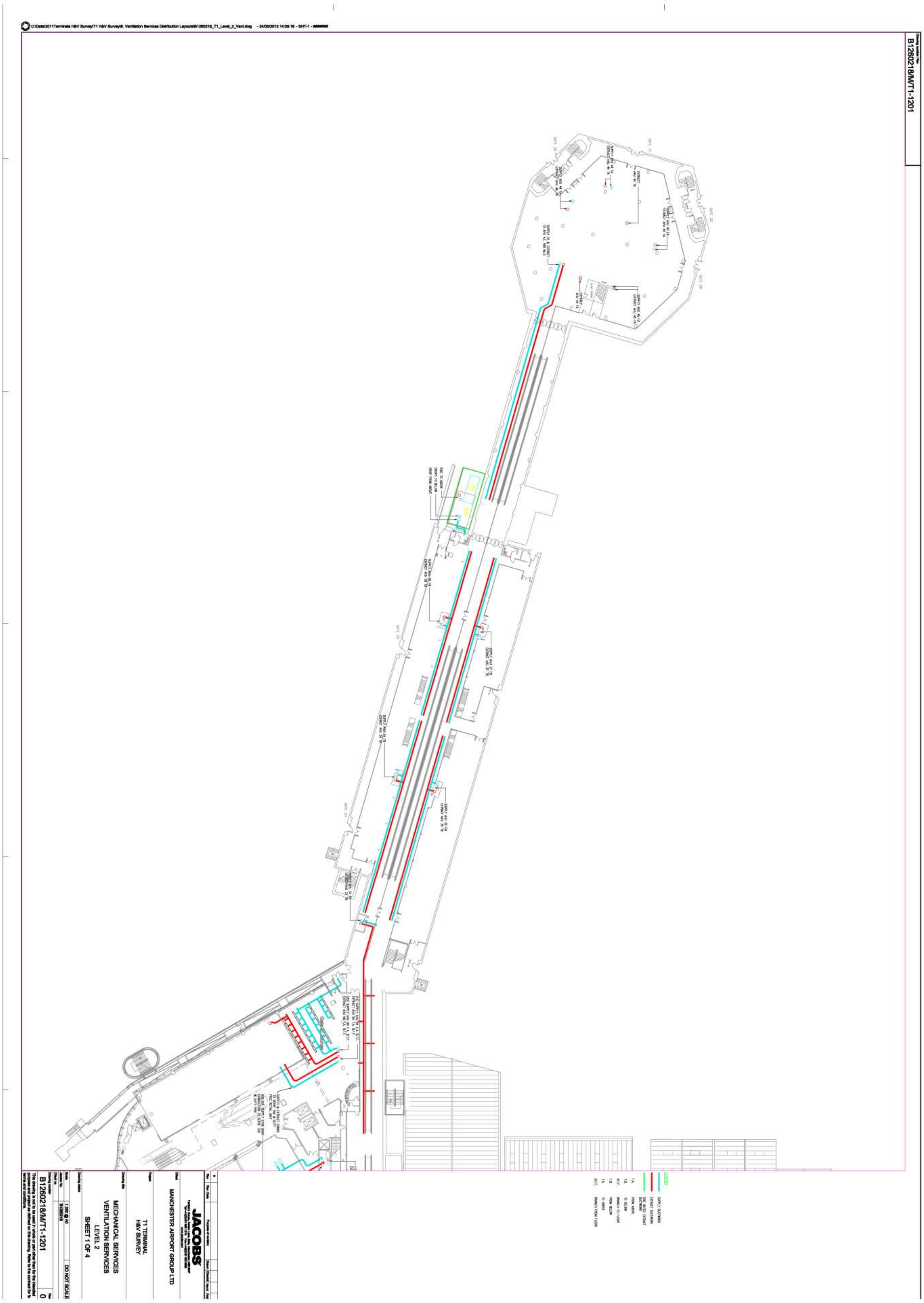


Figure 4.32 – Level 1 ductwork layout (Original Courtesy Airport Utilities)

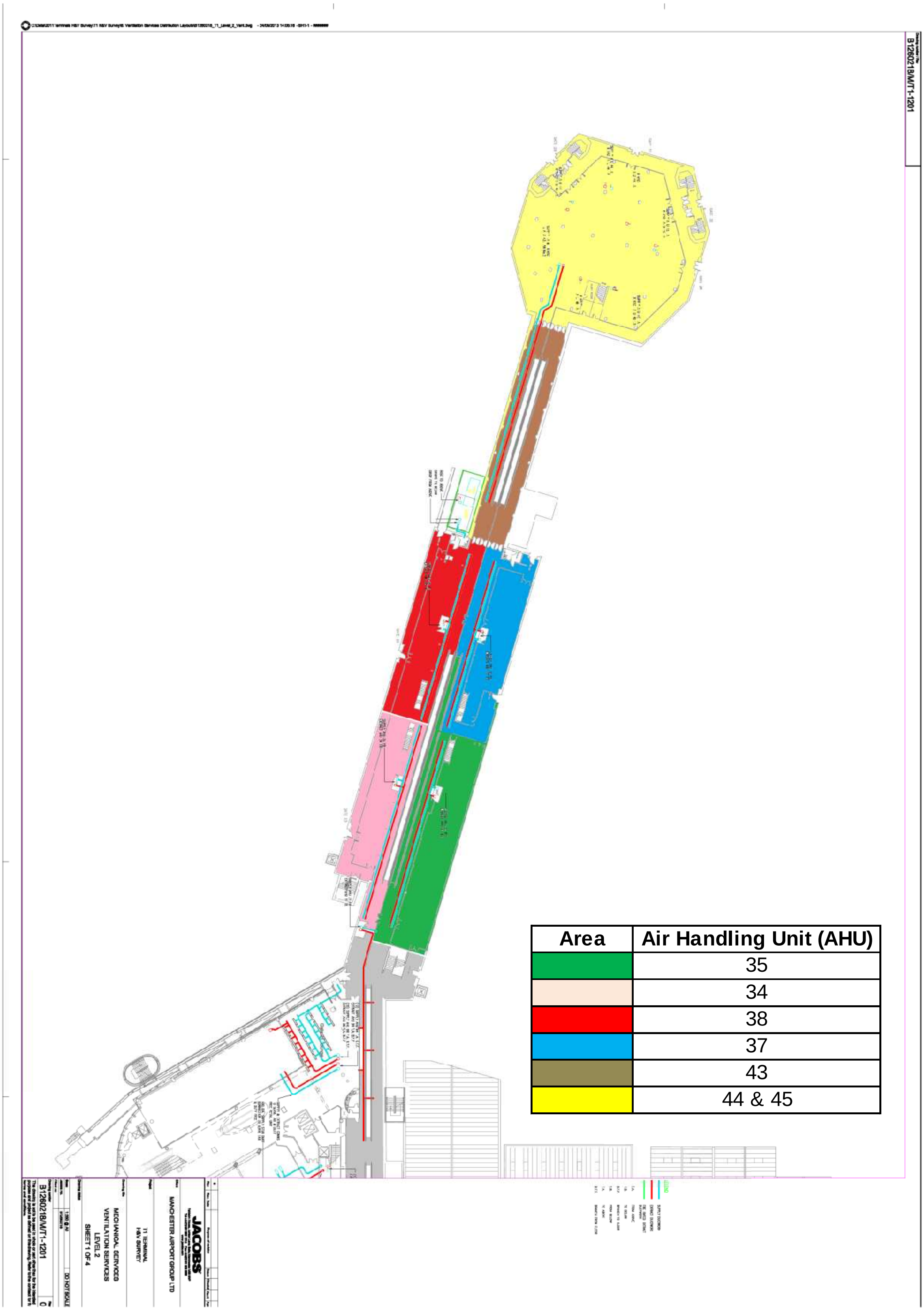


Figure 4.33 - Defined AHU areas (Original Courtesy Airport Utilities)

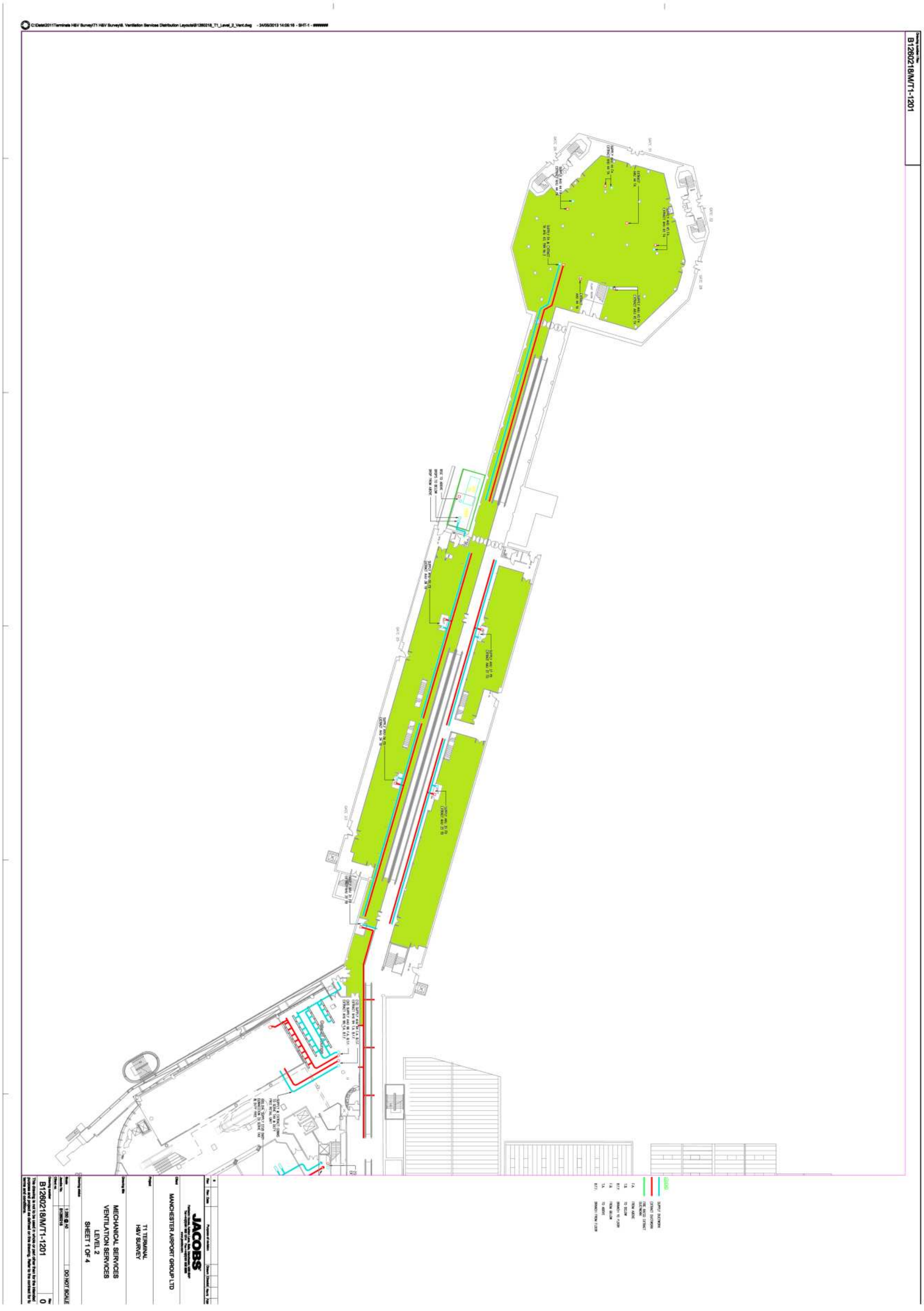


Figure 4.34 – Departure Zones (Original Courtesy Airport Utilities)

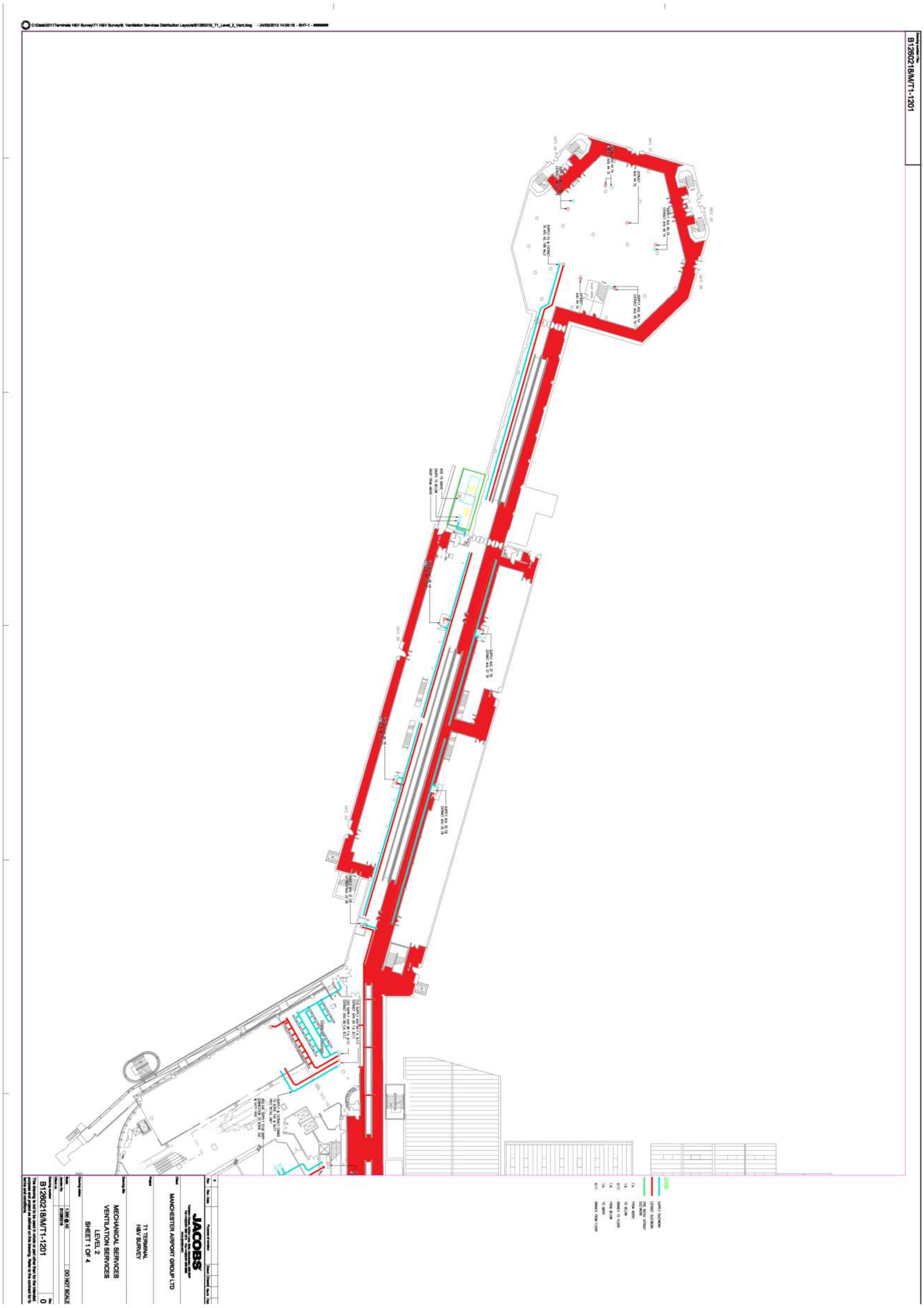


Figure 4.35 – Arrival Zones (Original Courtesy Airport Utilities)

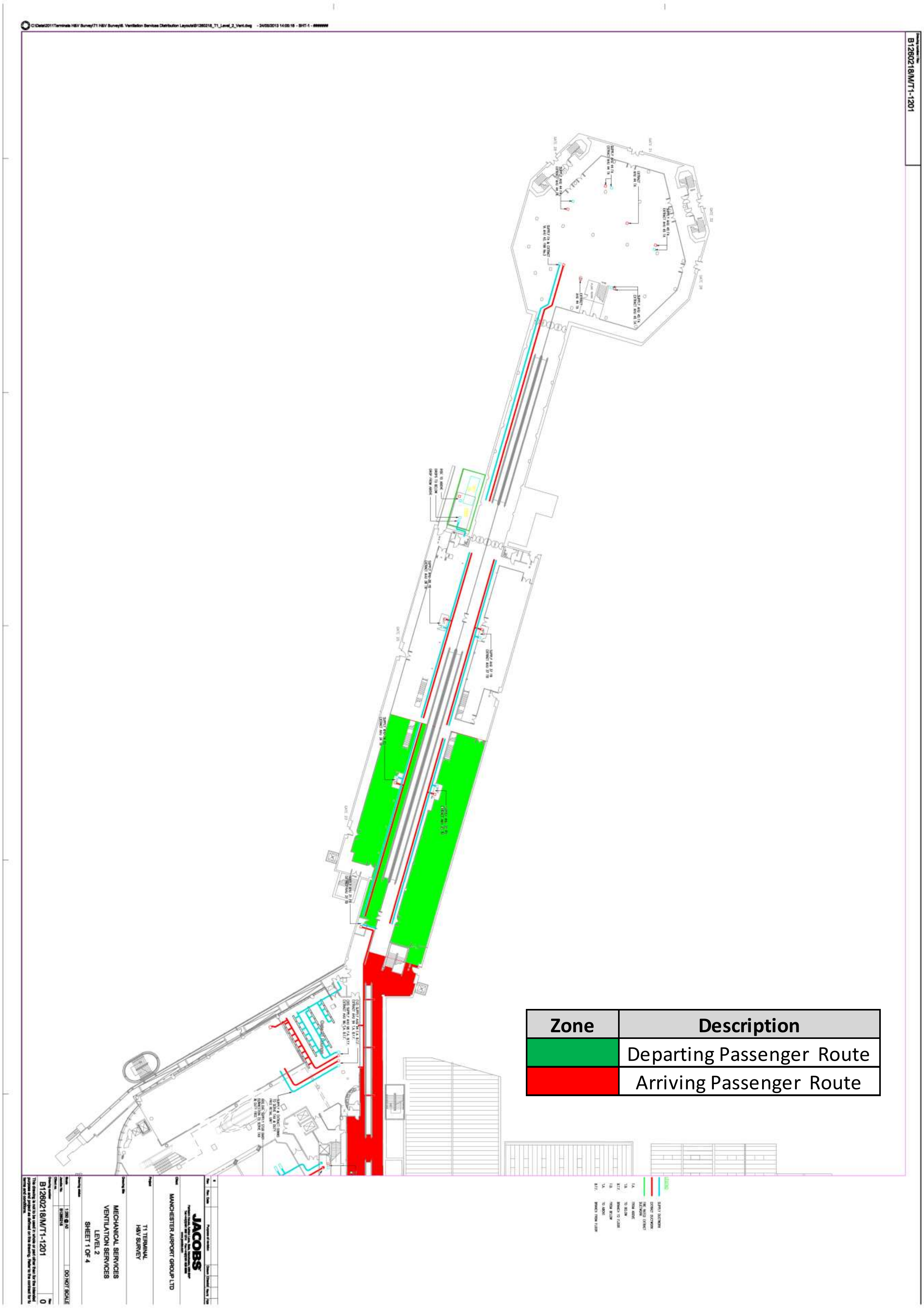


Figure 4.36 – Stand 22 Passenger Routes (Original Courtesy Airport Utilities)

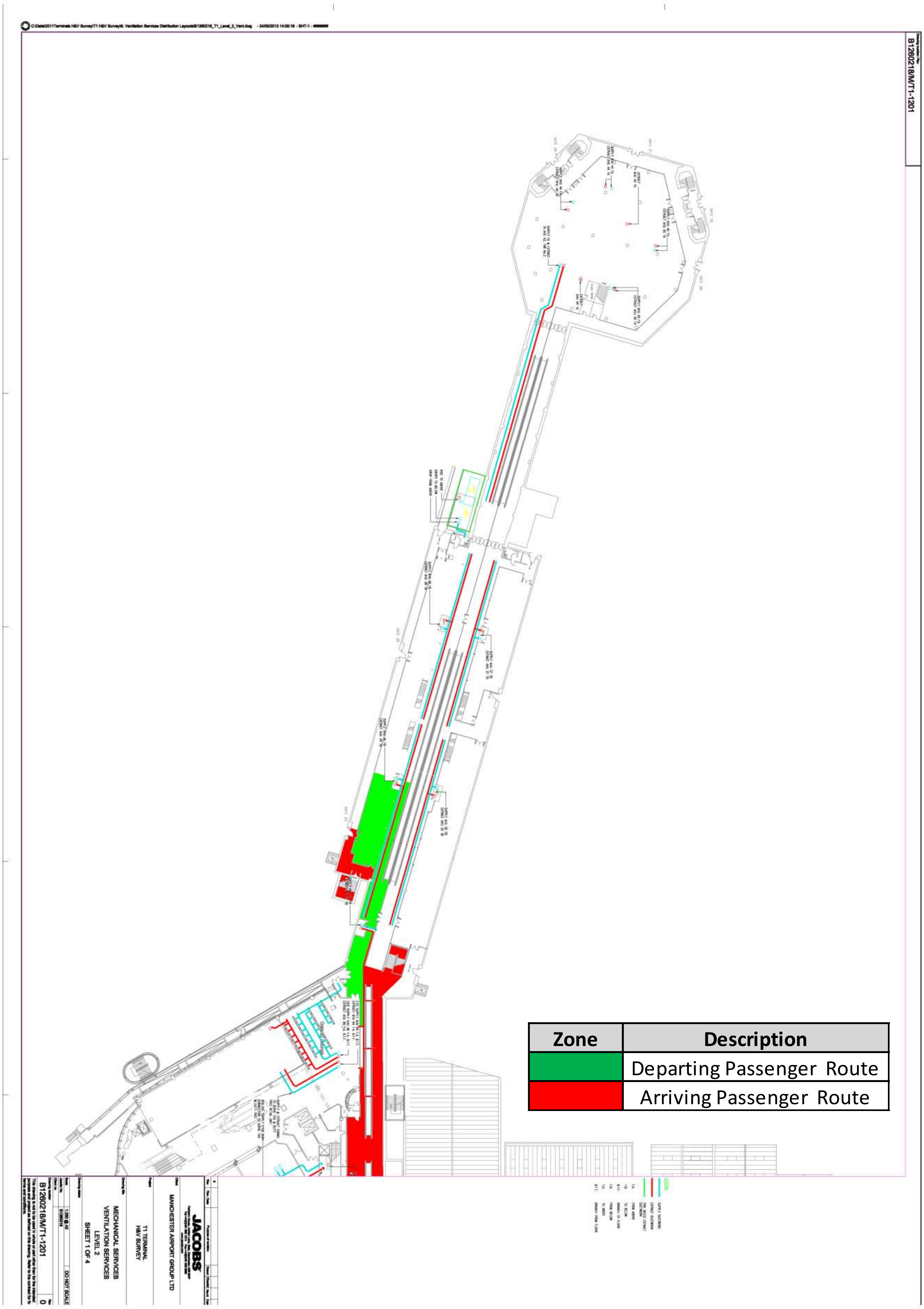
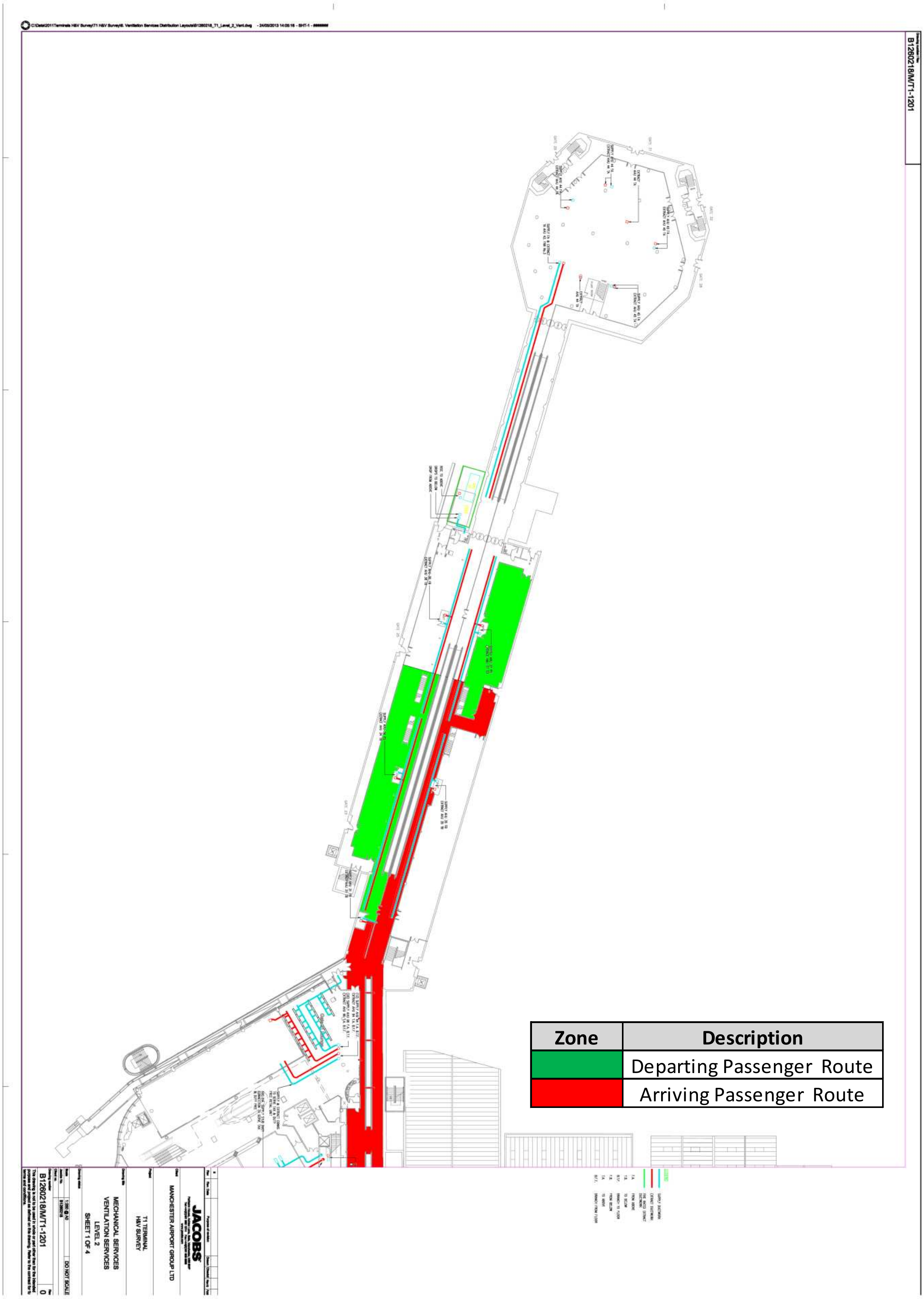


