AIR CONDITIONING IN 32 UK OFFICE BUILDINGS: MEASURED ENERGY & CARBON PERFORMANCE

By

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Summary:

This research has undertaken field energy monitoring to determine the energy consumption and associated carbon emissions of a number of air conditioning systems 'in-use' in UK office buildings. Aiming to determine the relative energy performance of different generic types of comfort cooling air conditioning systems, the main factors which influence cooling energy performance and the potential to reduce the carbon emissions from UK comfort cooling systems.

The results show that the energy performance of air conditioning systems varied substantially between the different generic types studied. Peak power demand for the systems range from about 50 to 70W/m^2 for the centralised air, direct expansion, variable refrigerant flow and fancoil systems, but to about 20W/m^2 for the average chilled ceiling system. Once the cooling energy demand was normalised for the internal loads the energy performance of chilled ceiling was confirmed as more efficient in providing cooling than the other generic system types.

Analysis of chiller part-load profiles indicated that none of the systems studied were sized appropriately to meet the cooling loads actually encountered, and that current sizing techniques are leading to installed capacities that are generally twice that required resulting in reduced energy efficiency of the systems studied.

The annual hours of operation indicated that most systems are running far longer expected and that in general around 50% energy consumption saving could be achieved on accurate time control alone.

The research has shown that cooling in UK Office buildings can be undertaken far more efficiently than generally occurs at present, by combining the selection highly efficient air conditioning systems, such as chilled ceilings, and by ensuring building design and operation is undertaken in an energy efficient manner. The potential energy consumption, carbon emissions and running cost savings appear to be comfortably over 50% compared to current practice.

DEDICATION

This thesis is dedicated first and foremost to my wife Barbara and daughter Michaela, because you make striving for success worthwhile and life truly fulfilling. But also to my parents Colin and Valerie, for providing the opportunities, freedom and most importantly the mindset to follow my interests in life.

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ABSTRACT

It is estimated[1] that the carbon emissions resulting from UK building services need to be reduced by 50% if the UK Government's green house gas targets for 2050[2] are to be achieved. However carbon emissions from air conditioning in the UK are increasing as air-conditioning is installed in more buildings[3].

Although it is considered good practice to "design out" the need for air-conditioning[4], there are situations where its use cannot be avoided or is the preferred option based on business productivity or air quality issues. In these situations, good practice dictates that the designer should minimise cooling demand and select the most efficient mechanical system available[4]. But from existing guidance it is not clear which systems are the most energy efficient 'in practice' or which are the most important issues to address in trying to achieve the best possible energy performance and lowest carbon emissions.

This research has undertaken field energy monitoring to determine the energy consumption and associated carbon emissions of a number of air conditioning systems 'as found' in occupied UK office buildings. With the aim to provide insight into the relative energy performance of different generic types of comfort cooling air conditioning systems, to identify the main factors which appear to influence the measured cooling energy performance, and to explore potential ways to reduce the carbon emissions from UK comfort cooling systems.

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[1] Watt, T; "Change for Good", Building Services Research Information Association (BSRIA) Briefing 2003, Energy Futures: Opportunities or Threats, 7 November 2003, UK.

[2] Blundell, T; "Energy – The Changing Climate", 22nd Report of Royal Commission on Environmental Pollution, London, June 2000.

[3] Pout, C.H., Hitchin, E.R; "The potential impact of air conditioning on UK carbon emissions in the next 20 years", 2nd International Conference on Improving Electricity Efficiency in Commercial Buildings, Nice, May 2002.

Observations from the field energy monitoring, show that the cooling energy demand and overall energy consumption vary substantially between the different generic comfort cooling systems[5]. Peak power demand for the generic systems range from about 50 to 70W/m^2 for the centralised air, direct expansion, variable refrigerant flow and fancoil systems, but to about 20W/m^2 for the average chilled ceiling system[5]. Once the cooling energy demand was normalised for the internal loads[6] the energy performance of chilled ceiling was confirmed as more efficient in providing cooling than the other generic system types[5].

However, the large numbers of variables that can affect AC energy performance in practice mean that the apparent superior energy performance of the chilled ceiling systems in part could be due to differences other than the inherent efficiency of the systems alone.

Analysis of chiller part-load profiles has indicated that none of the systems studied were sized appropriately to meet the cooling loads actually encountered, and the data suggests that current sizing techniques are leading to installed capacities that are generally twice that required[7]. To further emphasize the importance of the sizing issue, not only did over-sizing appear to be common practice the results indicate that it is leading to reduced energy efficiency of the systems studied and there would appear to be capital and running costs savings to be made as well[8].

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[4] Department of the Environment, Transport and the Regions (DETR); *"Good Practice Guide 71: Selecting air conditioning"*, Building Research Energy Conservation Unit (BRECSU), Garston, UK,
[5] Knight, I.P, Dunn, G.N; "Air Conditioning Energy Efficiency in UK Office Environments", International Conference on Electricity Efficiency in Commercial Buildings, Nice, France, 2002.
[6] Knight, I.P, Dunn, G.N; "Evaluation of Heat Gains in UK Office Environments", Worldwide CIBSE / ASHRAE Gathering of the Building Services Industry, Edinburgh, 24-26 September 2003.
[7] Knight, I.P, Dunn, G.N; "The Potential for Reducing Carbon Emissions from Air Conditioning Systems in UK Office Buildings", International Conference on Electricity Efficiency in Commercial Buildings, Frankfurt, Germany, 21-22 April 2004.
[8] Chartered Institution of Building Services Engineers (CIBSE); "Environmental design", CIBSE Guide A, London, UK, 1999.