Figure 4.37 - Stand 23 Passenger Routes (Original Courtesy Airport Utilities)



Zone	Description
(green)	Departing Passenger Route
(red)	Arriving Passenger Route

Figure 4.38 - Stand 24 Passenger Routes (Original Courtesy Airport Utilities)

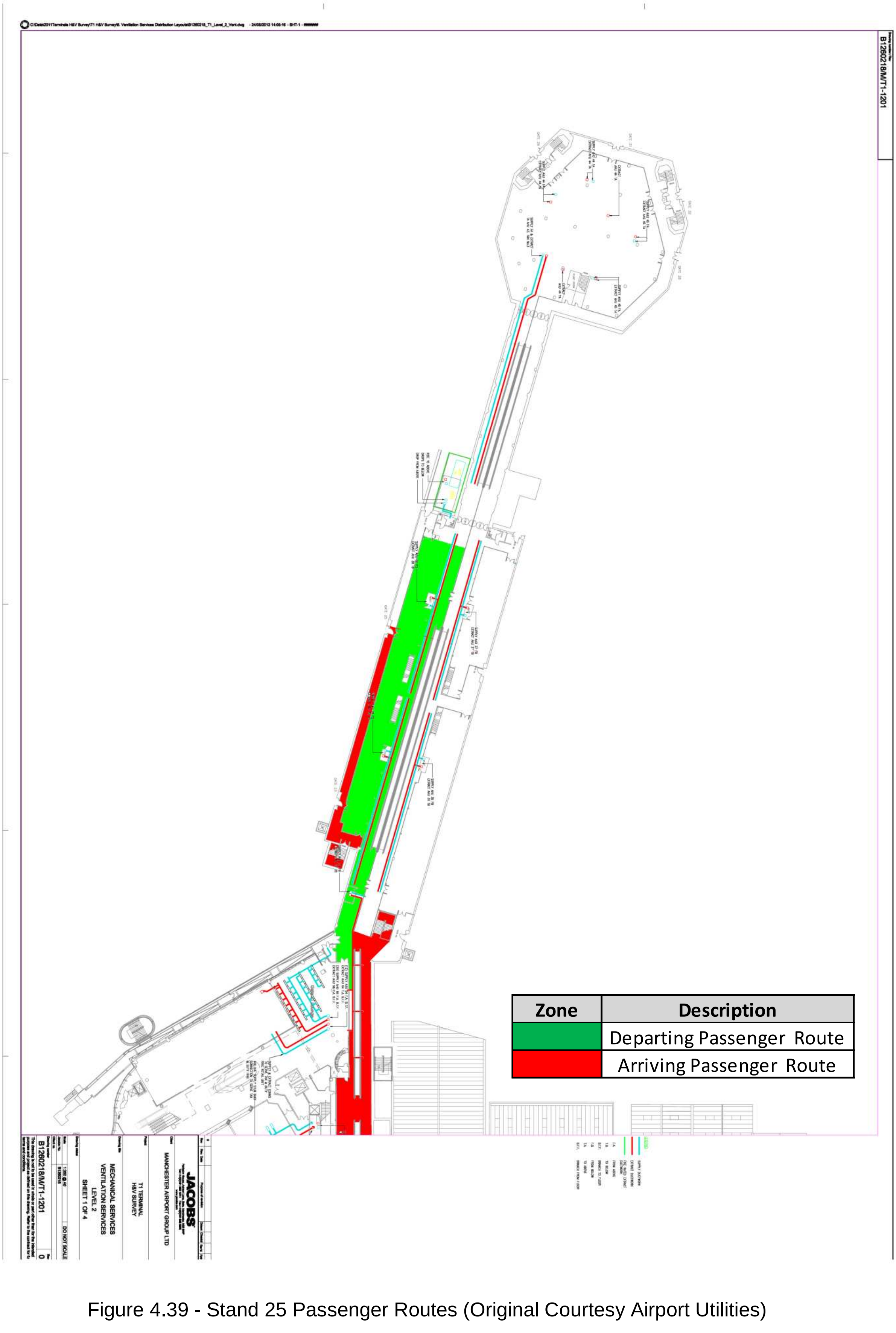


Figure 4.39 - Stand 25 Passenger Routes (Original Courtesy Airport Utilities)

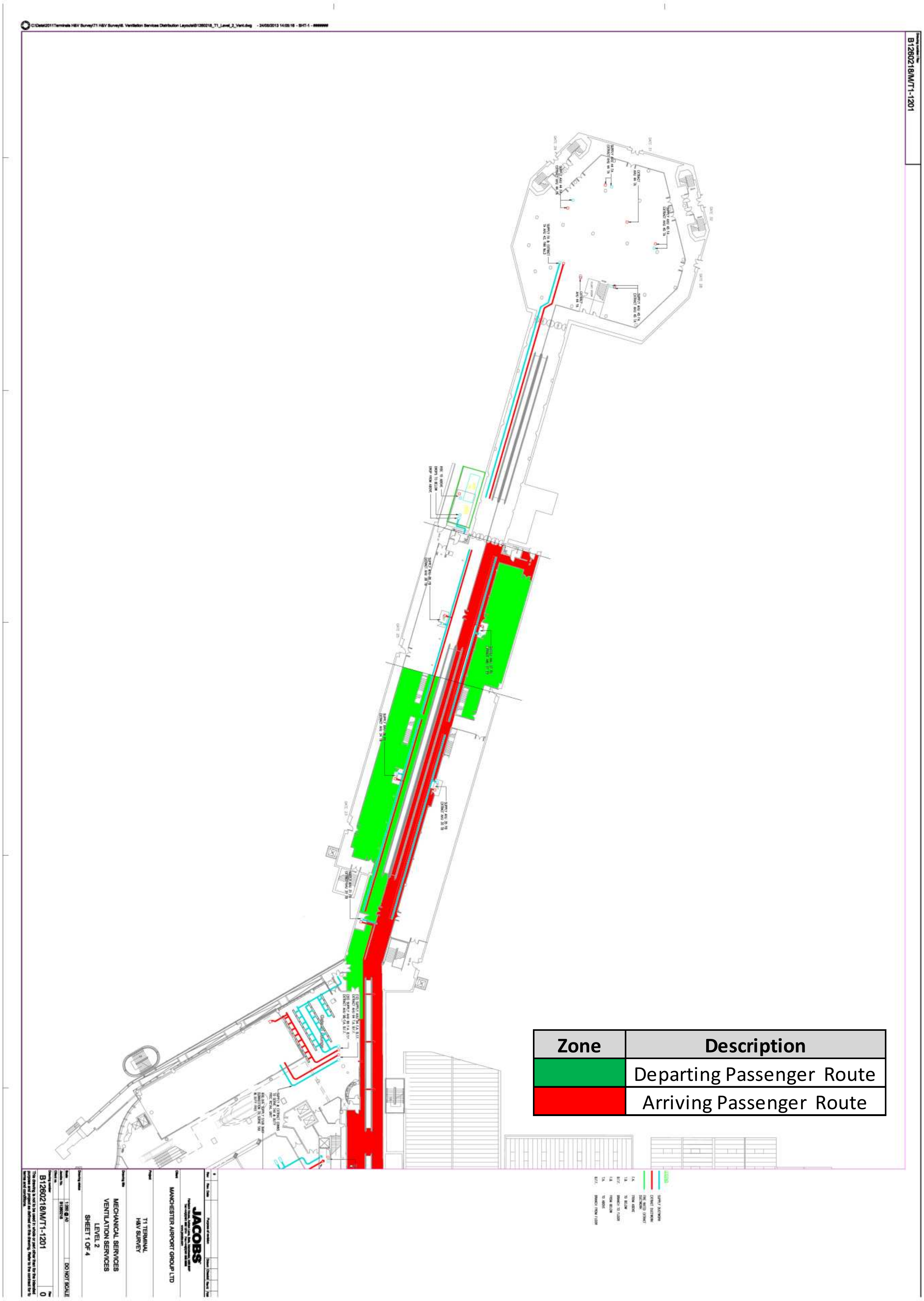


Figure 4.40 - Stand 26 Passenger Routes (Original Courtesy Airport Utilities)

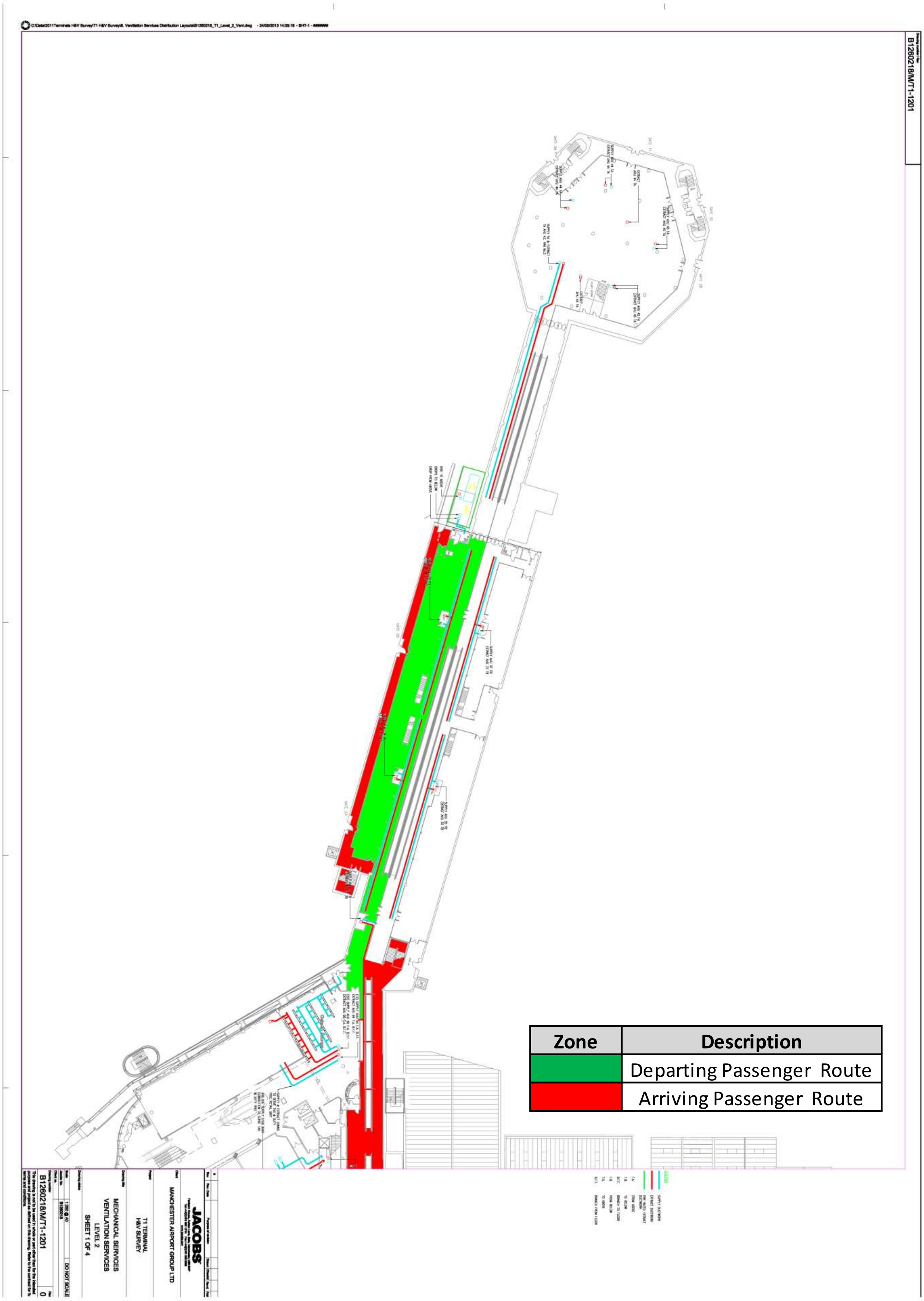


Figure 4.41 - Stand 27 Passenger Routes (Original Courtesy Airport Utilities)

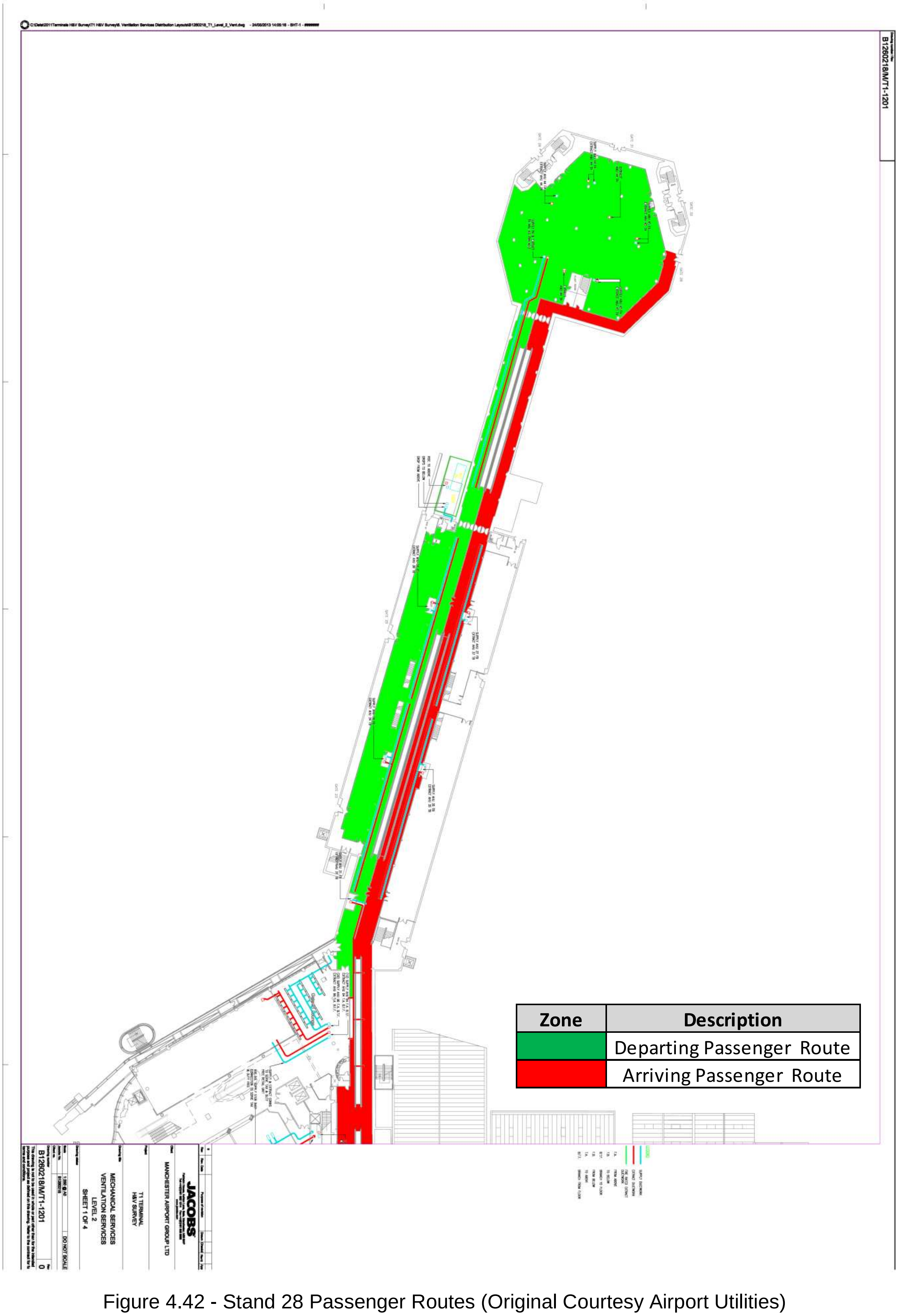


Figure 4.42 - Stand 28 Passenger Routes (Original Courtesy Airport Utilities)

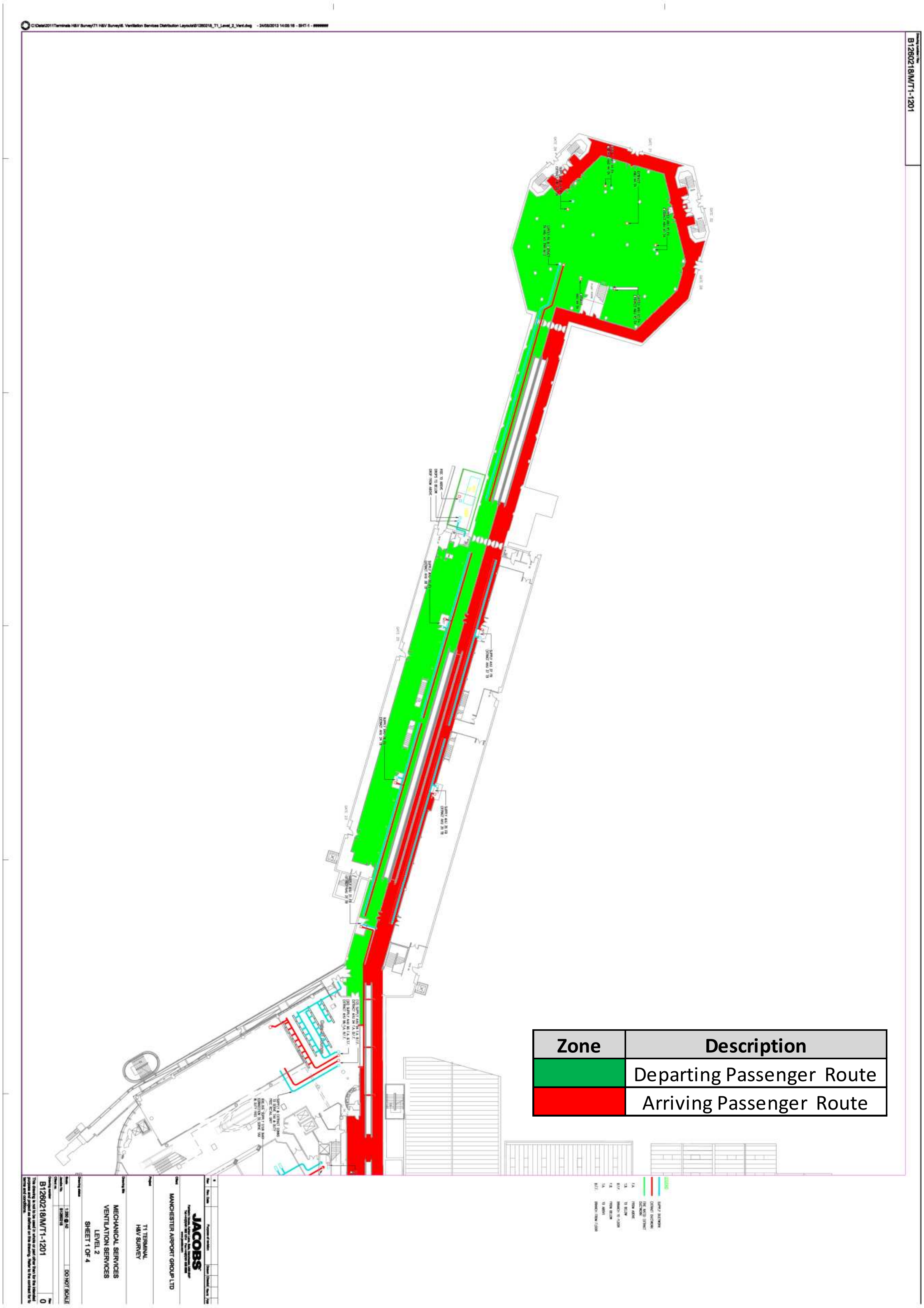


Figure 4.43 - Stand 29 Passenger Routes (Original Courtesy Airport Utilities)

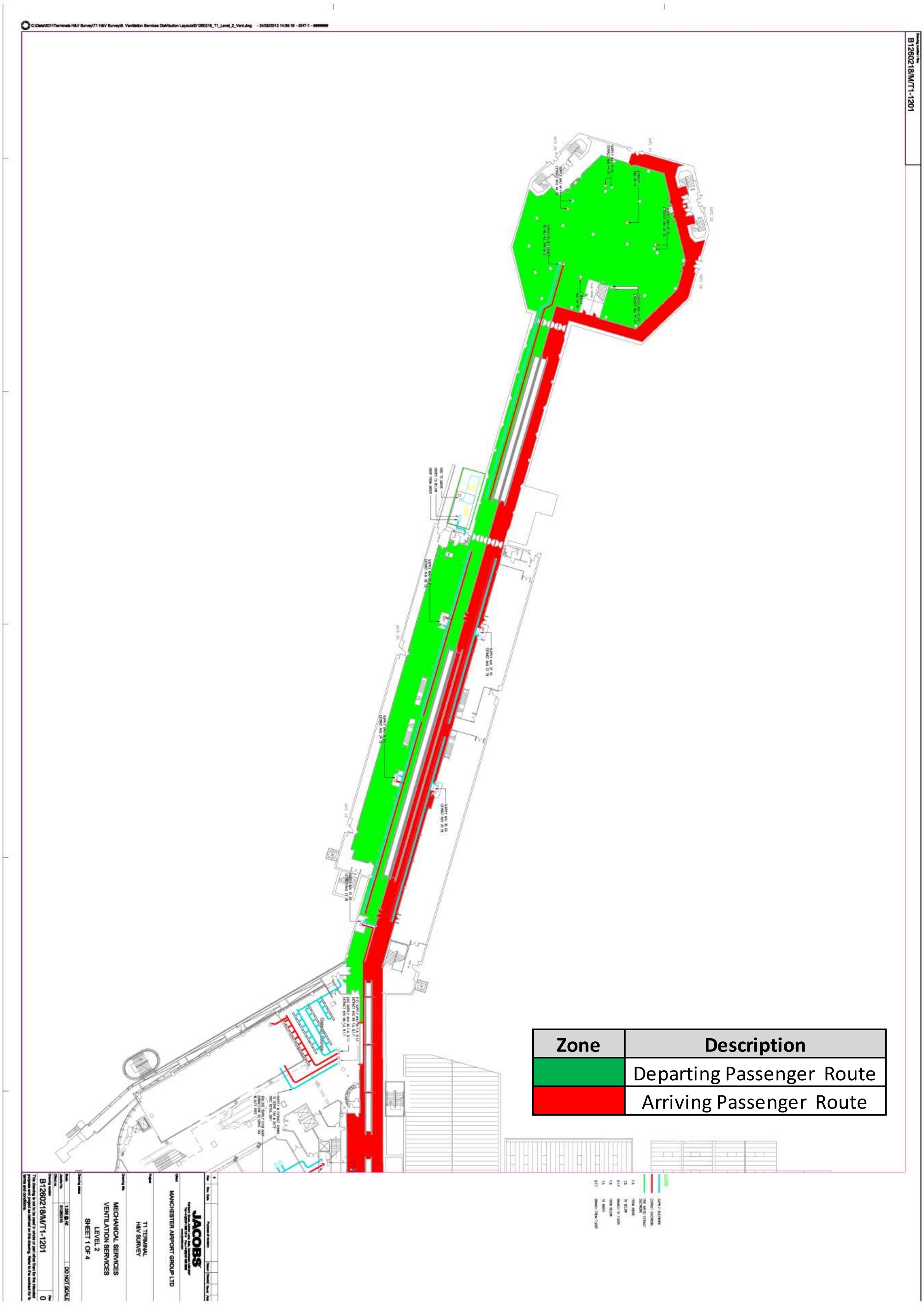


Figure 4.44 - Stand 31 Passenger Routes (Original Courtesy Airport Utilities)

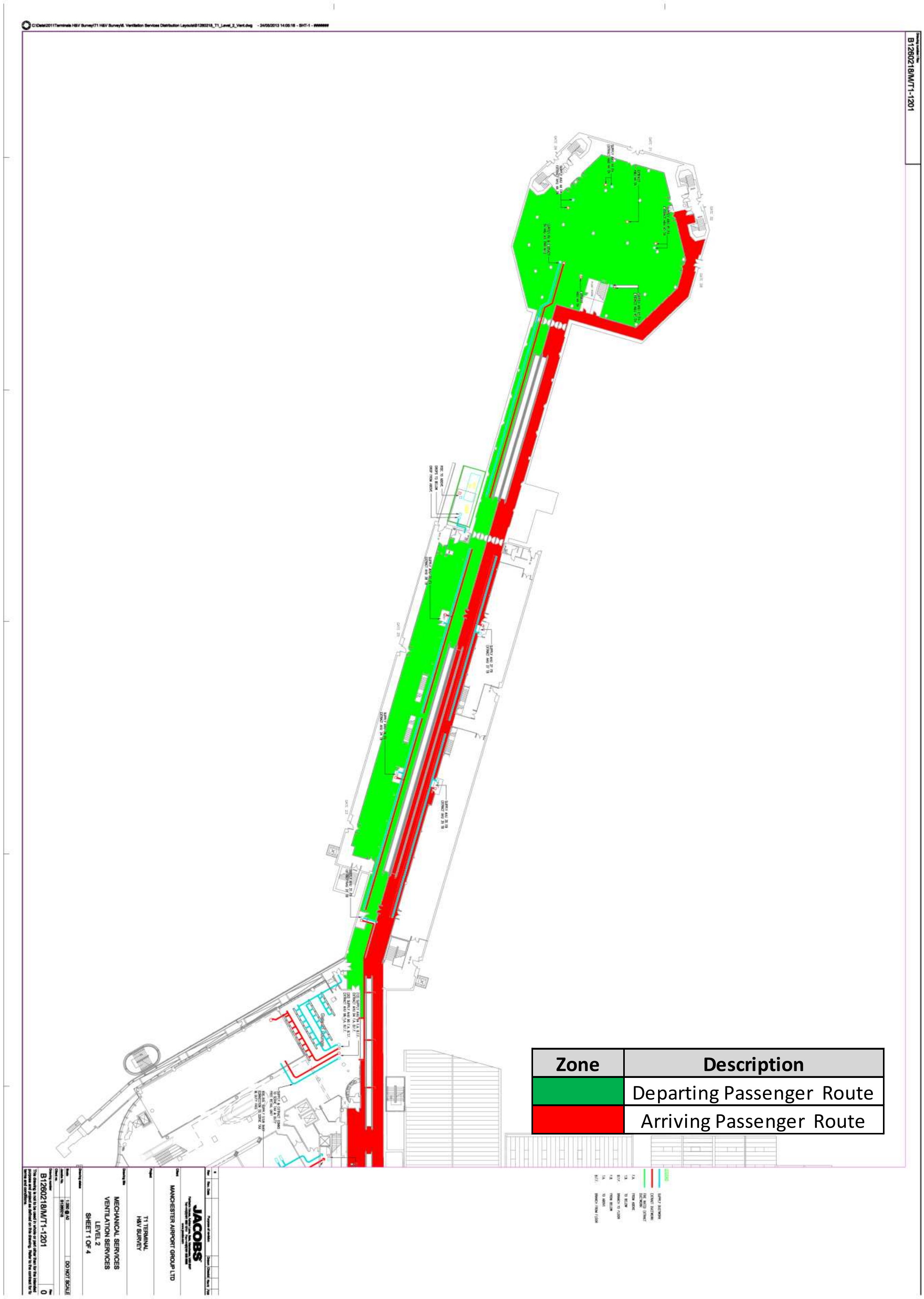


Figure 4.45 - Stand 32 Passenger Routes (Original Courtesy Airport Utilities)

4.4.4 Air Handling Unit allocation for Individual Departure Gates

Analysis of the air handling units serving specific areas has allowed the formulation of an air handling unit schedule for every departure gate route. Figure 4.46 details the air handling units schedule displaying which air handling units are required for comfort conditioning the journey to the departure stands.

Stand	AHU required for Departure Comfort Conditions						
22	34	35					
23	34						
24	34		37	38			
25	34			38			
26	34		37	38			
27	34			38			
28	34			38	43	44	45
29	34			38	43	44	45
31	34			38	43	44	45
32	34			38	43	44	45

Figure 4.46 – AHU allocation for departure Gates

4.4.5 Air Handling Unit allocation for Individual Arrival Gates

Analysis of the air handling units serving specific areas has allowed the formulation of an air handling unit schedule for every arrival gate route. Figure 4.47 details the air handling units schedule displaying which air handling units are required for comfort conditioning the journey from the arrival stands.

Stand	AHU required for Arrival Comfort Conditions						
22							
23							
24		35					
25							
26		35	37				
27							
28		35	37		43		
29		35	37		43		
31		35	37		43		
32		35	37		43		

Figure 4.47 – AHU allocation for Arrival Gates

4.4.6 Chroma data

Chroma Fusion is the prefeed choice of the Manchester Airport Group to provide the flight information services.

"Chroma helps airport operators deliver the next generation of airport operations by providing a single technology platform that is focused on stakeholder collaboration and integration". (www.amorgroup.com/transport/chroma-suite)

Chroma Fusion can provide important pieces of data including aircraft type, aircraft registration and passenger numbers. The information required for this particular research is limited to aircraft type, flight number, aircraft registration, stand allocation and actual departure/arrival times. The additional information is currently not being analysed but future research could incorporate this data, for example actual passenger numbers could be utilised to set the time period for disabling plants for arriving passengers. This could potentially reduce the operational time of the arrival AHU, if the passenger numbers are reduced.

The original data requested from the MAG Airfield Operations Department was flight information for a week within each season (Summer, Winter, Spring & Autumn). For the purpose of this research a random 24 hour period was selected for analysis. The period selected was the 8th April 2012. All original Chroma data can be viewed within Appendix A for future research.

The original data has been reduced and filtered to provide the required information needed for the research analysis. The data has been filtered into two different sections, one for departures and one for arrivals.

Figures 4.48 & 4.49 display the departure and arrival data respectively for the 24 hour period of the 8th April 2012.

Abbreviations used within the Chroma data are as follows:

- STD - Schedule Time of Departure
- ETD - Estimated Time of Departure
- ATD - Actual Time of Departure
- STA - Schedule Time of Arrival
- ETA - Estimated Time of Arrival
- ATA - Actual Time of Arrival

flight No	Aicraft type	Aircraft Reg.	Origin	STD	ETD	ATD	stand
TCX2016	76W	GTCCA	NBE	06:00:	06:00:	05:57:	32
EZY1971	320	GEZUC	PFO	07:00:	07:00:	07:00:	27
LS791	738	GGDFF	FCO	07:00:	07:00:	07:00:	28
LH949	320	GMIDO	FRA	07:05:	07:05:	07:05:	24
LS2125	733	GCELC	CMF	06:55:	06:55:	07:25:	23
EZY1923	320	GEZUG	AGP	07:20:	07:20:	07:29:	25
LS337	75W	GLSAB	CMF	08:00:	08:00:	08:17:	31
LS937	752	GLSAA	PFO	09:00:	09:00:	08:58:	22
TCX2536	752	GFCLJ	SSH	09:10:	09:10:	09:14:	27
EY016	332	A6EYR	AUH	09:25:	09:25:	09:20:	32
SK540	M81	SEDIL	CPH	10:15:	10:15:	10:15:	25
LH2501	319	DAILY	MUC	11:00:	11:00:	11:06:	23
TK1994	73H	TCJGI	IST	11:15:	11:25:	11:23:	27
LH943	320	GMIDO	FRA	12:35:	12:35:	12:27:	25
TCX2318	321	GOMYJ	ACE	12:45:	12:45:	12:35:	29
TCX2548	76W	GTCCB	AYT	13:55:	13:55:	13:50:	26
LS126C	75W	GLSAB	DUB	14:40:	14:40:	14:34:	31
TCX2466	320	GDHJZ	PFO	14:45:	14:55:	15:07:	29
LS887	738	GGDFJ	PRG	16:00:	16:10:	16:11:	27
TCX2456	76W	GTCCA	TFS	15:30:	16:30:	16:35:	22
LS703	320	LXSTB	CDG	17:00:	17:00:	16:56:	25
LH2503	320	DAIPT	MUC	17:25:	17:45:	17:34:	27
AY938	E90	OHLKP	HEL	17:50:	17:50:	17:50:	22
LH947	320	GMIDO	FRA	18:15:	18:15:	18:07:	25
SK2550	73G	SERER	ARN	18:35:	18:35:	18:28:	23
SK542	M87	SEDIP	CPH	19:10:	18:55:	18:55:	24
LX381	319	HBIPS	ZRH	18:50:	19:00:	19:01:	29
TK1996	73H	TCJFI	IST	15:55:	19:43:	19:56:	27
4U343	319	DAGWN	CGN	20:15:	20:15:	20:14:	25
SK4606	73W	LNTUL	BGO	20:35:	20:35:	20:25:	23
EY022	332	A6EYS	AUH	21:05:	20:50:	20:48:	32

Figure 4.48 – Chroma Data for 8th April Departure Flights

flight No	Aicraft type	Aircraft Reg.	Origin	STA	ETA	ATA	stand
EZY1856	320	GEZUG	SSH	00:40:	00:45:	00:47:	25
LS918	75W	GLSAB	TFS	00:55:	01:05:	01:24:	31
TCX2469	76W	GTCCB	BJL	04:45:	04:45:	04:45:	26
TCX473	332	GMLJL	SFB	05:25:	05:05:	05:03:	29
TCX2033	752	GFCLJ	RHO	07:40:	07:36:	07:47:	27
EY015	332	A6EYR	AUH	07:25:	07:16:	08:25:	32
SK539	M81	SEDIL	CPH	09:30:	09:30:	09:19:	25
LH2500	319	DAILY	MUC	10:10:	10:20:	10:26:	23
TK1993	73H	TCJGI	IST	10:15:	10:26:	10:27:	27
TCX2347	321	GOMYJ	ILD	11:30:	11:20:	11:25:	29
LH942	320	GMIDO	FRA	11:50:	11:45:	11:40:	25
LS832	320	LXSTB	PMI	13:20:	13:10:	13:15:	25
TCX2049	320	GDHJZ	AGP	13:35:	13:30:	13:35:	29
LS338	75W	GLSAB	CMF	13:05:	13:40:	13:45:	31
EY021	332	A6EYS	AUH	15:05:	14:55:	14:55:	32
LS876	738	GGDFJ	FAO	15:00:	15:00:	15:07:	27
TCX2017	76W	GTCCA	NBE	14:00:	14:58:	15:10:	22
AY937	E90	OHLKP	HEL	16:55:	16:42:	16:50:	22
LH2502	320	DAIPT	MUC	16:45:	16:50:	16:55:	27
LH946	320	GMIDO	FRA	17:30:	17:20:	17:20:	25
SK2549	73G	SERER	ARN	17:55:	17:50:	17:46:	23
TCX2135	321	GDHJH	ACE	17:50:	17:15:	17:50:	28
SK541	M87	SEDIP	CPH	18:30:	18:20:	18:10:	24
LX380	319	HBIPS	ZRH	18:10:	18:25:	18:14:	29
TK1995	73H	TCJFI	IST	15:05:	18:43:	18:52:	27
SK4605	73W	LNTUL	BGO	19:45:	19:30:	19:38:	23
4U342	319	DAGWN	CGN	19:45:	19:32:	19:42:	25
LS888	738	GGDFJ	PRG	21:20:	21:22:	21:25:	24
TCX2537	752	GFCLJ	SSH	21:50:	21:20:	21:35:	29
LH2504	320	DAIPK	MUC	23:00:	22:40:	22:42:	26
LS892	752	GLSAI	ACE	23:20:	22:40:	22:45:	23
EZY1888	320	GEZUC	MUC	23:00:	22:46:	22:51:	25

Figure 4.49 – Chroma Data for 8th April Arrivals

4.4.7 AHU Schedule for 8th April 2012 Departures

Incorporating the flight information data into the air handling unit allocation table we can produce an aircraft stand/air handling unit schedule for the departure flights for the 24 hour period o f the 8th April 2012. Figure 4.50 details the schedule displaying the air handling units required for each departure aircraft.

Aircraft Stand/AHU Schedule - Departures 8th April 2012															
flight No	Aicraft type	Aircraft Reg.	Origin	STD	ETD	ATD	stand		Air Handling Unit (AHU) Enabled						
TCX2016	76W	GTCCA	NBE	06:00:	06:00:	05:57:	32		34			38	43	44	45
EZY1971	320	GEZUC	PFO	07:00:	07:00:	07:00:	27		34			38			
LS791	738	GGDFF	FCO	07:00:	07:00:	07:00:	28		34			38	43	44	45
LH949	320	GMIDO	FRA	07:05:	07:05:	07:05:	24		34		37	38			
LS2125	733	GCELC	CMF	06:55:	06:55:	07:25:	23		34						
EZY1923	320	GEZUG	AGP	07:20:	07:20:	07:29:	25		34			38			
LS337	75W	GLSAB	CMF	08:00:	08:00:	08:17:	31		34			38	43	44	45
LS937	752	GLSAA	PFO	09:00:	09:00:	08:58:	22		34	35					
TCX2536	752	GFCLJ	SSH	09:10:	09:10:	09:14:	27		34			38			
EY016	332	A6EYR	AUH	09:25:	09:25:	09:20:	32		34			38	43	44	45
SK540	M81	SEDIL	CPH	10:15:	10:15:	10:15:	25		34			38			
LH2501	319	DAILY	MUC	11:00:	11:00:	11:06:	23		34						
TK1994	73H	TCJGI	IST	11:15:	11:25:	11:23:	27		34			38			
LH943	320	GMIDO	FRA	12:35:	12:35:	12:27:	25		34			38			
TCX2318	321	GOMYJ	ACE	12:45:	12:45:	12:35:	29		34			38	43	44	45
TCX2548	76W	GTCCB	AYT	13:55:	13:55:	13:50:	26		34		37	38			
LS126C	75W	GLSAB	DUB	14:40:	14:40:	14:34:	31		34			38	43	44	45
TCX2466	320	GDHJZ	PFO	14:45:	14:55:	15:07:	29		34			38	43	44	45
LS887	738	GGDFJ	PRG	16:00:	16:10:	16:11:	27		34			38			
TCX2456	76W	GTCCA	TFS	15:30:	16:30:	16:35:	22		34	35					
LS703	320	LXSTB	CDG	17:00:	17:00:	16:56:	25		34			38			
LH2503	320	DAIPT	MUC	17:25:	17:45:	17:34:	27		34			38			
AY938	E90	OHLKP	HEL	17:50:	17:50:	17:50:	22		34	35					
LH947	320	GMIDO	FRA	18:15:	18:15:	18:07:	25		34			38			
SK2550	73G	SERER	ARN	18:35:	18:35:	18:28:	23		34						
SK542	M87	SEDIP	CPH	19:10:	18:55:	18:55:	24		34		37	38			
LX381	319	HBIPS	ZRH	18:50:	19:00:	19:01:	29		34			38	43	44	45
TK1996	73H	TCJFI	IST	15:55:	19:43:	19:56:	27		34			38			
4U343	319	DAGWN	CGN	20:15:	20:15:	20:14:	25		34			38			
SK4606	73W	LNTUL	BGO	20:35:	20:35:	20:25:	23		34						
EY022	332	A6EYS	AUH	21:05:	20:50:	20:48:	32		34			38	43	44	45

Figure 4.50 – Aircraft Stand/AHU Schedule for 8th April 2012 Departures

4.4.8 AHU Schedule for 8th April 2012 Arrivals

Incorporating the flight information data into the air handling unit allocation table we can produce an aircraft stand/air handling unit schedule for the arrival flights for the 24 hour period o f the 8th April 2012. Figure 4.51 details the schedule displaying the air handling units required for each arrival aircraft.

Aircraft Stand/AHU Schedule - Arrivals 8th April 2012																
flight No	Aicraft type	Aircraft Reg.	Origin	STA	ETA	ATA	stand		Air Handling Unit (AHU) Enabled							
EZY1856	320	GEZUG	SSH	00:40:	00:45:	00:47:	25									
LS918	75W	GLSAB	TFS	00:55:	01:05:	01:24:	31			35	37		43			
TCX2469	76W	GTCCB	BJL	04:45:	04:45:	04:45:	26			35	37					
TCX473	332	GMLJL	SFB	05:25:	05:05:	05:03:	29			35	37		43			
TCX2033	752	GFCLJ	RHO	07:40:	07:36:	07:47:	27									
EY015	332	A6EYR	AUH	07:25:	07:16:	08:25:	32			35	37		43			
SK539	M81	SEDIL	CPH	09:30:	09:30:	09:19:	25									
LH2500	319	DAILY	MUC	10:10:	10:20:	10:26:	23									
TK1993	73H	TCJGI	IST	10:15:	10:26:	10:27:	27									
TCX2347	321	GOMYJ	ILD	11:30:	11:20:	11:25:	29			35	37		43			
LH942	320	GMIDO	FRA	11:50:	11:45:	11:40:	25									
LS832	320	LXSTB	PMI	13:20:	13:10:	13:15:	25									
TCX2049	320	GDHJZ	AGP	13:35:	13:30:	13:35:	29			35	37		43			
LS338	75W	GLSAB	CMF	13:05:	13:40:	13:45:	31			35	37		43			
EY021	332	A6EYS	AUH	15:05:	14:55:	14:55:	32			35	37		43			
LS876	738	GGDFJ	FAO	15:00:	15:00:	15:07:	27									
TCX2017	76W	GTCCA	NBE	14:00:	14:58:	15:10:	22									
AY937	E90	OHLKP	HEL	16:55:	16:42:	16:50:	22									
LH2502	320	DAIPT	MUC	16:45:	16:50:	16:55:	27									
LH946	320	GMIDO	FRA	17:30:	17:20:	17:20:	25									
SK2549	73G	SERER	ARN	17:55:	17:50:	17:46:	23									
TCX2135	321	GDHJH	ACE	17:50:	17:15:	17:50:	28			35	37		43			
SK541	M87	SEDIP	CPH	18:30:	18:20:	18:10:	24			35						
LX380	319	HBIPS	ZRH	18:10:	18:25:	18:14:	29			35	37		43			
TK1995	73H	TCJFI	IST	15:05:	18:43:	18:52:	27									
SK4605	73W	LNTUL	BGO	19:45:	19:30:	19:38:	23									
4U342	319	DAGWN	CGN	19:45:	19:32:	19:42:	25									
LS888	738	GGDFJ	PRG	21:20:	21:22:	21:25:	24			35						
TCX2537	752	GFCLJ	SSH	21:50:	21:20:	21:35:	29			35	37		43			
LH2504	320	DAIPK	MUC	23:00:	22:40:	22:42:	26			35	37					
LS892	752	GLSAI	ACE	23:20:	22:40:	22:45:	23									
EZY1888	320	GEZUC	MUC	23:00:	22:46:	22:51:	25									

Figure 4.51 – Aircraft Stand/AHU Schedule for 8th April 2012 Arrivals

4.4.9 Gating Rules

To create a realistic hypothetical relationship, the analysis is required to follow any procedures the Airport currently follows in a practicable manner. Aircraft are required to strictly adhere to the departure slots they are allocated to prevent any disruptions to ongoing operations, therefore Manchester Airport have a "Gating Rule" procedure in place. The Gating Rule is derived to allow passengers adequate time to travel to each departure gate in sufficient time as not to delay any embarkment of the aircraft.

The Gating Rule consists of two different gate calls for passenger information. The first call is a Gate call which is displayed on Flight Information Display Screens. The screens are situated around the main departure lounge and inform passengers from which gate the particular flight is departing. The second announcement is a Final gate call and is announced over the public address system to inform any delayed passengers they are required to go to the specific gate immediately or risk losing a position on the flight.

Figure 4.52 displays the Gating Rule procedure that is currently in place within Terminal 1 at Manchester Airport.

T1 Gating Rules Valid from 2009:

A/C Category	1	2	3	4	5	6	7	8	9
A/C Size	1 to 49 seat	50 - 99	100 - 149	150 - 199	200 - 349	350 - 399	400 - 499	450+	Default
Gate	Gate/Final	Gate/Final	Gate/Final	Gate/Final	Gate/Final	Gate/Final	Gate/Final	Gate/Final	Gate/Final
1-5	30/15	35/20	40/20	50/20	55/25	60/25	60/25	65/30	50/20
6-10	30/15	40/20	40/20	50/20	55/25	60/25	60/25	65/30	50/20
11-15	35/15	40/20	45/20	50/20	55/25	60/26	60/25	65/30	50/20
20 A-D	35/20	45/25	45/25	55/30	60/30	65/30	65/30	70/35	55/30
21-28	30/15	40/20	40/20	50/20	55/25	60/25	60/25	65/30	50/20
29-33	30/15	40/20	40/20	50/20	55/25	60/25	65/30	65/30	55/25

Figure 4.52 – T1 Gate Rules (Courtesy T1 Customer Services MAG)

For the purpose of the analysis and to adhere to the gating rules the departure and arrival times that have been selected are as follows:

Departure flights - Enable plant 60 minutes before departure time.

Disable plant on departure time

Arrival flights - Enable plant 15 minutes before arrival time.

Disable plant 30 minutes after arrival time.

For the purpose of the research the above data is adequate but further discussion on plant start times and procedures including optimum start, outside air compensation and fabric protection are covered in section 5.

4.4.10 Chronological flight order

Incorporating both the departure and arrival AHU schedules with the gating rules, a chronological flight order can be produced. This operational schedule will not only determine which plants are required for each departure and arrival journey, but will also determine when and which plants can be disabled without effecting the passenger comfort conditions being provided.

Careful consideration must be taken when analysis of the data is being performed, specifically with individual plant operational overlap. Certain plants are required for both the departure and arrival journeys, therefore each flight and AHU schedule has to be analysed in chronological order to determine the correct operational timescales of each plant for each journey. For the purpose of the analysis a timescale greater than 5 minutes has to exist for the plant to be disabled waiting on the next enable signal. For example if a certain AHU was required for a departure flight, and the same plant was required for an arrival journey within a 0-5mins timescale the plant will stay enabled and will be not forced to disable and then re-enable in such a short time period.

Figure 4.53 displays the Phase two operational schedule and details the time periods required for each individual Air Handling Unit. This data can then be used in conjunction with the available data from phase One to create the hypothetical kWh and CO_2 emission readings for Phase two operational relationship.

Type	Time	Stand		AHU							Time On	Time Off
Arr.	00:47:	25									Not required	
Arr.	01:24:	31			35	37		43			01:09:	01:54
Arr.	04:45:	26			35	37					04:30:	05:15
Arr.	05:03:	29			35	37		43			04:48:	05:33
Dep	05:57:	32		34			38	43	44	45	04:57:	05:57:
Dep	07:00:	27		34			38				06:00:	07:00:
Dep	07:00:	28		34			38	43	44	45	06:00:	07:00:
Dep	07:05:	24		34		37	38				06:05:	07:05:
Dep	07:25:	23		34							06:25:	07:25:
Dep	07:29:	25		34			38				06:29:	07:29:
Arr.	07:47:	27									Not required	
Dep	08:17:	31		34			38	43	44	45	07:17:	08:17:
Arr.	08:25:	32			35	37		43			08:10:	08:55:
Dep	08:58:	22		34	35						07:58:	08:58:
Dep	09:14:	27		34			38				08:14:	09:14:
Arr.	09:19:	25									Not required	
Dep	09:20:	32		34			38	43	44	45	08:20:	09:20:
Dep	10:15:	25		34			38				09:15:	10:15:
Arr.	10:26:	23									Not required	
Arr.	10:27:	27									Not required	
Dep	11:06:	23		34							10:06:	11:06:
Dep	11:23:	27		34			38				10:23:	11:23:
Arr.	11:25:	29			35	37		43			11:10:	11:55:
Arr.	11:40:	25									11:25:	12:10:
Dep	12:27:	25		34			38				11:27:	12:27:
Dep	12:35:	29		34			38	43	44	45	11:35:	12:35:
Arr.	13:15:	25									Not required	
Arr.	13:35:	29			35	37		43			13:20:	14:05:
Arr.	13:45:	31			35	37		43			13:30:	14:15:
Dep	13:50:	26		34		37	38				12:50:	13:50:
Dep	14:34:	31		34			38	43	44	45	13:34:	14:34:
Arr.	14:55:	32			35	37		43			14:40:	15:25:
Dep	15:07:	29		34			38	43	44	45	14:07:	15:07:
Arr.	15:07:00	27									Not required	
Arr.	15:10:00	22									Not required	
Dep	16:11:	27		34			38				15:11:	16:11:
Dep	16:35:	22		34	35						15:35:	16:35:
Arr.	16:50:00	22									Not required	
Arr.	16:55:00	27									Not required	
Dep	16:56:	25		34			38				15:56:	16:56:
Arr.	17:20:00	25									Not required	
Dep	17:34:	27		34			38				16:34:	17:34:
Arr.	17:46:	23									Not required	
Dep	17:50:	22		34	35						16:50:	17:50:
Arr.	17:50:	28			35	37		43			17:35:	18:20:
Dep	18:07:	25		34			38				17:07:	18:07:
Arr.	18:10:	24			35						17:55:	18:40:
Arr.	18:14:	29			35	37		43			17:59:	18:44:
Dep	18:28:	23		34							17:28:	18:28:
Arr.	18:52:00	27									Not required	
Dep	18:55:	24		34		37	38				17:55:	18:55:
Dep	19:01:	29		34			38	43	44	45	18:01:	19:01:
Arr.	19:38:00	23									Not required	
Arr.	19:42:00	25									Not required	
Dep	19:56:	27		34			38				18:56:	19:56:
Dep	20:14:	25		34			38				19:14:	20:14:
Dep	20:25:	23		34							19:25:	20:25:
Dep	20:48:	32		34			38	43	44	45	19:48:	20:48:
Arr.	21:25:	24			35						21:10:	21:55:
Arr.	21:35:	29			35	37		43			21:20:	22:05:
Arr.	22:42:	26			35	37					22:27:	23:12:
Arr.	22:45:	23									22:30:	23:15:
Arr.	22:51:	25									22:36:	23:21:

*Arrivals Route - Plant is enabled 15mins before arrival time and is disabled 30mins after arrival.
Departure route -Plant is enabled 1 hour before departure.

Figure 4.53 – Phase Two Schedule of Operation

4.4.11 Phase Two Electrical Consumption

4.4.11.1 AHU 34

Figure 4.54 displays the operational hours run for Air Handling Unit 34 during the phase two operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation by enabling and disabling of the air conditioning plant in conjunction with providing the required comfort conditions for the actual departing and arrival flights.

AHU	Enable (Time)	Disable (Time)	Run hrs.
34	04:57	12:35	07:38
	12:50	20:48	07:58
		Total	**15:36**

Figure 4.54 – AHU 34 Operational Hours Run

Figure 4.55 displays the energy consumption of AHU 34 during both the phase one and phase two system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	% Saving
AHU 34	Supply	11	7.4	177.6	114.7	35
AHU 34	Extract	1.1	1.1	26.4	17.1	35
Estimated Run Hrs		*15hrs 36mins*				

Figure 4.55 – AHU 34 Phase Two electrical motor consumption

4.4.11.2 AHU 35

Figure 4.56 displays the operational hours run for Air Handling Unit 35 during the phase two operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation by enabling and disabling of the air conditioning plant in conjunction with providing the required comfort conditions for the actual departing and arrival flights.

AHU	Enable (Time)	Disable (Time)	Run hrs.
35	01:09	01:54	**00:45**
	04:30	05:33	**01:03**
	08:10	08:58	**00:48**
	11:10	11:55	**00:45**
	13:20	14:15	**00:55**
	14:40	15:25	**00:45**
	15:35	16:35	**01:00**
	16:50	18:44	**01:54**
	21:10	22:05	**00:55**
	22:27	23:12	**00:45**
		Total	**09:35**

Figure 4.56 – AHU 35 Operational Hours Run

Figure 4.57 displays the energy consumption of AHU 35 during both the phase one and phase two system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	% Saving
AHU 35	Supply	11	7.3	175.2	69.4	60
AHU 35	Extract	1.1	1.1	26.4	10.5	60
Estimated Run Hrs		*9hrs 35mins*				

Figure 4.57 – AHU 35 Phase Two electrical motor consumption

4.4.11.3 AHU 37

Figure 4.58 displays the operational hours run for Air Handling Unit 37 during the phase two operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation by enabling and disabling of the air conditioning plant in conjunction with providing the required comfort conditions for the actual departing and arrival flights.

AHU	Enable (Time)	Disable (Time)	Run hrs.
37	01:09	01:54	**00:45**
	04:30	05:33	**01:03**
	06:05	07:05	**01:00**
	08:10	08:55	**00:45**
	11:10	11:55	**00:45**
	12:50	14:15	**01:25**
	14:40	15:25	**00:45**
	17:35	18:55	**01:20**
	21:20	22:05	**00:45**
	22:27	23:12	**00:45**
		Total	**09:18**

Figure 4.58 – AHU 37 Operational Hours Run

Figure 4.59 displays the energy consumption of AHU 37 during both the phase one and phase two system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

`	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	% Saving
AHU 37	Supply	11	7.4	177.6	69.0	61
AHU 37	Extract	1.1	1.1	26.4	10.3	61
Estimated Run Hrs		*9hrs 18mins*				

Figure 4.59 – AHU 37 Phase Two electrical motor consumption

4.4.11.4 AHU 38

Figure 4.60 displays the operational hours run for Air Handling Unit 38 during the phase two operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation by enabling and disabling of the air conditioning plant in conjunction with providing the required comfort conditions for the actual departing and arrival flights.

AHU	Enable (Time)	Disable (Time)	Run hrs.
38	04:57	12:35	**07:38**
	12:50	20:48	**07:58**
		Total	**15:36**

Figure 4.60 – AHU 38 Operational Run Hours

Figure 4.61 displays the energy consumption of AHU 38 during both the phase one and phase two system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	% Saving
AHU 38	Supply	11	7.4	177.6	114.7	35
AHU 38	Extract	1.1	1.1	26.4	17.1	35
Estimated Run Hrs		*15hrs 36mins*				

Figure 4.61 – AHU 38 Phase Two electrical motor consumption

4.4.11.5 AHU 43

Figure 4.62 displays the operational hours run for Air Handling Unit 43 during the phase two operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation by enabling and disabling of the air conditioning plant in conjunction with providing the required comfort conditions for the actual departing and arrival flights.

AHU	Enable (Time)	Disable (Time)	Run hrs.
43	01:09	01:54	**00:45**
	04:48	07:00	**02:12**
	07:17	09:20	**02:03**
	11:10	12:35	**01:25**
	13:20	15:25	**02:05**
	17:35	19:01	**01:26**
	19:48	20:48	**01:00**
	21:20	22:05	**00:45**
		Total	**11:41**

Figure 4.62 – AHU 43 Operational Run Hours

Figure 4.63 displays the energy consumption of AHU 43 during both the phase one and phase two system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	% Saving
AHU 43	Supply	3	1.3	31.2	15.1	52
AHU 43	Extract	3	3.4	81.6	39.4	52
Estimated Run Hrs		*11hrs 41mins*				

Figure 4.63 – AHU 43 Phase Two electrical motor consumption

4.4.11.6 AHU 44

Figure 4.64 displays the operational hours run for Air Handling Unit 44 during the phase two operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation by enabling and disabling of the air conditioning plant in conjunction with providing the required comfort conditions for the actual departing and arrival flights.

AHU	Enable (Time)	Disable (Time)	Run hrs.
44	04:57	07:00	**02:03**
	07:17	09:20	**02:03**
	11:35	12:35	**01:00**
	13:34	15:07	**01:33**
	18:01	19:01	**01:00**
	19:48	20:48	**01:00**
		Total	**08:39**

Figure 4.64 – AHU 44 Operational Hours Run

Figure 4.65 displays the energy consumption of AHU 44 during both the phase one and phase two system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	% Saving
AHU 44	Supply	15	10.0	240.0	86.0	64
AHU 44	Extract	7.5/1.9	5.0	120.0	43.0	64
Estimated Run Hrs		*8hrs 39mins*				

Figure 4.65 – AHU 44 Phase Two electrical motor consumption

4.4.11.7 AHU 45

Figure 4.66 displays the operational hours run for Air Handling Unit 45 during the phase two operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation by enabling and disabling of the air conditioning plant in conjunction with providing the required comfort conditions for the actual departing and arrival flights.

AHU	Enable (Time)	Disable (Time)	Run hrs.
45	04:57	07:00	**02:03**
	07:17	09:20	**02:03**
	11:35	12:35	**01:00**
	13:34	15:07	**01:33**
	18:01	19:01	**01:00**
	19:48	20:48	**01:00**
		Total	**08:39**

Figure 4.66 – AHU 45 Operational Hours Run

Figure 4.67 displays the energy consumption of AHU 45 during both the phase one and phase two system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	% Saving
AHU 45	Supply	15	10.0	240.0	86.0	64
AHU 45	Extract	7.5/1.9	8.8	211.2	75.7	64
Estimated Run Hrs		*8hrs 39mins*				

Figure 4.67 – AHU 45 Phase Two electrical motor consumption

4.4.12 Phase Two CO_2 Emissions

In order to evaluate the gas emissions from the electricity used by the temperature control plant, the derived data has to be converted into CO_2 emissions. The Department for Environment Food & Rural Affairs (DEFRA) publish conversion factors for organisations to report their emissions from different sources.

Organisations are required to report the electricity used on sites that are under their control. These reports are classified as scope 2 indirect emissions. DEFRA also publish factors for scope 3 emissions which are not directly under the organisations control. DEFRA advise organisations to include the scope 3 results which are *transmission and distribution* (T&D) losses of electricity they purchase, which occur between the power station and their particular site. The separate *transmission and distribution* losses are usually reported separate from the scope 2 results.

The conversion factors cover individual GHG including CO_2, CH_4 & N_2O and a combined factor of CO_2e. For the purpose of graphical representation of emissions throughout the research, the kg CO_2 factor within the scope 2 *Electricity generated* will be calculated and displayed only. Figures 4.68 & 4.69 display the conversion tables published from DEFRA.

Activity	Country	Unit	Year	kg CO_2e	**kg CO_2**	kg CH_4	kg N_2O
Electricity generated	Electricity: UK	kWh	2013	0.44548	**0.44238**	0.00029	0.00281

Figure 4.68 – DEFRA Scope 2 electricity generated factor

Source: www.ukconversionfactorscarbonsmart.co.uk June 22nd 2013

Activity	Type	Unit	Year	kg CO_2e	kg CO_2	kg CH_4	kg N_2O
T&D- UK electricity	Electricity: UK	kWh	2013	0.03809	0.03783	0.00002	0.00024

Figure 4.69 – DEFRA Scope 3 Transmission & Distribution factor

Source: www.ukconversionfactorscarbonsmart.co.uk June 22nd 2013

The hypothetical phase two relationship between the temperature control and stand allocation management has been examined and the results of the emissions from the individual plant can be calculated. Phase two creates the relationship that provides comfort conditions to the designated areas during required occupancy periods only. CO_2 emissions have been calculated for the individual air conditioning plants for comparison with phase one results and inclusion within phase three analysis.

4.4.12.1 AHU 34 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two
AHU 34	Supply	11	7.4	177.6	114.7	78.6	50.7
AHU 34	Extract	1.1	1.1	26.4	17.1	11.7	7.5
					Totals	**90.2**	**58.3**

Figure 4.70 –Phase Two AHU 34 CO_2 emissions

4.4.12.2 AHU 35 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two
AHU 35	Supply	11	7.3	175.2	69.4	77.5	30.7
AHU 35	Extract	1.1	1.1	26.4	10.5	11.7	4.6
					Totals	**89.2**	**35.3**

Figure 4.71 – Phase Two AHU 35 CO_2 emissions

4.4.12.3 AHU 37 CO_2 Emissions

`	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two
AHU 37	Supply	11	7.4	177.6	69.0	78.6	30.5
AHU 37	Extract	1.1	1.1	26.4	10.3	11.7	4.5
					Totals	**90.2**	**35.1**

Figure 4.72 – Phase Two AHU 37 CO_2 emissions

4.4.12.4 AHU 38 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two
AHU 38	Supply	11	7.4	177.6	114.7	78.6	50.7
AHU 38	Extract	1.1	1.1	26.4	17.1	11.7	7.5
					Totals	**90.2**	**58.3**

Figure 4.73 – Phase Two AHU 38 CO_2 emissions

4.4.12.5 AHU 43 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two
AHU 43	Supply	3	1.3	31.2	15.1	13.8	6.7
AHU 43	Extract	3	3.4	81.6	39.4	36.1	17.4
					Totals	**49.9**	**24.1**

Figure 4.74 – Phase Two AHU 43 CO_2 emissions

4.4.12.6 AHU 44 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two
AHU 44	Supply	15	10.0	240.0	86.0	106.2	38.0
AHU 44	Extract	7.5/1.9	5.0	120.0	43.0	53.1	19.0
					Totals	**159.3**	**57.1**

Figure 4.75 – Phase Two AHU 44 CO_2 emissions

4.4.12.7 AHU 45 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two
AHU 45	Supply	15	10.0	240.0	86.0	106.2	38.0
AHU 45	Extract	7.5/1.9	8.8	211.2	75.7	93.4	33.5
					Totals	**199.6**	**71.5**

Figure 4.76 – Phase Two AHU 45 CO_2 emissions

4.4.13 Phase two relationship simulation

A simulation model was created from the data to provide a graphical representation of the hypothetical relationship between the services provided and the existing building operation. The simulation was created to compliment the accumulated data. (The simulation provides a greater insight into the relationship for non-technical personnel). The simulation is an exact replication of the flight activity associated with the 24 hour period of the 8th April 2012. The simulation incorporates the colour coding associated with each individual air handling unit zone which is detailed in figure 4.33 to clearly display when a specific zone is being comfort conditioned.

The simulation model has a time frame of 24 minutes which relates to the timescale of 1min simulation is the equivalent of 1 hour actual activity.(1 second/1 minute). The full simulation is available and can be viewed on the accompanying compact disc located within Appendix A.

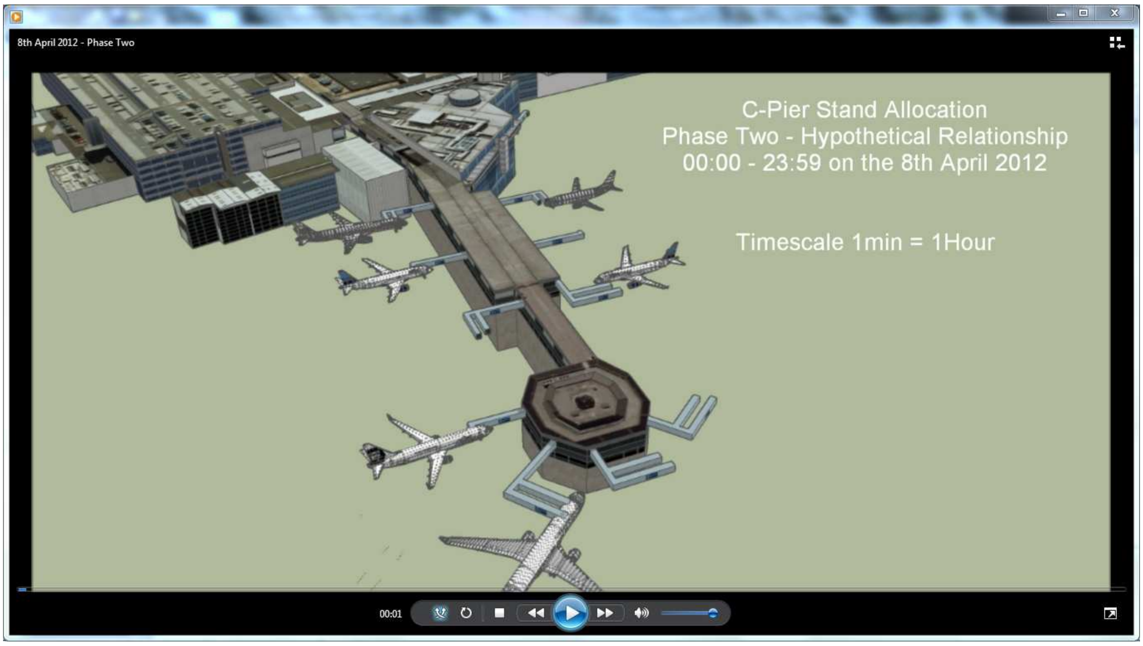


Figure 4.77 – Phase Two Simulation Screenshot

4.5 PHASE THREE

Phase two incorporated a hypothetical interaction between the temperature control services and the existing stand allocation operation. The interaction between the system and the operation was improved to provide temperature control only when required to analyse if the operational cycle could be made more efficient.

Phase two had a greater impact on the airport system by creating a time schedule for the delivered services from data available from the actual operation being performed.

Phase three takes a closer look at the operational side of the relationship to see if any feasible alteration to the operation (stand management) has any effect on the efficiency of the cycle.

The allocation of stands has to comply with particular restrictions enforced by Government agencies including the Department of Transport and the Revenue Commissioners. Special regulations may be enforced on certain flights which may require Customs Border Protection and these flights may take priority with specific stands.

The contributing operation is the aircraft stand management. This operation involves allocating specific aircraft types to specific aircraft stands.

The ability to allocate stands for aircraft at airports is an essential role in the any airport. Key elements within the role are ensuring the correct stand size is used for the size of the specific aircraft. Communication with third parties such as ground handling companies also plays a significant role. Other criteria when allocating stands to consider are airbridge requirements, passenger control requirements, stand equipment and efficiency.

Manchester Airport Airfield operations controls and manages stand allocation, and produces a seasonal guide based on schedule traffic information submitted by operators to the airport.

A custom of preferred use of contact stands exists within airports and to minimise commercial ambiguity agreement have been made with airlines and handling agents on a seasonal basis, about the preferred use of one or more specific stands. An airline that operates a high frequency of departures to the same destination on a daily basis may qualify for a designated stand.

The hypothetical operation performed in phase three was carried out incorporating the available data of aircraft sizes and stand sizes only. Any specific l requirements for individual aircraft or regulations for that period have not been considered,

The research results could produce an interesting debate on whether the efficiency of the system and operation relationship is of higher importance than the airports relationship with specific airlines that currently have preferred stands?

4.5.1 Aircraft Types and sizes

Manchester Airport's Airfield Operations provided data on the maximum aircraft type allowed on the specific stands at terminal 1. The data also detailed certain exceptions that can also be accommodated on certain stands. Figure 4.78 displays the filtered data to represent the maximum aircraft types allowed on the aircraft stands located around C-Pier.(Complete aircraft stand data available in Appendix A)

Stand	Max Aircraft Type (Span)	Max Aicraft Type Group	Exceptions
22	BOEING 767-300	8	M81, M82, M83, M84, M87, M88, M90, 154, L10, L11, ILW, IL6, ATP, TU5. CAN ACCEPT SIZE 3 AIRCRAFT: 732, 733, 734, 735,E70,E90,E95 AND SIZE 9 AIRCRAFT 76W,764
23	BOEING 767-300(W)	8	M81, M82, M83, M87, M88, M90, ATP, TU5, IL6, ILW, 154, IL9, D8M. CAN ACCEPT SIZE 9 A/C L15,D1C,76W. CAN ACCEPT SIZE 3 A/C 732,733,734,735,E70,E90,E95
24	BOEING 737-900(W)	6	100, F27, F50, F70, DH4, DH7, D95, E90, E95, ATP. CAN ACCEPT SIZE 2 AIRCRAFT: ARJ, AR1, AR7, AR8, 141,142,143,146, RJ70, RJ85, RJ1
25	BOEING 737-900	6	73H,73J,73W,100, F27, F50, F70, DH4, DH7, D95, E90, E95, ATP. CAN ACCEPT SIZE 2 AIRCRAFT: ARJ, AR1, AR7, AR8, 141,142,143,146, RJ70, RJ85, RJ1
26	BOEING 777-200	10	M81, M82, M83, M87, M88, M90, ATP, TU5, 154, IL6, ILW,772 773,777, CAN ACCEPT SIZE 3 AIRCRAFT: 732, 733, 734, 735,E70,E90,E95
27	BOEING 777-300ER	10	M81, M82, M83, M87, M88, M90, ATP, TU5, 154, IL6, ILW, 773. CAN ACCEPT SIZE 3 AIRCRAFT: 732, 733, 734, 735 ,E70,E90,E95 AND SIZE 11 AIRCRAFT 346, 77W, 744.
28	BOEING 737-900	5	M81, M82, M83, M87, M88, M90, ATP, 154. CAN ACCEPT SIZE 3 AIRCRAFT: 732, 733, 734, 735
29	AIRBUS A330-300	9	M81, M82, M83, M87, M88, M90, ATP, IL6, ILW, D8M, IL9, 737, 73W, 738, 73H, 739. CAN ACCEPT SIZE 10 332,333,342,343,788. NO SIZE 1,2,3,5,6 AIRCRAFT.
31	BOEING 747-400	10	M81, M82, M83, M87, M88, M90, ATP, TU5, 154, IL6, ILW, IL9, D8M. NO SIZE 1,2,3,5.6 AIRCRAFT. CAN ACCEPT SIZE 11 AIRCRAFT: 346,77W,744
32	BOEING 747-400	10	M81, M82, M83, M87, M88, M90, ATP, TU5, 154, IL6, ILW, IL9, D8M. NO SIZE 1,2,3,5,6 AIRCRAFT. CAN ACCEPT SIZE 11 AIRCRAFT: 346,77W,744

Figure 4.78 – C-Pier Stands Maximum Aircraft Size Allocation.

(Original Courtesy Airfield Operations Manchester Airport)

Manchester Airports Airfield Operations provided data on Aircraft types and the allocated size that the aircraft are associated to. Figure 4.79 displays the filtered data to display the actual aircraft types for the specific research area of c-pier on 8th April 2012 (full aircraft type list available in Appendix A)

Manufacturer	Type	IATA Code	Wingspan/m (Over winglets)	Length/m (Overall)
SIZE 3				
Embraer	ERJ190	E90	28.72	36.24
SIZE 4				
McDonnel Douglas	MD-81	M81	32.85	45.02
McDonnel Douglas	MD-87	M87	32.85	39.75
Airbus Industrie	A320-100	320	33.91	37.57
Airbus Industrie	A320-200	320	33.91	37.57
Airbus Industrie	A321-100	321	33.91	44.5
Airbus Industrie	A319-100	319	34.1	33.84
SIZE 5				
Boeing	B737-700	73G	34.32	33.63
Boeing	B737-800	738	34.32	39.5
SIZE 6				
Boeing	B737-700W	73W	35.8	33.63
Boeing	B737-800H	73H	35.8	39.5
Boeing	BBJ	73W	35.8	33.63
SIZE 7				
Boeing	B757-200	752	38.06	47.33
Boeing	B757-200W	75W	41	47.33
SIZE 9				
Boeing	B767-300W	76W	50.9	54.94
SIZE 10				
Airbus Industrie	A330-200	332	60.3	59.4

Figure 4.79 – Actual Aircraft Types arrived on C-Pier on 8th April 2012

The data provided has been manipulated to create an arrival flight schedule that incorporates the aircraft size groups. This will provide the opportunity for further analysis to be carried out to determine which stands could be made available that meet the particular aircraft type requirements.

Flight No	Aircraft Reg	Aircraft Type	Aircraft Size	Actaul Arr	Stand
EZY1856	GEZUG	320	4	00:47:	25
LS918	GLSAB	75W	7	01:24:	31
TCX2469	GTCCB	76W	9	04:45:	26
TCX473	GMLJL	332	10	05:03:	29
TCX2033	GFCLJ	752	7	07:47:	27
EY015	A6EYR	332	10	08:25:	32
SK539	SEDIL	M81	4	09:19:	25
LH2500	DAILY	319	4	10:26:	23
TK1993	TCJGI	73H	6	10:27:	27
TCX2347	GOMYJ	321	4	11:25:	29
LH942	GMIDO	320	4	11:40:	25
LS832	LXSTB	320	4	13:15:	25
TCX2049	GDHJZ	320	4	13:35:	29
LS338	GLSAB	75W	7	13:45:	31
EY021	A6EYS	332	10	14:55:	32
LS876	GGDFJ	738	5	15:07:	27
TCX2017	GTCCA	76W	9	15:10:	22
AY937	OHLKP	E90	3	16:50:	22
LH2502	DAIPT	320	4	16:55:	27
LH946	GMIDO	320	4	17:20:	25
SK2549	SERER	73G	5	17:46:	23
TCX2135	GDHJH	321	4	17:50:	28
SK541	SEDIP	M87	4	18:10:	24
LX380	HBIPS	319	4	18:14:	29
TK1995	TCJFI	73H	6	18:52:	27
SK4605	LNTUL	73W	6	19:38:	23
4U342	DAGWN	319	4	19:42:	25
LS888	GGDFJ	738	5	21:25:	24
TCX2537	GFCLJ	752	7	21:35:	29
LH2504	DAIPK	320	4	22:42:	26
LS892	GLSAI	752	7	22:45:	23
EZY1888	GEZUC	320	4	22:51:	25

Figure 4.80 – Arrival Flight schedule with Aircraft Size

4.5.2 Phase Three stand allocation

Flight No	Aircraft Reg	Aircraft Type	Aircraft Size	ATA	Original Stand	Proposed Stand
EZY1856	GEZUG	320	4	00:47:	25	Original
LS918	GLSAB	75W	7	01:24:	31	Original
TCX2469	GTCCB	76W	9	04:45:	26	Original
TCX473	GMLJL	332	10	05:03:	29	Original
TCX2033	GFCLJ	752	7	07:47:	27	Original
EY015	A6EYR	332	10	08:25:	32	Original
SK539	SEDIL	M81	4	09:19:	25	Original
LH2500	DAILY	319	4	10:26:	23	Original
TK1993	TCJGI	73H	6	10:27:	27	22
TCX2347	GOMYJ	321	4	11:25:	29	22
LH942	GMIDO	320	4	11:40:	25	Original
LS832	LXSTB	320	4	13:15:	25	Original
TCX2049	GDHJZ	320	4	13:35:	29	27
LS338	GLSAB	75W	7	13:45:	31	Original
EY021	A6EYS	332	10	14:55:	32	Original
LS876	GGDFJ	738	5	15:07:	27	24
TCX2017	GTCCA	76W	9	15:10:	22	Original
AY937	OHLKP	E90	3	16:50:	22	Original
LH2502	DAIPT	320	4	16:55:	27	23
LH946	GMIDO	320	4	17:20:	25	Original
SK2549	SERER	73G	5	17:46:	23	Original
TCX2135	GDHJH	321	4	17:50:	28	Original
SK541	SEDIP	M87	4	18:10:	24	Original
LX380	HBIPS	319	4	18:14:	29	25
TK1995	TCJFI	73H	6	18:52:	27	22
SK4605	LNTUL	73W	6	19:38:	23	Original
4U342	DAGWN	319	4	19:42:	25	Original
LS888	GGDFJ	738	5	21:25:	24	Original
TCX2537	GFCLJ	752	7	21:35:	29	Original
LH2504	DAIPK	320	4	22:42:	26	Original
LS892	GLSAI	752	7	22:45:	23	Original
EZY1888	GEZUC	320	4	22:51:	25	Original

Figure 4.81 – Phase Three Stand Allocation for Arriving Flights

4.5.3 AHU Schedule for Phase Three Departures

Incorporating phase three stand allocation data into the original air handling unit allocation table we can produce an aircraft stand/air handling unit schedule for the departure flights for the same 24 hour period of the 8th April 2012. Figure 4.82 details the schedule displaying the air handling units required for each departing aircraft.

Aircraft Stand/AHU Schedule - Departures 8th April 2012 Phase 3															
flight No	Aicraft type	Aircraft Reg.	Origin	STD	ETD	ATD	stand		Air Handling Unit (AHU) Required						
TCX2016	76W	GTCCA	NBE	06:00:	06:00:	05:57:	32		34			38	43	44	45
EZY1971	320	GEZUC	PFO	07:00:	07:00:	07:00:	27		34			38			
LS791	738	GGDFF	FCO	07:00:	07:00:	07:00:	28		34			38	43	44	45
LH949	320	GMIDO	FRA	07:05:	07:05:	07:05:	24		34		37	38			
LS2125	733	GCELC	CMF	06:55:	06:55:	07:25:	23		34						
EZY1923	320	GEZUG	AGP	07:20:	07:20:	07:29:	25		34			38			
LS337	75W	GLSAB	CMF	08:00:	08:00:	08:17:	31		34			38	43	44	45
LS937	752	GLSAA	PFO	09:00:	09:00:	08:58:	22		34	35					
TCX2536	752	GFCLJ	SSH	09:10:	09:10:	09:14:	27		34			38			
EY016	332	A6EYR	AUH	09:25:	09:25:	09:20:	32		34			38	43	44	45
SK540	M81	SEDIL	CPH	10:15:	10:15:	10:15:	25		34			38			
LH2501	319	DAILY	MUC	11:00:	11:00:	11:06:	23		34						
TK1994	73H	TCJGI	IST	11:15:	11:25:	11:23:	22		34	35					
LH943	320	GMIDO	FRA	12:35:	12:35:	12:27:	25		34			38			
TCX2318	321	GOMYJ	ACE	12:45:	12:45:	12:35:	22		34	35					
TCX2548	76W	GTCCB	AYT	13:55:	13:55:	13:50:	26		34		37	38			
LS126C	75W	GLSAB	DUB	14:40:	14:40:	14:34:	31		34			38	43	44	45
TCX2466	320	GDHJZ	PFO	14:45:	14:55:	15:07:	27		34			38			
LS887	738	GGDFJ	PRG	16:00:	16:10:	16:11:	24		34		37	38			
TCX2456	76W	GTCCA	TFS	15:30:	16:30:	16:35:	22		34	35					
LS703	320	LXSTB	CDG	17:00:	17:00:	16:56:	25		34			38			
LH2503	320	DAIPT	MUC	17:25:	17:45:	17:34:	23		34						
AY938	E90	OHLKP	HEL	17:50:	17:50:	17:50:	22		34	35					
LH947	320	GMIDO	FRA	18:15:	18:15:	18:07:	25		34			38			
SK2550	73G	SERER	ARN	18:35:	18:35:	18:28:	23		34						
SK542	M87	SEDIP	CPH	19:10:	18:55:	18:55:	24		34		37	38			
LX381	319	HBIPS	ZRH	18:50:	19:00:	19:01:	25		34			38			
TK1996	73H	TCJFI	IST	15:55:	19:43:	19:56:	22		34	35					
4U343	319	DAGWN	CGN	20:15:	20:15:	20:14:	25		34			38			
SK4606	73W	LNTUL	BGO	20:35:	20:35:	20:25:	23		34						
EY022	332	A6EYS	AUH	21:05:	20:50:	20:48:	32		34			38	43	44	45

Figure 4.82 – Phase Three Aircraft Stand/AHU Schedule for 8th April 2012 Departures

4.5.4 AHU Schedule for Phase Three Arrivals

Incorporating phase three stand allocation data into the original air handling unit allocation table we can produce an aircraft stand/air handling unit schedule for the arrival flights for the same 24 hour period of the 8th April 2012. Figure 4.83 details the schedule displaying the air handling units required for each arriving aircraft.

Aircraft Stand/AHU Schedule - Arrivals 8th April 2012 Phase 3															
flight No	Aicraft typ	Aircraft Reg.	Origin	STA	ETA	ATA	stand		Air Handling Unit (AHU) Required						
EZY1856	320	GEZUG	SSH	00:40:	00:45:	00:47:	25								
LS918	75W	GLSAB	TFS	00:55:	01:05:	01:24:	31			35	37		43		
TCX2469	76W	GTCCB	BJL	04:45:	04:45:	04:45:	26			35	37				
TCX473	332	GMLJL	SFB	05:25:	05:05:	05:03:	29			35	37		43		
TCX2033	752	GFCLJ	RHO	07:40:	07:36:	07:47:	27								
EY015	332	A6EYR	AUH	07:25:	07:16:	08:25:	32			35	37		43		
SK539	M81	SEDIL	CPH	09:30:	09:30:	09:19:	25								
LH2500	319	DAILY	MUC	10:10:	10:20:	10:26:	23								
TK1993	73H	TCJGI	IST	10:15:	10:26:	10:27:	22								
TCX2347	321	GOMYJ	ILD	11:30:	11:20:	11:25:	22								
LH942	320	GMIDO	FRA	11:50:	11:45:	11:40:	25								
LS832	320	LXSTB	PMI	13:20:	13:10:	13:15:	25								
TCX2049	320	GDHJZ	AGP	13:35:	13:30:	13:35:	27								
LS338	75W	GLSAB	CMF	13:05:	13:40:	13:45:	31			35	37		43		
EY021	332	A6EYS	AUH	15:05:	14:55:	14:55:	32			35	37		43		
LS876	738	GGDFJ	FAO	15:00:	15:00:	15:07:	24			35					
TCX2017	76W	GTCCA	NBE	14:00:	14:58:	15:10:	22								
AY937	E90	OHLKP	HEL	16:55:	16:42:	16:50:	22								
LH2502	320	DAIPT	MUC	16:45:	16:50:	16:55:	23								
LH946	320	GMIDO	FRA	17:30:	17:20:	17:20:	25								
SK2549	73G	SERER	ARN	17:55:	17:50:	17:46:	23								
TCX2135	321	GDHJH	ACE	17:50:	17:15:	17:50:	28			35	37		43		
SK541	M87	SEDIP	CPH	18:30:	18:20:	18:10:	24			35					
LX380	319	HBIPS	ZRH	18:10:	18:25:	18:14:	25								
TK1995	73H	TCJFI	IST	15:05:	18:43:	18:52:	22								
SK4605	73W	LNTUL	BGO	19:45:	19:30:	19:38:	23								
4U342	319	DAGWN	CGN	19:45:	19:32:	19:42:	25								
LS888	738	GGDFJ	PRG	21:20:	21:22:	21:25:	24			35					
TCX2537	752	GFCLJ	SSH	21:50:	21:20:	21:35:	29			35	37		43		
LH2504	320	DAIPK	MUC	23:00:	22:40:	22:42:	26			35	37				
LS892	752	GLSAI	ACE	23:20:	22:40:	22:45:	23								
EZY1888	320	GEZUC	MUC	23:00:	22:46:	22:51:	25								

Figure 4.83 - Phase Three Aircraft Stand/AHU Schedule for 8th April 2012 Arrivals

4.5.5 Chronological flight Order

Incorporating both the departure and arrival AHU schedules with the gating rules, a chronological flight order can be produced. This operational schedule will not only determine which plants are required for each departure and arrival journey, but will also determine when and which plants can be disabled without effecting the passenger comfort conditions being provided.

Figure 4.84 displays the Phase Three operational schedule and details the time periods required for each individual Air Handling Unit. This data can then be used in conjunction with the available data from phase One to create the hypothetical kWh and Co2 emission readings for Phase Three operational relationship.

Type	Time	Stand		AHU							Time On	Time Off
Arr	00:47:	25									Not Required	
Arr	01:24:	31			35	37		43			01:09	01:54
Arr	04:45:	26			35	37					04:30	05:15
Arr	05:03:	29			35	37		43			04:48	05:33
Dep	05:57:	32		34			38	43	44	45	04:57	05:57
Dep	07:00:	27		34			38				06:00	07:00
Dep	07:00:	28		34			38	43	44	45	06:00	07:00
Dep	07:05:	24		34		37	38				06:05	07:05
Dep	07:25:	23		34							06:25	07:25
Dep	07:29:	25		34			38				06:29	07:29
Arr	07:47:	27									Not Required	
Dep	08:17:	31		34			38	43	44	45	07:17	08:17
Arr	08:25:	32			35	37		43			08:10	08:55
Dep	08:58:	22		34	35						07:58	08:58
Dep	09:14:	27		34			38				08:14	09:14
Arr	09:19:	25									Not Required	
Dep	09:20:	32		34			38	43	44	45	08:20	09:20
Dep	10:15:	25		34			38				09:15	10:15
Arr	10:26:	23									Not Required	
Arr	10:27:	22									Not Required	
Dep	11:06:	23		34							10:06	11:06
Dep	11:23:	22		34	35						10:23	11:23
Arr	11:25:	22									Not Required	
Arr	11:40:	25									Not Required	
Dep	12:27:	25		34			38				11:27	12:27
Dep	12:35:	22		34	35						11:35	12:35
Arr	13:15:	25									Not Required	
Arr	13:35:	27									Not Required	
Arr	13:45:	31			35	37		43			13:30	14:15
Dep	13:50:	26		34		37	38				12:50	13:50
Dep	14:34:	31		34			38	43	44	45	13:34	14:34
Arr	14:55:	32			35	37		43			14:40	15:25
Dep	15:07:	27		34			38				14:07	15:07
Arr	15:07:	24			35						14:52	15:37
Arr	15:10:	22									Not Required	
Dep	16:11:	24		34		37	38				15:11	16:11
Dep	16:35:	22		34	35						15:35	16:35
Arr	16:50:	22									Not Required	
Arr	16:55:	23									Not Required	
Dep	16:56:	25		34			38				15:56	16:56
Arr	17:20:	25									Not Required	
Dep	17:34:	23		34							16:34	17:34
Arr	17:46:	23									Not Required	
Dep	17:50:	22		34	35						16:50	17:50
Arr	17:50:	28			35	37		43			17:35	18:20
Dep	18:07:	25		34			38				17:07	18:07
Arr	18:10:	24			35						17:55	18:40
Arr	18:14:	25									Not Required	
Dep	18:28:	23		34							17:28	18:28
Arr	18:52:	22									Not Required	
Dep	18:55:	24		34		37	38				17:55	18:55
Dep	19:01:	25		34			38				18:01	19:01
Arr	19:38:	23									Not Required	
Arr	19:42:	25									Not Required	
Dep	19:56:	22		34	35						18:56	19:56
Dep	20:14:	25		34			38				19:14	20:14
Dep	20:25:	23		34							19:25	20:25
Dep	20:48:	32		34			38	43	44	45	19:48	20:48
Arr	21:25:	24			35						21:10	21:55
Arr	21:35:	29			35	37		43			21:20	22:05
Arr	22:42:	26			35	37					22:27	23:12
Arr	22:45:	23									Not Required	
Arr	22:51:	25									Not Required	

Figure 4.84 – Phase Three Schedule of Operation

4.5.6 Phase Three Electrical Consumption

4.5.6.1 AHU 34

Figure 4.85 displays the operational hours run for Air Handling Unit 34 during the phase three operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation which is created by enabling and disabling the air conditioning plant in occupancy periods only. The occupancy period is derived from the phase three stand allocation procedure.

AHU	Enable (Time)	Disable (Time)	Run hrs.
34	04:57	12:35	**07:38**
	12:50	20:48	**07:58**
		Total	**15:36**

Figure 4.85 – AHU Phase Three Operational Hours

Figure 4.86 displays the energy consumption of AHU 34 during both the phase one, two and three system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	% Saving (From Phase One)
AHU 34	Supply	11	7.4	177.6	114.7	114.7	35
AHU 34	Extract	1.1	1.1	26.4	17.1	17.1	35
Estimated Run Hrs		*15hrs 36mins*					

Figure 4.86 – AHU 34 Phase Three electrical motor consumption

4.5.6.2 AHU 35

Figure 4.87 displays the operational hours run for Air Handling Unit 34 during the phase three operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation which is created by enabling and disabling the air conditioning plant in occupancy periods only. The occupancy period is derived from the phase three stand allocation procedure.

AHU	Enable (Time)	Disable (Time)	Run hrs.
35	01:09	01:54	**00:45**
	04:30	05:33	**01:03**
	08:10	08:58	**00:48**
	10:23	12:35	**02:12**
	13:30	14:15	**00:45**
	14:40	16:35	**01:55**
	16:50	18:40	**01:50**
	18:56	19:56	**01:00**
	21:10	22:05	**00:55**
	22:27	23:12	**00:45**
		Total	**11:58**

Figure 4.87 – AHU 35 Operational Hours Run

Figure 4.88 displays the energy consumption of AHU 35 during both the phase one, two and three system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	% Saving (From Phase One)
AHU 35	Supply	11	7.3	175.2	69.4	87.6	50
AHU 35	Extract	1.1	1.1	26.4	10.5	13.2	50
Estimated Run Hrs		*11hrs 58mins*					

Figure 4.88 – AHU 35 Phase Three electrical motor consumption

4.5.7 AHU 37

Figure 4.89 displays the operational hours run for Air Handling Unit 37 during the phase three operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation which is created by enabling and disabling the air conditioning plant in occupancy periods only. The occupancy period is derived from the phase three stand allocation procedure.

AHU	Enable (Time)	Disable (Time)	Run hrs.
37	01:09	01:54	**00:45**
	04:30	05:33	**01:03**
	06:05	07:05	**01:00**
	08:10	08:55	**00:45**
	12:50	14:15	**01:25**
	14:40	16:11	**01:31**
	17:35	18:55	**01:20**
	21:20	22:05	**00:45**
	22:27	23:12	**00:45**
		Total	**09:19**

Figure 4.89 – AHU 37 Phase Three Operational Hours

Figure 4.90 displays the energy consumption of AHU 37 during both the phase one, two and three system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

`	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	% Saving (From Phase One)
AHU 37	Supply	11	7.4	177.6	69.0	69.0	61
AHU 37	Extract	1.1	1.1	26.4	10.3	10.3	61
Estimated Run Hrs		*9hrs 19mins*					

Figure 4.90 – AHU 37 Phase Three electrical motor consumption

4.5.8 AHU 38

Figure 4.91 displays the operational hours run for Air Handling Unit 38 during the phase three operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation which is created by enabling and disabling the air conditioning plant in occupancy periods only. The occupancy period is derived from the phase three stand allocation procedure.

AHU	Enable (Time)	Disable (Time)	Run hrs.
38	04:57	10:15	**05:18**
	11:27	12:27	**01:00**
	12:50	20:48	**07:58**
		Total	**14:16**

Figure 4.91 – AHU 38 Phase Three Operational hours

Figure 4.92 displays the energy consumption of AHU 38 during both the phase one, two and three system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	% Saving (From Phase One)
AHU 38	Supply	11	7.4	177.6	114.7	105.5	41
AHU 38	Extract	1.1	1.1	26.4	17.1	15.7	41
Estimated Run Hrs		*14hrs 16mins*					

Figure 4.92 – AHU 38 Phase Three electrical motor consumption

4.5.9 AHU 43

Figure 4.93 displays the operational hours run for Air Handling Unit 43 during the phase three operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation which is created by enabling and disabling the air conditioning plant in occupancy periods only. The occupancy period is derived from the phase three stand allocation procedure.

AHU	Enable (Time)	Disable (Time)	Run hrs.
43	01:09	01:54	**00:45**
	04:48	07:00	**02:12**
	07:17	09:20	**02:03**
	13:30	15:25	**01:55**
	17:35	18:20	**00:45**
	19:48	20:48	**01:00**
	21:20	22:05	**00:45**
		Total	**09:25**

Figure 4.93 – AHU 43 Phase Three Operational Hours

Figure 4.94 displays the energy consumption of AHU 43 during both the phase one, two and three system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	% Saving (From Phase One)
AHU 43	Supply	3	1.3	31.2	15.1	12.4	60
AHU 43	Extract	3	3.4	81.6	39.4	32.3	60
Estimated Run Hrs		*9hrs 25mins*					

Figure 4.94 – AHU 43 Phase Three electrical motor consumption

4.5.10 AHU 44

Figure 4.95 displays the operational hours run for Air Handling Unit 44 during the phase three operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation which is created by enabling and disabling the air conditioning plant in occupancy periods only. The occupancy period is derived from the phase three stand allocation procedure.

AHU	Enable (Time)	Disable (Time)	Run hrs.
44	04:57	07:00	**02:03**
	07:17	09:20	**02:03**
	13:34	14:34	**01:00**
	19:48	20:48	**01:00**
		Total	**06:06**

Figure 4.95 – AHU 44 Phase Three Operational Hours

Figure 4.96 displays the energy consumption of AHU 44 during both the phase one, two and three system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	% Saving (From Phase One)
AHU 44	Supply	15	10.0	240.0	86.0	60	75
AHU 44	Extract	7.5/1.9	5.0	120.0	43.0	30	75
Estimated Run Hrs		*6hrs 6mins*					

Figure 4.96 – AHU44 Phase Three electrical motor consumption

4.5.11 AHU 45

Figure 4.97 displays the operational hours run for Air Handling Unit 45 during the phase three operational cycle. The hours run is derived from the hypothetical relationship between the systems and operation which is created by enabling and disabling the air conditioning plant in occupancy periods only. The occupancy period is derived from the phase three stand allocation procedure.

AHU	Enable (Time)	Disable (Time)	Run hrs.
45	04:57	07:00	**02:03**
	07:17	09:20	**02:03**
	13:34	14:34	**01:00**
	19:48	20:48	**01:00**
		Total	**06:06**

Figure 4.97 – AHU 45 Phase Three Operational Hours

Figure 4.98 displays the energy consumption of AHU 45 during both the phase one, two and three system/operation relationships. Phase one results have been included for a visual comparison and to show any potential savings/increase.

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	% Saving (From Phase One)
AHU 45	Supply	15	10.0	240.0	86.0	60	75
AHU 45	Extract	7.5/1.9	8.8	211.2	75.7	52.8	75
Estimated Run Hrs		*6hrs 6mins*					

Figure 4.98 – AHU 45 Phase Three electrical motor consumption

4.5.12 Phase Three CO_2 Emissions

In order to evaluate the gas emissions from the electricity used by the temperature control plant, the derived data has to be converted into CO_2 emissions. The Department for Environment Food & Rural Affairs (DEFRA) publish conversion factors for organisations to report their emissions from different sources.

Organisations are required to report the electricity used on sites that are under their control. These reports are classified as scope 2 indirect emissions. DEFRA also publish factors for scope 3 emissions which are not directly under the organisations control. DEFRA advise organisations to include the scope 3 results which are *transmission and distribution* (T&D) losses of electricity they purchase, which occur between the power station and their particular site. The separate *transmission and distribution* losses are usually reported separate from the scope 2 results.

The conversion factors cover individual GHG including CO_2, CH_4 & N_2O and a combined factor of CO_2e. For the purpose of graphical representation of emissions throughout the research, the kg CO_2 factor within the scope 2 *Electricity generated* will be calculated and displayed only. Figures 4.99 & 4.100 display the conversion tables published from DEFRA.

Activity	Country	Unit	Year	kg CO_2e	**kg CO_2**	kg CH_4	kg N_2O
Electricity generated	Electricity: UK	kWh	2013	0.44548	**0.44238**	0.00029	0.00281

Figure 4.99 – DEFRA Scope 2 electricity generated factor

Source: www.ukconversionfactorscarbonsmart.co.uk June 22nd 2013

Activity	Type	Unit	Year	kg CO_2e	kg CO_2	kg CH_4	kg N_2O
T&D- UK electricity	Electricity: UK	kWh	2013	0.03809	0.03783	0.00002	0.00024

Figure 4.100 – DEFRA Scope 3 Transmission & Distribution factor

Source: www.ukconversionfactorscarbonsmart.co.uk June 22nd 2013

The hypothetical phase three relationship between the temperature control and stand allocation management has been examined and the results of the emissions from the individual plant can be calculated. Phase three creates the relationship that provides comfort conditions to the designated areas during required occupancy periods only. The phase three AHU/Stand allocation schedule has been recreated by evaluating the stand allocation management and relocating specific aircraft types where feasible to a more efficient location. CO_2 emissions have been calculated for the individual air conditioning plants for comparison with phase one and phase three analysis results.

4.5.12.1 AHU 34 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	kg CO2/24hrs Phase One	kg CO2/24hrs Phase Two	kg CO2/24hrs Phase Three
AHU 34	Supply	11	7.4	177.6	114.7	114.7	78.6	50.7	50.7
AHU 34	Extract	1.1	1.1	26.4	17.1	17.1	11.7	7.5	7.5
						Totals	**90.2**	**58.3**	**58.3**

Figure 4.101 - Phase Three AHU 34 CO_2 emissions

4.5.12.2 AHU 35 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual (kW)	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	kg CO_2/24hrs Phase One	kg CO_2/24hrs Phase Two	kg CO_2/24hrs Phase Three
AHU 35	Supply	11	7.3	175.2	69.4	87.6	77.5	30.7	38.8
AHU 35	Extract	1.1	1.1	26.4	10.5	13.2	11.7	4.6	5.8
						Totals	**89.2**	**35.3**	**44.6**

Figure 4.102 - Phase Three AHU 35 CO_2 emissions

4.5.12.3 AHU 37 CO_2 Emissions

`	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	kg CO_2/24hrs Phase One	kg CO_2/24hrs Phase Two	kg CO_2/24hrs Phase Three
AHU 37	Supply	11	7.4	177.6	69.0	71.04	78.6	30.5	31.4
AHU 37	Extract	1.1	1.1	26.4	10.3	10.23	11.7	4.5	4.5
						Totals	**90.2**	**35.1**	**35.9**

Figure 4.103 - Phase Three AHU 37 CO_2 emissions

4.5.12.4 AHU 38 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	kg CO_2/24hrs Phase One	kg CO_2/24hrs Phase Two	kg CO_2/24hrs Phase Three
AHU 38	Supply	11	7.4	177.6	114.7	105.45	78.6	50.7	46.6
AHU 38	Extract	1.1	1.1	26.4	17.1	15.675	11.7	7.5	6.9
						Totals	**90.2**	**58.3**	**53.6**

Figure 4.104 - Phase Three AHU 38 CO_2 emissions

4.5.12.5 AHU 43 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	kg CO_2/24hrs Phase One	kg CO_2/24hrs Phase Two	kg CO_2/24hrs Phase Three
AHU 43	Supply	3	1.3	31.2	15.1	12.35	13.8	6.7	5.5
AHU 43	Extract	3	3.4	81.6	39.4	32.3	36.1	17.4	14.3
						Totals	**49.9**	**24.1**	**19.8**

Figure 4.105 - Phase Three AHU 43 CO_2 emissions

4.5.12.6 AHU 44 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	kg CO_2/24hrs Phase One	kg CO_2/24hrs Phase Two	kg CO_2/24hrs Phase Three
AHU 44	Supply	15	10.0	240.0	86.0	60	106.2	38.0	26.5
AHU 44	Extract	7.5/1.9	5.0	120.0	43.0	30	53.1	19.0	13.3
						Totals	**159.3**	**57.1**	**39.8**

Figure 4.106 - Phase Three AHU 44 CO_2 emissions

4.5.12.7 AHU 45 CO_2 Emissions

AHU No.	Fan	motor rating kW	actual kW	kWh/24hrs Phase One	kWh/24hrs Phase Two	kWh/24hrs Phase Three	kg CO_2/24hrs Phase One	kg CO_2/24hrs Phase Two	kg CO_2/24hrs Phase Three
AHU 45	Supply	15	10.0	240.0	86.0	60	106.2	38.0	26.5
AHU 45	Extract	7.5/1.9	8.8	211.2	75.7	52.8	93.4	33.5	23.4
						Totals	**199.6**	**71.5**	**49.9**

Figure 4.107 - Phase Three AHU 45 CO_2 emissions

4.5.13 Phase three relationship simulation

A simulation model was created from the data to provide a graphical representation of the hypothetical relationship between the services provided and the hypothetical building operation. The simulation was created to compliment the accumulated data. (The simulation provides a greater insight into the relationship for non-technical personnel). The simulation is an exact replication of the flight activity associated with the 24 hour period of the 8th April 2012. The simulation incorporates the colour coding associated with each individual air handling unit zone which is detailed in figure 4.33 to clearly display when a specific zone is being comfort conditioned.

The simulation model has a time frame of 24 minutes which relates to the timescale of 1min simulation is the equivalent of 1 hour actual activity.(1 second/1 minute). The full simulation is available and can be viewed on the accompanying compact disc located within Appendix A.

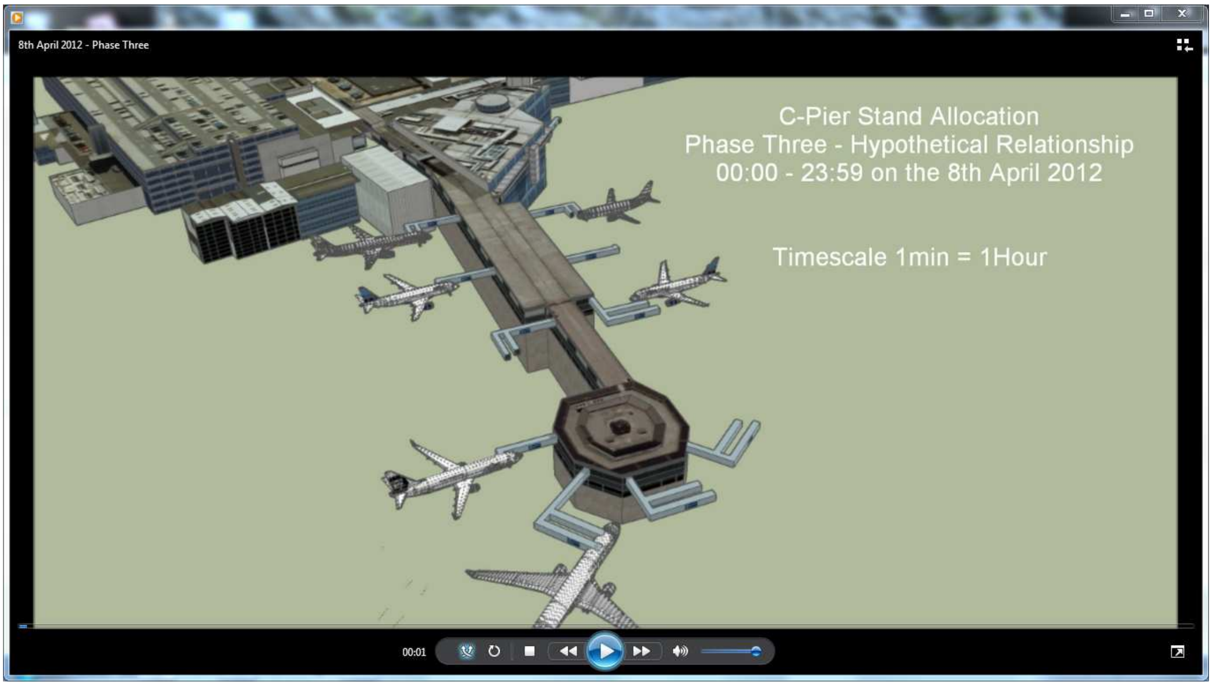


Figure 4.108 – Phase three simulation screenshot

5.0 DISCUSSION AND CONCLUSION

5.1 INTRODUCTION

This chapter discusses the overall findings from the existing and hypothetical relationships performed and the contributions of this research. The findings provide insights into the effect different interaction between systems and operations can have on the efficiency of a building. The contribution of this research to the knowledge in the fields of building efficiency and information systems integration is presented towards the end of this chapter. A review of the original research objectives and questions are discussed to evaluate whether they have been answered. The contributions are highlighted from the perspective of the theoretical and practical aspects. This thesis concludes with recommendations for future research work.

5.2 DISCUSSION OF THE FINDINGS WITHIN THE VARIOUS RELATIONSHIP PHASES

Phase one is the analysis of the existing relationship between services and operations. The temperature control plants and the stand allocation management form part of the Airports operational cycle. This research is interested in the effect this relationship can have on efficiency of this cycle. The efficiency will be measured by the energy consumption of the temperature control plant motors during the operational periods.

Phase one originally analysed the energy consumption for all temperature control plant associated within the specific area of International C-Pier. Subsequent analysis during phase two discovered certain plants incorporated within phase one research data did not form part of the required AHU/Stand schedule. Therefore this data has been eliminated from the research data evaluated within phase two and three analysis and also the final conclusion.

Figure 5.1 displays a multi bar chart of the electrical consumption of AHU 34 from the three different stages of analysis. The results of the Phase two analysis highlight a significant reduction in electrical usage, by a figure of 35%. This reduction was created by improving the interaction between the services provided and the stand allocation operation. The relationship was improved by incorporating the available flight information data into an operational schedule for the temperature control units. The introduction of the operational schedule reduced the running hours of the plant from 24 hours to 15 hours 36 minutes. With the introduction of the AHU/Stand schedule the reduced operating hours still maintained the comfort conditions required for the specific passenger routes to the allocated stands. Phase three analysis revealed no change in data figures from phase two results. This is due to the location of the specific area being comfort conditioned by AHU 34. AHU 34 is required for provision of comfort conditions for all routes to the departure gates, and is not required for any arrival routes. This can be seen in the departure/arrival AHU schedules in figures 4.45 & 4.46 in section 4. Therefore the hypothetical operational adjustment applied within phase three would not have any effect on the individual electrical consumption results of AHU34

Figure 5.2 displays a multi bar chart of the calculated CO_2 emissions from the three different stages of analysis. The graph displays the existing and hypothetical quantity of emissions from the operational hours of AHU 34 during the three different relationship phases. The emission analysis results are derived from the kWh figures obtained from the running hours of the plant. Due to the improved relationship between services and operations for AHU 34, the reduction rate of the emissions from the specific plant will therefore mirror the consumption reduction figure of 35%,

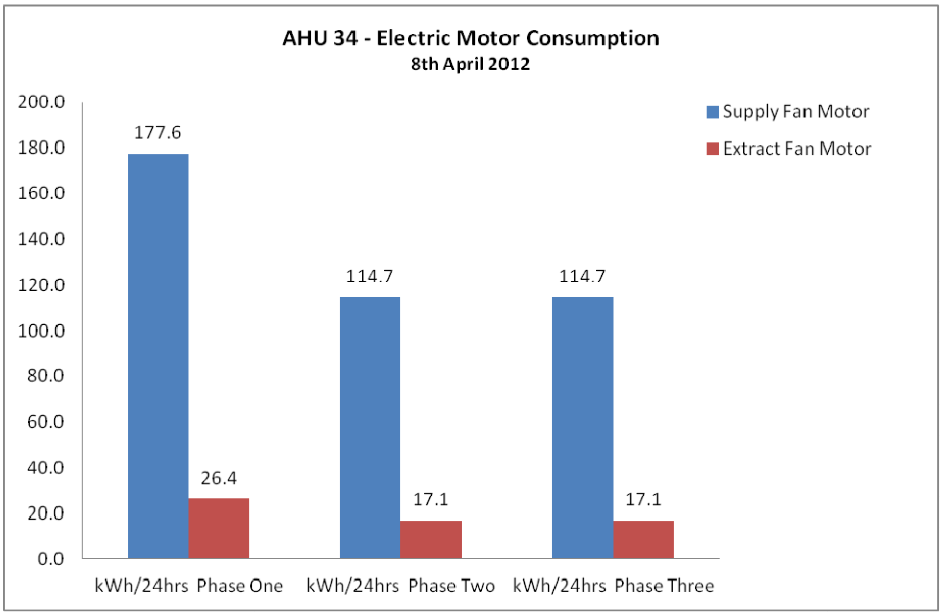


Figure 5.1 - AHU 34 Electrical Consumption

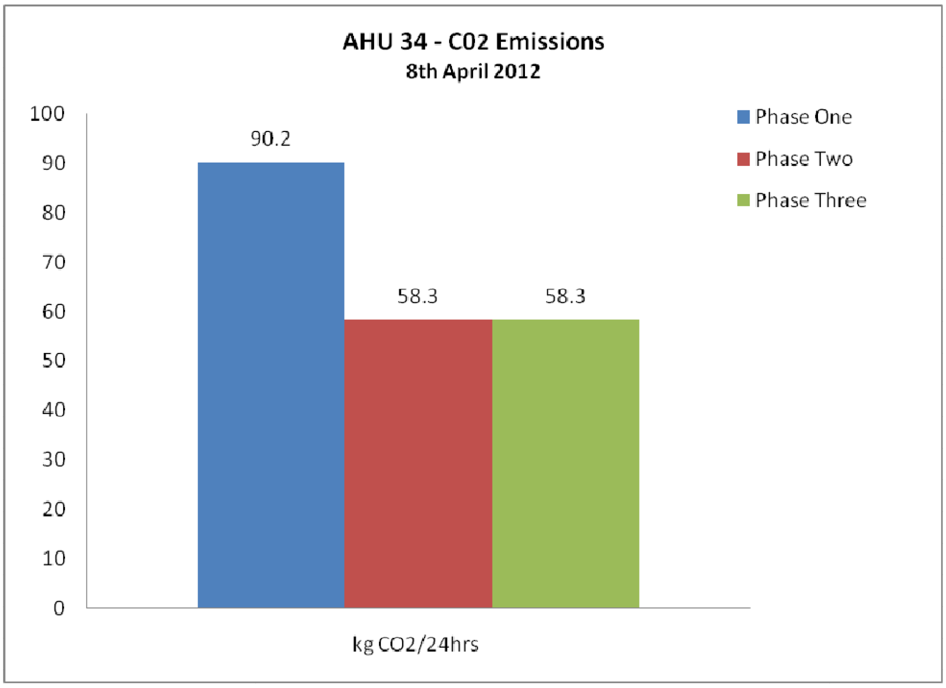


Figure 5.2 – AHU 34 CO_2 Emissions

Figure 5.3 displays a multi bar chart of the electrical consumption of AHU 35 from the three different stages of analysis. The results of the Phase two analysis highlight a significant reduction in electrical usage, by a figure of 60%. This reduction was created by improving the interaction between the services provided and the stand allocation operation. The relationship was improved by incorporating the available flight information data into an operational schedule for the temperature control units. The introduction of the operational schedule reduced the running hours of the plant from 24 hours to 9 hours 35 minutes. With the introduction of the AHU/Stand schedule the reduced operating hours still maintained the comfort conditions required for the specific passenger routes to the allocated stands. Phase three analysis revealed a 50% reduction in electrical consumption from phase one, but a 10% increase from phase two. This is due to the location of the specific area being comfort conditioned by AHU 35. AHU 35 is required for provision of comfort conditions for the passenger route to the departure gate 22 only, and is required for the arrival routes from stands 24, 26, 28, 29, 31 and 32. This can be seen in the departure/arrival AHU schedules in figures 4.45 & 4.46 in section 4. The re-scheduling of aircraft allocation in phase three has actually increased the operational hours of AHU 35 from phase two results to an operational time of 15 hours 36 minutes. Consideration must be given to the overall results of the combined relationship as a whole between services and operation as well as the plants individually. The efficiency of the relationship will be determined by the phase results as a whole and not by individual plant performance. The re-scheduling of aircraft to incorporate the use of AHU 35 in an increased capacity allows the function to disable further additional plants that would have been in operation within the original aircraft allocation. Therefore the increase in operation of AHU 35 has allowed a decrease in other plants operation whilst maintaining the required comfort conditions for passenger routes for the specific flights.

Figure 5.4 displays a multi bar chart of the calculated CO_2 emissions from the three different stages of analysis. The graph displays the existing and hypothetical quantity of emissions from the operational hours of AHU 35 during the three different relationship phases. The emission analysis results are derived from the kWh figures obtained from the running hours of the plant. Due to the improved relationship between services and operations for AHU 35, the reduction rate of the emissions from the specific plant will therefore mirror the consumption reduction figure of 60% for phase one and 50% for phase two.

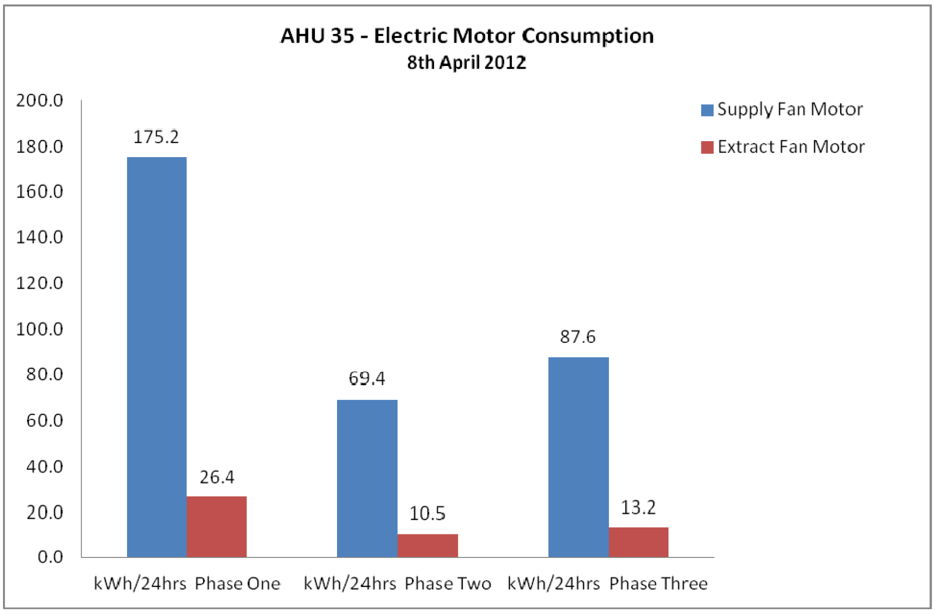


Figure 5.3 – AHU 35 Electrical Consumption

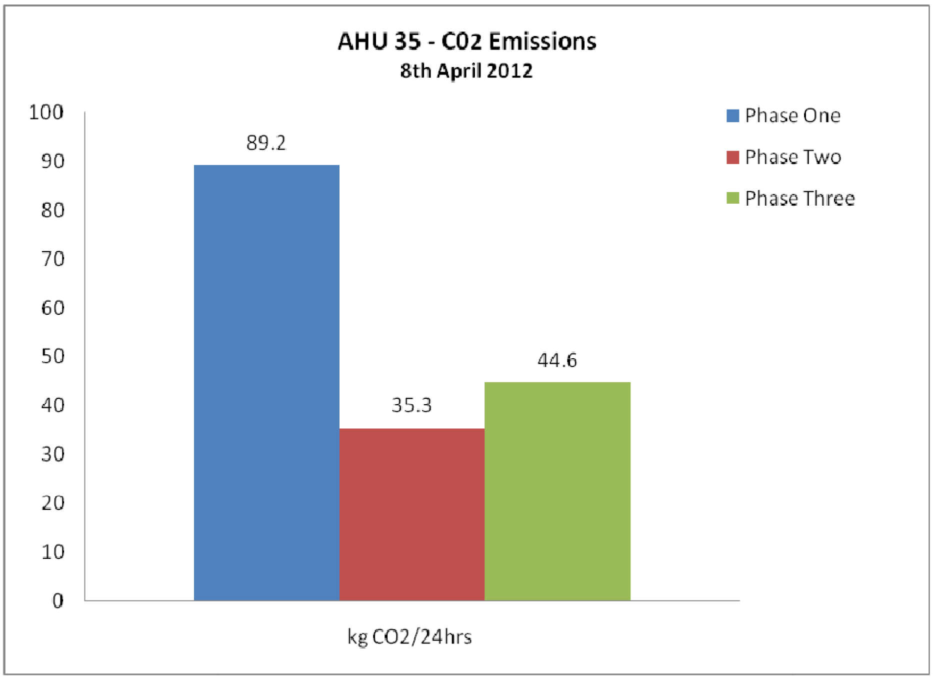


Figure 5.4 – AHU 35 CO_2 Emissions

Figure 5.5 displays a multi bar chart of the electrical consumption of AHU 37 from the three different stages of analysis. The results of the Phase two analysis highlight a significant reduction in electrical usage, by a figure of 61%. This reduction was created by improving the interaction between the services provided and the stand allocation operation. The relationship was improved by incorporating the available flight information data into an operational schedule for the temperature control units. The introduction of the operational schedule reduced the running hours of the plant from 24 hours to 9 hours 18 minutes. With the introduction of the AHU/Stand schedule the reduced operating hours still maintained the comfort conditions required for the specific passenger routes to the allocated stands. Phase three analysis also revealed a 61% reduction in electrical consumption from phase one. This is due to the location of the specific area being comfort conditioned by AHU 37. AHU 37 is required for provision of comfort conditions for the passenger route to the departure gates 24 and 26, and is required for the arrival routes from stands 26, 28, 29, 31, and 32. This can be seen in the departure/arrival AHU schedules in figures 4.45 & 4.46 in section 4. The re-scheduling of aircraft allocation in phase three has actually maintained the virtually the same operational hours of AHU 37, with a slight increase of one minute from phase two results to an operational time of 9 hours 19 minutes. Consideration must be given to the overall results of the combined relationship as a whole between services and operation as well as the plants individually. The efficiency of the relationship will be determined by the phase results as a whole and not by individual plant performance. The re-scheduling of aircraft has allowed a decrease in operation hours of AHU 37 whilst maintaining the required comfort conditions for passenger routes for the specific flights.

Figure 5.6 displays a multi bar chart of the calculated CO_2 emissions from the three different stages of analysis. The graph displays the existing and hypothetical quantity of emissions from the operational hours of AHU 37 during the three different relationship phases. The emission analysis results are derived from the kWh figures obtained from the running hours of the plant. Due to the improved relationship between services and operations for AHU 37, the reduction rate of the emissions from the specific plant will therefore mirror the consumption reduction figure of 61% from phase one.

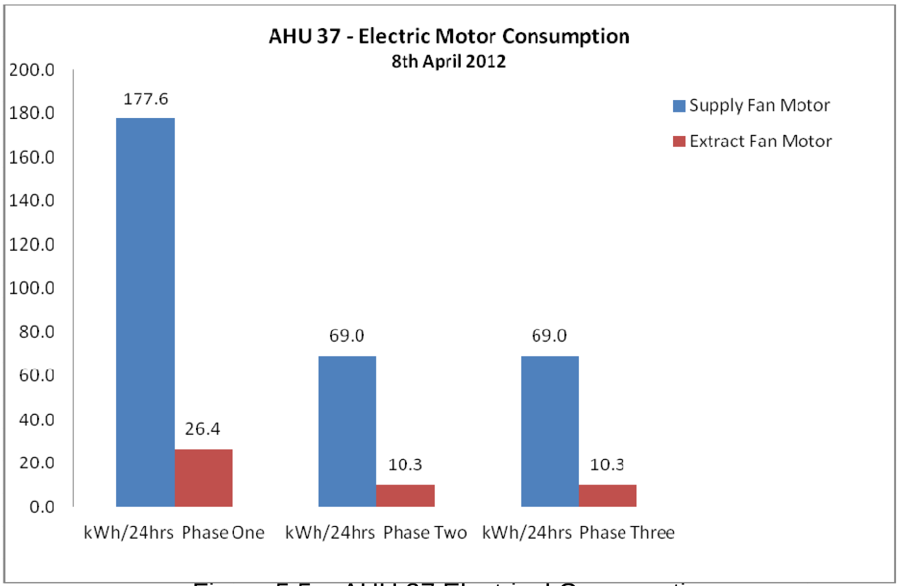


Figure 5.5 – AHU 37 Electrical Consumption

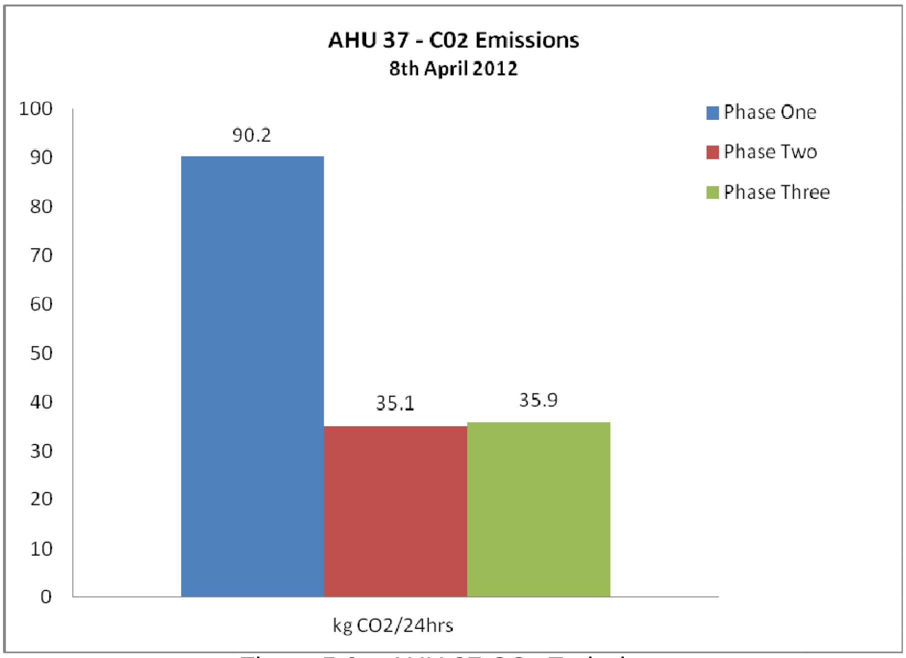


Figure 5.6 – AHU 37 CO_2 Emissions

Figure 5.7 displays a multi bar chart of the electrical consumption of AHU 38 from the three different stages of analysis. The results of the Phase two analysis highlight a significant reduction in electrical usage, by a figure of 35%. This reduction was created by improving the interaction between the services provided and the stand allocation operation. The relationship was improved by incorporating the available flight information data into an operational schedule for the temperature control units. The introduction of the operational schedule reduced the running hours of the plant from 24 hours to 15 hours 36 minutes. With the introduction of the AHU/Stand schedule the reduced operating hours still maintained the comfort conditions required for the specific passenger routes to the allocated stands. Phase three analysis revealed a 41% reduction in electrical consumption from phase one. This is due to the location of the specific area being comfort conditioned by AHU 38. AHU 38 is required for provision of comfort conditions for the passenger route to the departure gates 24, 25, 26, 27, 28, 29, 31, and 32, and is not required for any arrival routes. This can be seen in the departure/arrival AHU schedules in figures 4.45 & 4.46 in section 4. The re-scheduling of aircraft allocation in phase three has actually decreased the operational hours of AHU 38 from phase two results to an operational time of 14 hours 16 minutes. Consideration must be given to the overall results of the combined relationship as a whole between services and operation as well as the plants individually. The efficiency of the relationship will be determined by the phase results as a whole and not by individual plant performance. The re-scheduling of aircraft has allowed a decrease in operation hours of AHU 38 whilst maintaining the required comfort conditions for passenger routes for the specific flights.

Figure 5.8 displays a multi bar chart of the calculated CO_2 emissions from the three different stages of analysis. The graph displays the existing and hypothetical quantity of emissions from the operational hours of AHU 38 during the three different relationship phases. The emission analysis results are derived from the kWh figures obtained from the running hours of the plant. Due to the improved relationship between services and operations for AHU 38, the reduction rate of the emissions from the specific plant will therefore mirror the consumption reduction figure of 35% for phase one and 41% for phase two.

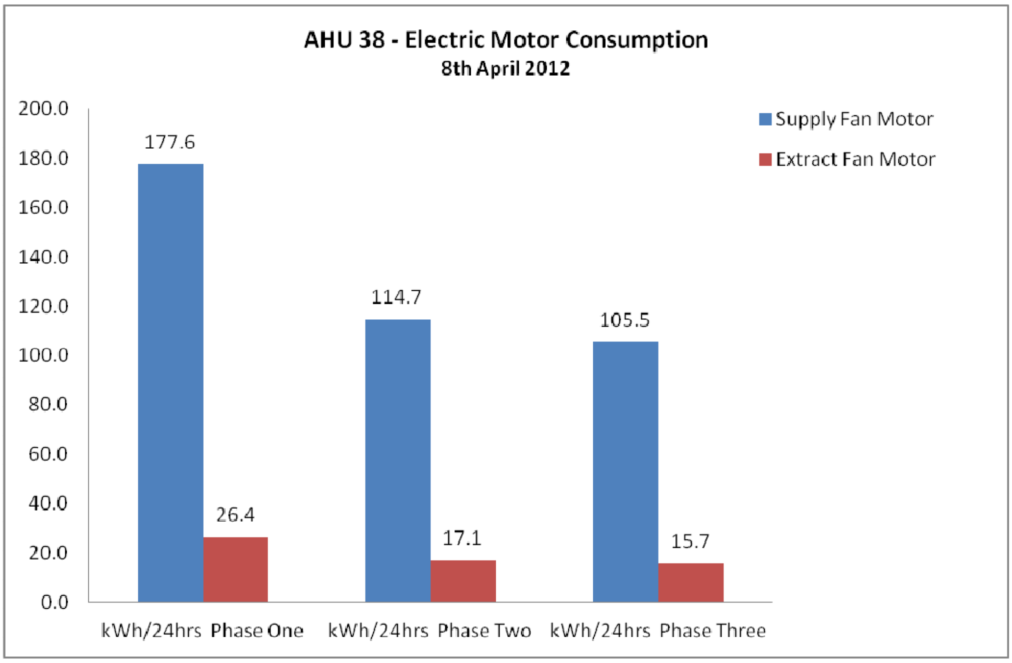


Figure 5.7 – AHU 38 Electrical Consumption

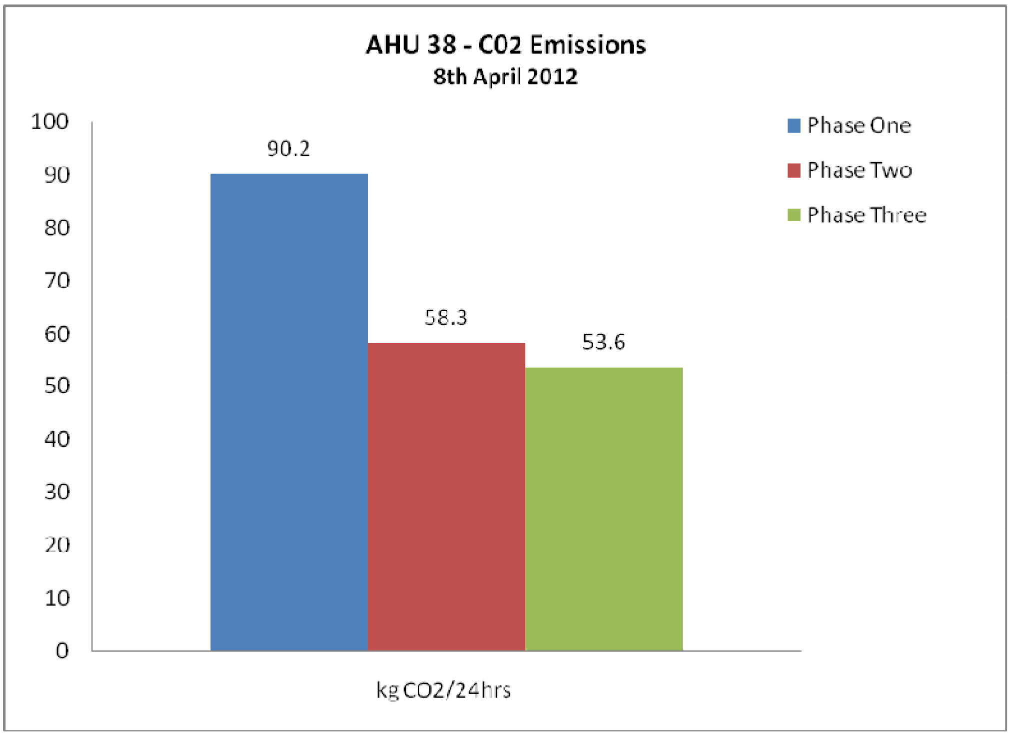


Figure 5.8 – AHU 38 CO_2 Emission

Figure 5.9 displays a multi bar chart of the electrical consumption of AHU 43 from the three different stages of analysis. The results of the Phase two analysis highlight a significant reduction in electrical usage, by a figure of 52%. This reduction was created by improving the interaction between the services provided and the stand allocation operation. The relationship was improved by incorporating the available flight information data into an operational schedule for the temperature control units. The introduction of the operational schedule reduced the running hours of the plant from 24 hours to 11 hours 41 minutes. With the introduction of the AHU/Stand schedule the reduced operating hours still maintained the comfort conditions required for the specific passenger routes to the allocated stands. Phase three analysis revealed a 60% reduction in electrical consumption from phase one. This is due to the location of the specific area being comfort conditioned by AHU 43. AHU 43 is required for provision of comfort conditions for the passenger route to the departure gates 28, 29, 31, and 32, and is required for 28, 29, 31 and 32 arrival routes. This can be seen in the departure/arrival AHU schedules in figures 4.45 & 4.46 in section 4. The re-scheduling of aircraft allocation in phase three has actually decreased the operational hours of AHU 43 from phase two results to an operational time of 9hours 25 minutes. Consideration must be given to the overall results of the combined relationship as a whole between services and operation as well as the plants individually. The efficiency of the relationship will be determined by the phase results as a whole and not by individual plant performance. The re-scheduling of aircraft has allowed a decrease in operation hours of AHU 43 whilst maintaining the required comfort conditions for passenger routes for the specific flights.

Figure 5.10 displays a multi bar chart of the calculated CO_2 emissions from the three different stages of analysis. The graph displays the existing and hypothetical quantity of emissions from the operational hours of AHU 43 during the three different relationship phases. The emission analysis results are derived from the kWh figures obtained from the running hours of the plant. Due to the improved relationship between services and operations for AHU 43, the reduction rate of the emissions from the specific plant will therefore mirror the consumption reduction figure of 52% for phase two and 60% for phase three.

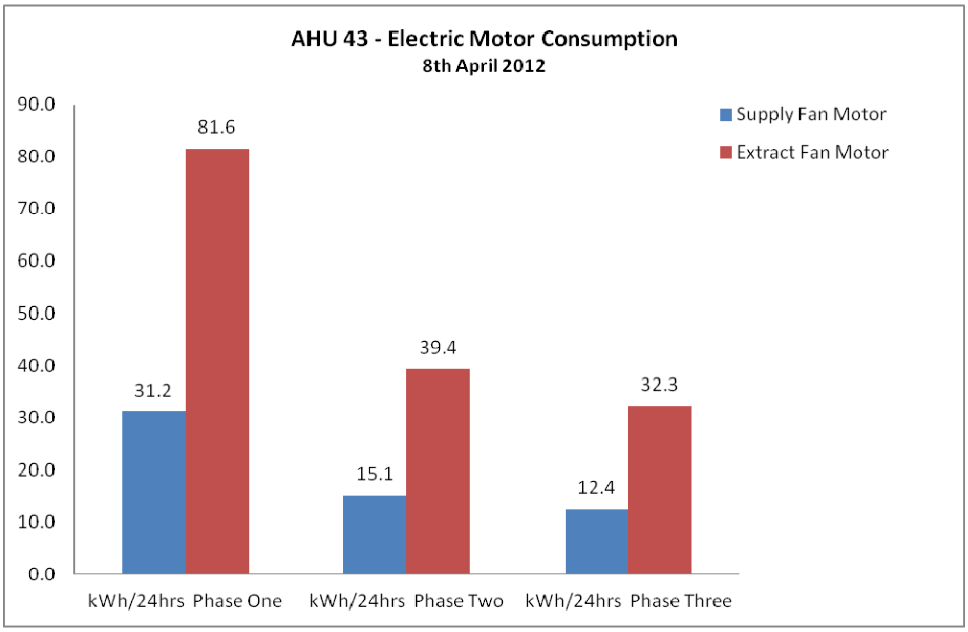


Figure 5.9 – AHU 43 Electrical Consumption

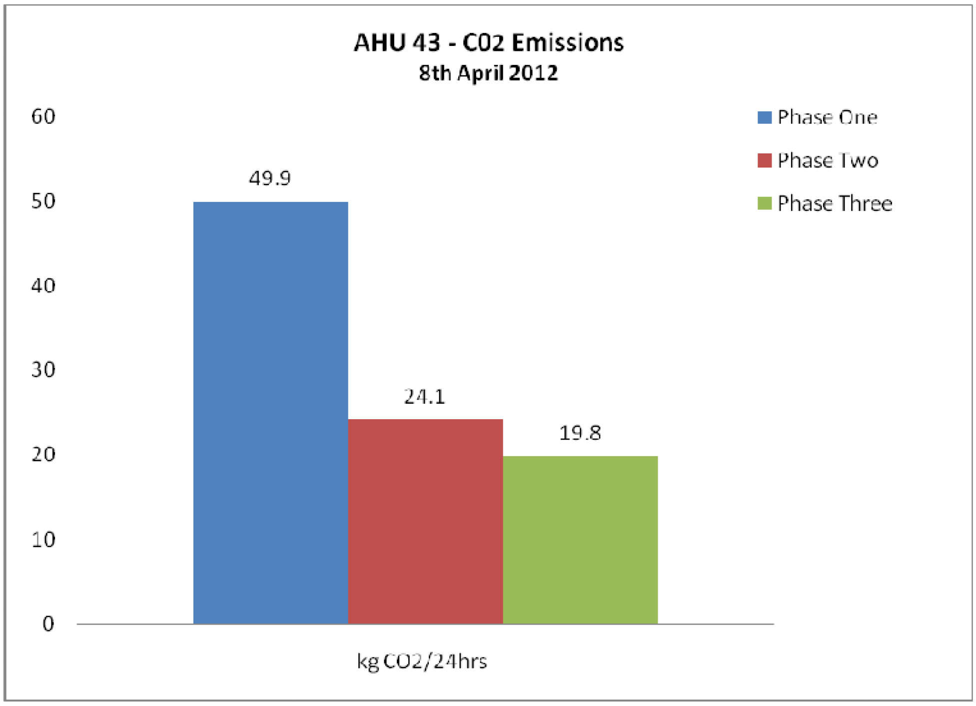


Figure 5.10 – AHU 43 CO_2 Emissions

Figure 511 displays a multi bar chart of the electrical consumption of AHU 44 from the three different stages of analysis. The results of the Phase two analysis highlight a significant reduction in electrical usage, by a figure of 64%. This reduction was created by improving the interaction between the services provided and the stand allocation operation. The relationship was improved by incorporating the available flight information data into an operational schedule for the temperature control units. The introduction of the operational schedule reduced the running hours of the plant from 24 hours to 8 hours 39 minutes. With the introduction of the AHU/Stand schedule the reduced operating hours still maintained the comfort conditions required for the specific passenger routes to the allocated stands. Phase three analysis revealed a 75% reduction in electrical consumption from phase one. This is due to the location of the specific area being comfort conditioned by AHU 44. AHU 44 is required for provision of comfort conditions for the passenger route to the departure gates 28, 29, 31, and 32, and is not required for any arrival routes. This can be seen in the departure/arrival AHU schedules in figures 4.45 & 4.46 in section 4. The re-scheduling of aircraft allocation in phase three has actually decreased the operational hours of AHU 44 from phase two results to an operational time of 6 hours 6 minutes. Consideration must be given to the overall results of the combined relationship as a whole between services and operation as well as the plants individually. The efficiency of the relationship will be determined by the phase results as a whole and not by individual plant performance. The re-scheduling of aircraft has allowed a decrease in operation hours of AHU 44 whilst maintaining the required comfort conditions for passenger routes for the specific flights.

Figure 5.12 displays a multi bar chart of the calculated CO_2 emissions from the three different stages of analysis. The graph displays the existing and hypothetical quantity of emissions from the operational hours of AHU 44 during the three different relationship phases. The emission analysis results are derived from the kWh figures obtained from the running hours of the plant. Due to the improved relationship between services and operations for AHU 44, the reduction rate of the emissions from the specific plant will therefore mirror the consumption reduction figure of 64% for phase one and 75% for phase two.

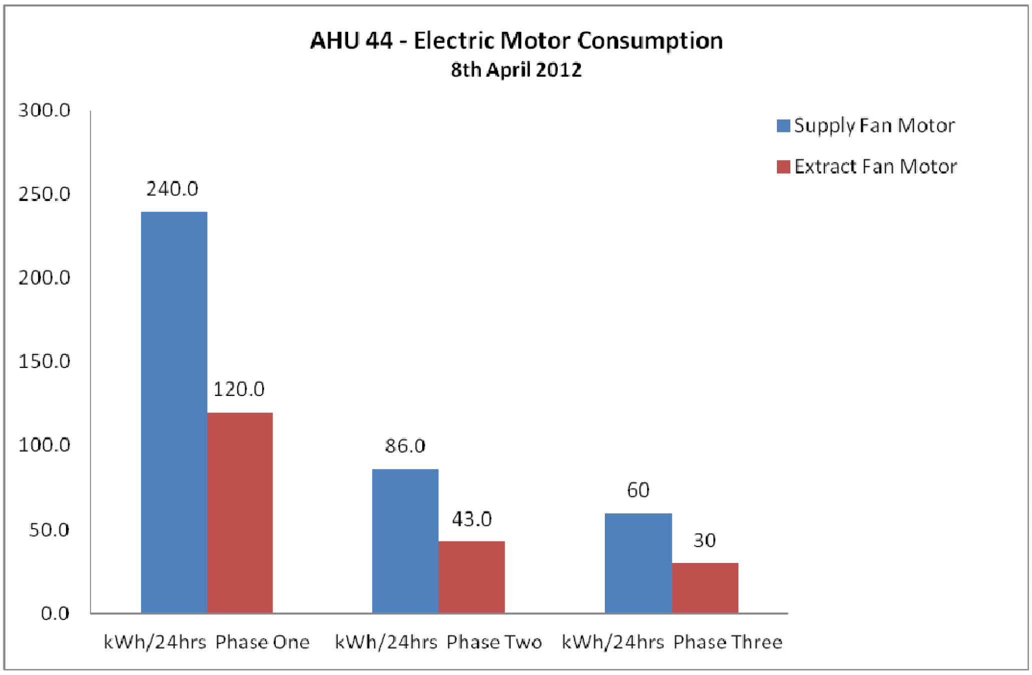


Figure 5.11 – AHU 44 Electrical Consumption

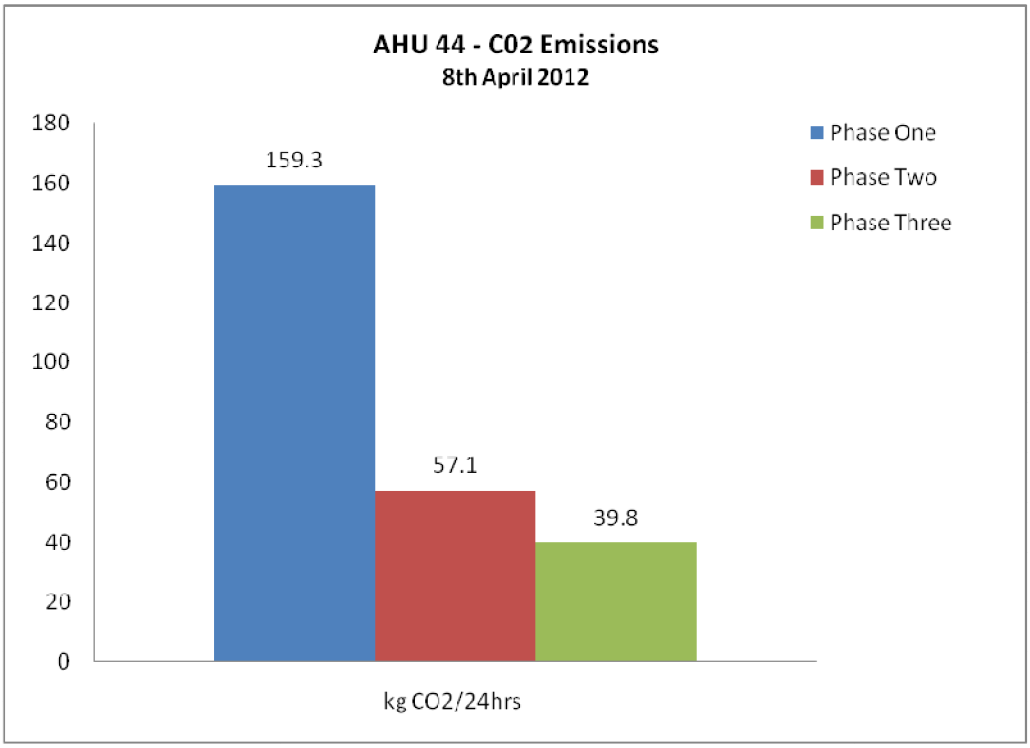


Figure 5.12 – AHU 44 CO_2 Emissions

Figure 5.13 displays a multi bar chart of the electrical consumption of AHU 45 from the three different stages of analysis. The results of the Phase two analysis highlight a significant reduction in electrical usage, by a figure of 64%. This reduction was created by improving the interaction between the services provided and the stand allocation operation. The relationship was improved by incorporating the available flight information data into an operational schedule for the temperature control units. The introduction of the operational schedule reduced the running hours of the plant from 24 hours to 8 hours 39 minutes. With the introduction of the AHU/Stand schedule the reduced operating hours still maintained the comfort conditions required for the specific passenger routes to the allocated stands. Phase three analysis revealed a 75% reduction in electrical consumption from phase one. This is due to the location of the specific area being comfort conditioned by AHU 45. AHU 45 is required for provision of comfort conditions for the passenger route to the departure gates 28, 29, 31, and 32, and is not required for any arrival routes. This can be seen in the departure/arrival AHU schedules in figures 4.45 & 4.46 in section 4. The re-scheduling of aircraft allocation in phase three has actually decreased the operational hours of AHU 45 from phase two results to an operational time of 6 hours 6 minutes. Consideration must be given to the overall results of the combined relationship as a whole between services and operation as well as the plants individually. The efficiency of the relationship will be determined by the phase results as a whole and not by individual plant performance. The re-scheduling of aircraft has allowed a decrease in operation hours of AHU 45 whilst maintaining the required comfort conditions for passenger routes for the specific flights.

Figure 5.14 displays a multi bar chart of the calculated CO_2 emissions from the three different stages of analysis. The graph displays the existing and hypothetical quantity of emissions from the operational hours of AHU 45 during the three different relationship phases. The emission analysis results are derived from the kWh figures obtained from the running hours of the plant. Due to the improved relationship between services and operations for AHU 45, the reduction rate of the emissions from the specific plant will therefore mirror the consumption reduction figure of 64% for phase one and 75% for phase two.

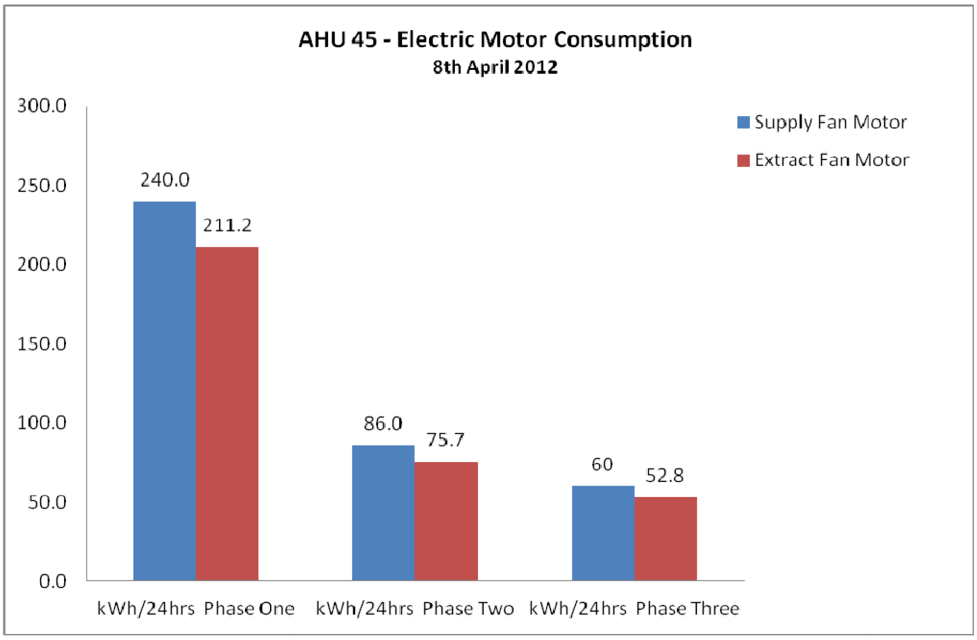


Figure 5.13 – AHU 45 Electrical Consumption

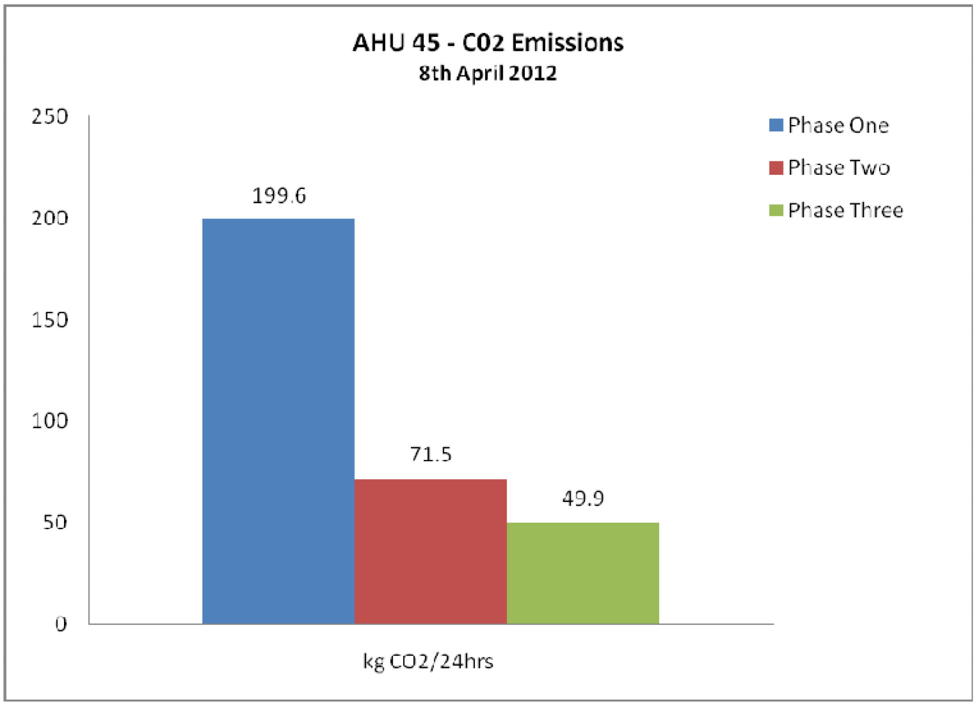


Figure 5.14 – AHU 45 CO_2 Emissions

Figure 5.15 displays a multi bar chart of the total electrical consumption of all the air handling units associated with providing comfort conditions during the research time period. The data displayed in multi bar chart form for graphical representation of the data, is the total consumption from the original and hypothetical relationships formed within each analysis phase.

The data analysed in phase two highlights a significant reduction of overall electrical consumption from the building services units that provide the required comfort conditions. Overall the electrical consumption was reduced by a figure of 56%. This was achieved by using the services only when demand was required. The demand was determined by the operation being performed within that area. The operation was the aircraft allocation for individual flights to specific departure/arrival gates. The current occupancy activity or passenger routes are determined by the existing building design and layout. Departing and arrival passengers must be kept separate therefore the building has been retrofitted to facilitate this requirement. This allowed the opportunity to formulate an AHU/stand schedule which determined which air handling unit would be required for a specific departure/arrival gate passenger route.

This demonstrates that the interaction between the buildings services being provided and the specific building operation can become a major tool in energy reduction. Adjustment of the services being provided to accommodate the existing operation has provided a significant reduction in energy use and subsequent CO_2 emissions.

With advancements with communication protocols and manufacturers producing gateways for communication between the different protocols, passing information between different systems is becoming increasingly available. With the introduction of Standard protocols like BACnet which is used within the Building and Automation Controls networks. Information can be passed between products which are produced by different manufacturers when connected on the network. BACnet also incorporates within in standards items such as Schedules. Schedules are what the controls system can use to enable and disable particular plant on specific time/date schedules.

Manufacturers of SQL databases can develop their code to provide useable data that is available through dedicated interfaces. This data can then be incorporated into products from different manufacturers within the Building and Automation Controls network to communicate with each other.

During phase three analysis, it was noted that certain individual air handling unit's electrical consumption actual increased. This was due to its increase in the AHU/stand schedule but facilitated the opportunity to decrease the electrical consumption of other units.

This demonstrates not only the interaction between services and operations can affect the building emissions, but greater understanding of the building design and how it operates when providing these services can be a major tool in assisting Manchester Airports with its aim of achieving targeted reductions in CO_2 emissions. As discussed in section one, the operation cycle is a continuous relationship between services and operations, where any alteration with one can have an effect on the other. For the most efficient cycle the services should only react to demand of the operation, but the operation should be planned where practicable to operate in a manner that creates the least demand on the services.

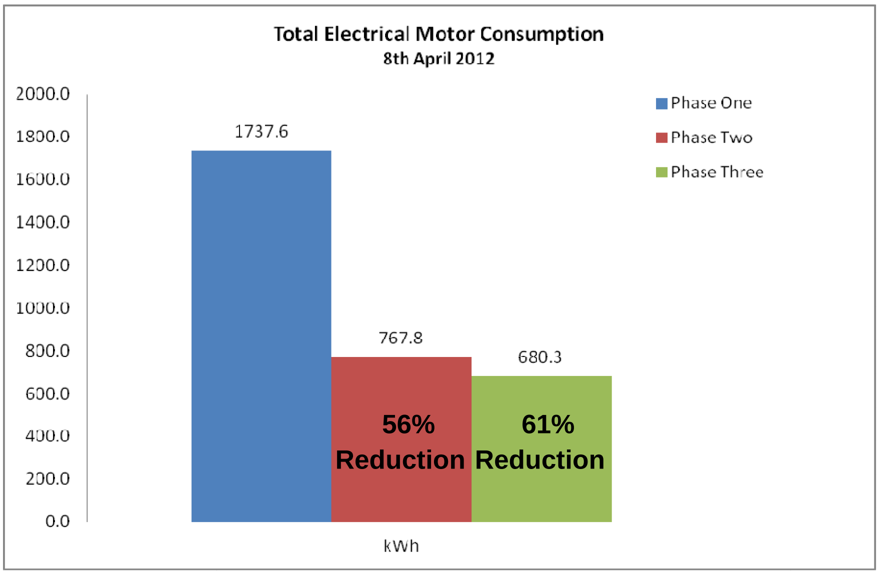


Figure 5.15 – Total Electrical Consumption

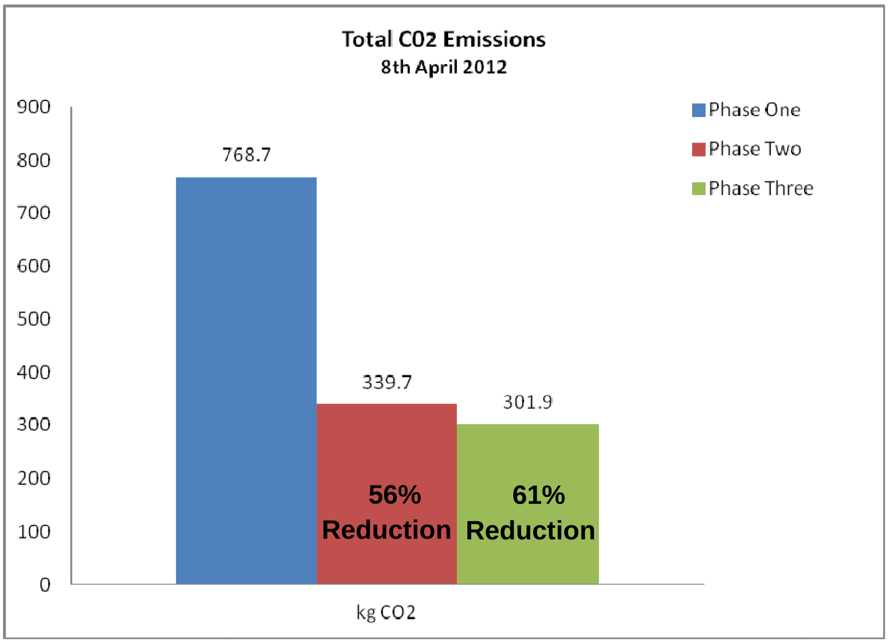


Figure 5.16 – Total CO_2 Emissi

5.3 SUMMARY OF RELATIONSHIP MODEL BOUNDARIES AND FINDINGS

To create the hypothetical relationships between the services and operations for analysis, specific parameters had to be chosen and implemented within the different relationships. The parameters that have been chosen were the plant enable and plant disable time periods between each flight.

Parameter Description	Time Period (mins)	Variable used
Enable plant for Departure	60 mins before Schedule Time of Departure	60
Disable plant for Departure	Actual Time of Departure	ATD
Enable plant for Arrival	15 mins before Schedule Time of Arrival	15
Disable plant for Arrival	30 mins after Actual Time of Arrival	30

The variables were chosen in conjunction with the “Gate Calling Procedure” currently in place at Manchester Airport. For the purpose of this research the figures proved to be effect in the assistance to improve the efficiency of operation cycle.

All variables can be adjusted to accommodate different sites and preferences for the particular buildings. Alterations of the variable will obviously have an effect on the electrical consumption and subsequent CO_2 emissions.

The variables used within this particular research worked extremely well for data analysis, with the actual results proving to be extremely satisfactory.

Additional control methods could replace the variable and be placed into the procedure, if disabling the plant is not the preferred option. A “set back mode” could be implemented instead of disabling the plant completely during the no-passenger demand periods. Set back mode would reduce the fan speed (if VDS are installed) to provide a minimum air flow and increase the dead band of the control strategy. Increasing the dead band would allow the room temperature to deviate from the actual set point by a larger margin before the heating or cooling control would be called for. This procedure would not achieve the same results as completely disabling the plant, but reducing fan speed and reducing heating/cooling demand would create energy savings.

5.4 REVIEW OF THE RESEARCH PURPOSE

This research is about *an analysis of the relationship between airport systems and operations and the impact the efficiency of this cycle can have on environmental emissions.* In order to achieve the research purpose data was collated from a specific chosen airport operation and system to examine the effect their relationship had on environmental emissions. Hypothetical relationships between the same operation and system were modelled with various adjustments made to the system and then operation. This was done to analyse the performance of each relationship by measuring the energy demand and subsequent environmental emissions for comparison to the existing relationship.

5.5 REVIEW OF THE RESEARCH OBJECTIVES

The research objectives were formulated to reflect the research purpose. Chapter One describes in detail the research objectives, below is a summary of these objectives:

1. Collate data on the existing temperature control plants.
2. Collate data on the existing aircrafts stand allocation.
3. Model the existing Airport operation and system relationship.
4. Extract data from the model to analyse the effect the relationship has on current environmental emissions.
5. Model a hypothetical Airport operation and system relationship with system adjustments
6. Extract data from the model to analyse the effect the relationship would have on environmental emissions.
7. Model a hypothetical Airport operation and systems relationship with operational adjustments.
8. Extract data from the model to analyse the effect the relationship would have on environmental emissions.

The first objective was achieved by reviewing data provided by Manchester Airport Utilities Team and logging actual run load current readings of the associated Air Handling Unit motors.

The second objective was achieved by reviewing actual flight data provided by Manchester Airport Engineering via the CHROMA system. The data was filtered to provide the relevant information required for the research specific areas.

The third objective was achieved by analysing the collated data and creating a 24 hour simulation of the operational relationship for a visual representation of the relationship. This simulation was created utilising the open source Sketchup software package and downloading the individual aircraft type models detailed in the Chroma data. The individual slides created were then imported into a video software package and an exact 24 hour simulation of the relationship can be viewed graphically.

The fourth objective was achieved by analysing the data created in the existing relationship and calculating the emissions by multiplying the actual electrical energy used by the present Government CO_2 emissions factor.

Fifth, six, seventh and eighth objective were achieved with the same modelling process after certain system variables had been introduced. The system variables are explained further in the summary of relationship model variables section.

5.6 CONTRIBUTIONS OF THE RESEARCH

The contribution of this research can be viewed from aspects of the methodology, theory and practical implications. Based on the motivation for this research, the literature review and findings from the analysis, the contributions can be summarised as follows:

Methodological contribution

The main contribution of this research is the models of the relationships between services and operations within a building. These models were created through quantitative analysis techniques. Quantitative methodology has proven to be a useful tool in the aim of CO2 reduction within the building.

Theoretical contribution

The research has highlighted the importance of the relationship between a buildings services and its operation can have on the building energy efficiency. There are many research papers available on the optimisation of buildings systems to contribute towards a building efficiency (Qiao et al., 2006; Yang.R & Wang.L 2012) and many research papers on reducing a buildings CO_2 emissions (Reilly, 2013; Castro Boluarte et al, 2013) but there is a literature gap in the area of the building system and operations relationship. Arkin, H., & Paciuk, M. (1997).states “building intelligence is not related to the sophistication of service systems in a building, but rather to the integration among the various service systems, and between the systems and the building structure” the paper examines some existing buildings that call themselves intelligent buildings due to the level of systems integration but concludes there are limits within the building integration. The TINA reports published by the Low carbon Innovation Co-ordination Group in 2012 highlighted within the UK, Company’s innovation developments for non domestic buildings within the Integrated Design categories as “Critical Failure”. This only reiterates the importance of further research into the integration between information systems to assist in the operational cycle within today’s commercial buildings to contribute towards the buildings efficiency and to contribute towards the UK’s CO_2 reduction commitment.

Practical contribution

The research has highlighted the improvement on the buildings energy consumption and subsequent CO_2 emissions in introducing the hypothetical relationships between the buildings services and its operation. This has further implications within applying the method in additional areas within the airport site but also wider implications by introducing the methodology into the Manchester Airports Group.

Conclusion

Combining both the theoretical and practical contributions, gives rise to further opportunities outside the scope of the original research remit of airport system and operations. The same research approach could be incorporated into other commercial buildings to assist in the energy management of its operational cycle.

5.7 CONSIDERATIONS & SUGGESTIONS FOR FUTURE RESEARCH

During the process of the research journey and carrying out surveys on the building environment, paying particular attention to additional service which was not to be covered within the remit of this research, it was becoming apparent that if the research results were favourable the opportunities for energy reduction incorporating the same methodology would be great. The next obvious services that could be incorporated in to the new schedule would be lighting circuits. Manchester Airport is currently involved with in a separate energy reduction programme of replacing existing inefficient light fittings with the more efficient LED technology lighting within its terminal 2 building. Amongst the obvious energy advantages of installing LED lighting is that the technology has the capability for the LED lamp to be dimmable. This would create the opportunity to maintain a desired lux level in zoned areas with the installation of lux level sensors in appropriate locations. Interface modules between lighting controllers and BMS are readily available and the controllers could be incorporated in the zoned schedule programme. Alternatively the areas that are not directly involved within the departing or arriving passengers routes could be controlled to a lower lux level not only reducing energy but with the potential to assist with the passenger journey to the appropriate gates. Within the busy environment of the airport some passengers can get confused when trying to locate their particular flight gate, but with greater lux levels on the routes to the active departing gates this may have the opportunity to alleviate some of these issues which may cause delays.

The research has highlighted the importance that correct zoning of the services in relation to the operations being performed can have on overall efficiency. Additional savings opportunities relating to the improved relationship between the services and operations created by incorporating the operational interface into the air conditioning schedule can be examining in the same zoned manner. Additional services being provided within the particular zone that is disabled or enabled that may have the opportunity to be incorporated into the same time schedules could be (but not limited to), advertising signs, vending machines and toilet facilities.

Advertising signs may be turned off during the disabled period of that zone as passengers should not be in the area during that time period. There are income issues relating to this particular item, but relationships between parties may be improved with the options of discounted advertising or refunds relating to the actual operational hours.

The same opportunities and issues may also be addressed in relation to electrical devices installed for public use such as vending machines and arcade games.

Toilet facilities provide multiple opportunities to assist in the airport energy reduction commitment. Not only on electrical consumption but also in the additional area of waste water management which is also of concern for the airport (MAG 2007). Within the disabled time zone the toilet facilities in that zone could have the lighting disabled (or dimmed) with the option of installing an override function via passive infra red sensors or a timed manual switch (Timed switch prevents the lights being left switched on). Within the gentlemen's toilet facilities, the option of stopping (or reducing) the urinal flush times would improve the waste water management. The option to install solenoid valves onto the main hot and cold water mains into the facilities may also provide the opportunity to turn off the whole water supply during the disabled time zone. This will prevent the regular occurrence of passengers leaving taps running within the toilet facilities.

Additional options could arise from examining the domestic hot water circuit providing the water to the basins within the facility. Reduction of the hot water set point to the lowest acceptable temperature (being conscious of legionella) during the disabled time period would produce less demand on the calorifiers supplying the domestic hot water to that area. The above procedure of installing solenoid valves on to the hot water supply creating a bypass from that facility would also reduce the calorifier demand, if supplying multiple facilities.

Manchester Airport has links with the MET office that provides them with the most up to date weather forecast. This data could be utilised to reset zone area temperature set points in advance to reduce the heating or cooling loads and react to climate changes. Historical weather data could also be incorporated into time series forecasting methods to produce the predicted set point. This data could be included in additional energy forecasting procedures.(Weather data examples in Appendix A)

Heating and cooling loads will vary in each zone dependant on the building fabric, external temperatures and solar gains. The separate zone temperature and valve positions on the plant could be a consideration when allocating aircraft stands. If there are multiple feasible stands available, it would make efficient sense to allocate the aircraft to the zone that has the least heating or cooling demand.

Planned Preventative Maintenance on the air handling units could be programmed into the zone disable schedule created from the passenger demand interface. This would prevent any maintenance being performed on plant whilst passenger demand is required.

It is difficult to quantify the savings on the main boiler and cooling plants that would be associated with the savings displayed within the research results. However it would be possible to gather the details of the heating and cooling coils installed within each air handling unit and determine their kW rating at full load. There would also be additional savings on pump speeds for the heating and cooling circuits if they have the VSD installed.

A large section of the international pier is glazing, which could benefit from the installation of automatic blinds which react to reduce the solar gains.

Chroma can provide additional information that was not utilised in the main research. The actual passenger numbers on board are also available which could be incorporated into the control. Different levels of passenger numbers could be associated with different variables used in the model boundaries. An example of this would be if an arriving aircraft had only half its passenger numbers, the model variable of 30 minutes runtime for arriving flights could be reduced to 15 minutes therefore reducing the running hours of the plant.

Sequencing of the plants whilst being enabled or disabled for the passenger route could also produce additional savings. Calculating the average time it takes a passenger to enter one zone from another could be the variable added onto the enable signal for the next plant. This process can only be utilised in the initial start up or stop sequence.

Further research with neural network technology could attempt to learn passenger activity for specific flights. With schedule flights in particular the passenger activity can be assessed over time. With flights to nightclub destinations where the majority of the passengers will be in their 20's may gather in the bar area and make frequent visits to the toilets. The comfort conditions can be adjusted accordingly. Where other flights may observe the majority of passengers gather in the cafeteria areas etc. Another important criteria to consider the type of clothing the passengers are likely to be wearing. The outside weather conditions can also affect the way in which people dress. If the temperature is cold when they are leaving their homes to travel to the airport, they may put an extra layer of clothing to compensate; this could be taken into account when they arrive in the departure lounge by lowering the temperature set point by 1^{O}C.

There are many energy reduction procedures and available technologies to make the plant more efficient whilst operating, but as the research results demonstrate there is no better procedure than turning the plant off when not required.

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Appendix A

CD Containing:

- Simulation models for Phase One, Two and Three.
- Chroma Flight Data
- Aircraft Size per Stand
- Aircraft Types
- Weather Data