Once the annual hours of AC system operation were studied it was clear that on average most systems are running far longer than we might have expected and that in general around 50% energy consumption saving could be achieved on accurate time control alone[7].

Looking in to the future carbon emissions associated with air conditioning use, the monitored field data suggests that increasing the efficiency of ALL air conditioning systems, current and future, to the most efficient currently available would reduce emissions by 58% compared to year 2000 levels by 2020[7]. But assuming market growth continues beyond 2020 we will also have to address the market growth and the carbon intensity of the electricity supply in order to meet current stated emissions targets.

Overall these results imply that the provision of cooling in UK Office buildings can be undertaken far more efficiently than generally occurs at present, by combining the selection highly efficient air conditioning systems, such as chilled ceilings, but also ensuing building design and operation is undertaken in an energy efficient manner.

The potential energy consumption, carbon emissions and running cost appear to be comfortably over 50% compared to current practice. Significantly this means the proportion savings required from air conditioning to meet future UK carbon emission targets can be met using existing air conditioning technology available in the UK market today.

AIMS OF THE RESEARCH

This research aims to determine the energy consumption and associated atmospheric carbon emissions of a number of air conditioning systems as installed in occupied office buildings in the UK, in order to provide the following

- Insight into the relative energy performance of different generic air conditioning systems in meeting comfort cooling demands in UK office buildings.
- To identify the main factors which appear to influence the measured cooling energy performance of the systems studied.
- Explore potential ways to provide thermal comfort in UK buildings without comprising greenhouse gas emissions targets.

This will be achieved by monitoring the energy consumption of a number of air conditioning systems 'in use' within actual occupied office buildings throughout the UK over an extended monitoring period which will determine the following:

- The overall energy consumption of each air conditioned building monitored.
- The power and energy consumption of all building services used to deliver primary cooling within each of the buildings monitored.
- Estimate the cooling loads served in order to normalise for any building and occupancy differences in the buildings monitored.

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1.0 INTRODUCTION

It is now generally accepted that the Earth's climate is changing as a result of greenhouse gas emissions produced by man's activity[1]. This prospect has far reaching implications to the way we live, our relationship to our environment, and has led to initiatives aiming to reduce the 'human' contribution to climate change. In particular, many of these initiatives focus on reducing greenhouse gas emissions associated with energy use. In the UK, the main focus of this effort has been the Government's commitment to the international treaties on climate change at Kyoto[2] and ozone depleting materials at Montreal[3].

The Kyoto Protocol requires the UK Government to reduce green house gas emissions by 12.5% below 1990 levels[2] by the year 2010, but the Government has also identified the need to further reduce emissions to 60% below 1990 levels by 2050[4]. The solution to reduce carbon emissions will probably have to address both energy supply and demand issues. The energy supply side is likely to involve cleaner energy generation and delivery, as well as the increased use of renewable energy systems. However, current thinking suggests that the UK National Grid would only support a certain proportion of renewable energy, limiting large scale renewable uptake, and potentially much of the reduction in carbon emissions achieved from renewable energy resources could be offset by a reduced use of nuclear energy[6]. A substantial proportion of the required carbon emissions reduction will therefore have to be met through demand side management.

UK energy use in 1994 was responsible for 532 million tonnes of carbon dioxide emissions[5] and nineteen percent (101 million tonnes CO_2) of this was attributable to non-domestic buildings[5]. Forty five percent of the emissions from non-domestic buildings, about forty five million tones, were from building services including air conditioning systems.

It is estimated[6] that the carbon emissions resulting from UK building services, including air conditioning, need to be reduced by 50% if the UK Government's target of a 60% reduction in emissions of greenhouse gases by 2050[7] is to be achieved. However UK carbon emissions from air conditioning, particularly in the commercial sector, are increasing as air-conditioning is installed in more buildings[8]. This growth in air conditioning use is of particular concern because of the energy intensive nature of air conditioning, since air conditioned buildings typically consume 50% more energy than other buildings[9], and its dependence on refrigerants that also tend to be significant greenhouse gases, linked to climate change and global warming. Furthermore, UK market penetration level of air conditioning systems is currently only around 10% of the total non-domestic floor space, so the potential for growth in considerable[8]. Therefore dealing with the growth in emissions resulting from air conditioning is one of the most important building related issues to address in order for the UK to meet its future greenhouse gas emissions targets.

Although it is widely considered good practice to "design out" the need for energy intensive building services such as air-conditioning[10], there are situations where the use of mechanical cooling cannot be avoided or is preferred for other reasons, such as perceived productivity and air quality advantages. In these situations, good practice dictates that the designer should minimise cooling demand and select the most efficient mechanical system available[10]. However, existing guidance does not provide information as to which systems are the most energy efficient 'in practice' or which issues are the most important to address, in order to achieve the lowest possible energy performance.

Furthermore, the policy to 'design-out' air conditioning appears to conflict with the expectations of the commercial market, which increasingly demands mechanical systems to satisfy increasing expectations of building occupants for thermal comfort[11] and business on perceived productivity grounds, leading to a market premium being placed on 'air conditioned' buildings. This apparent conflict between Government policy and the market could lead to government policy being seen as 'out-of-touch' if guidance on suitable compromise solutions is not available.

If Government policy is ignored, because it is perceived to be out-of-touch, and a business-as-usual approach is taken, any attempt to reduce carbon emissions from the UK buildings is at risk of failure. Therefore it is vital that appropriate guidance on which factors affect the energy performance of UK buildings, and which air conditioning systems are the most energy efficient 'in practice', is available to building and services designers so they can make informed decisions that meet their client's expectations for comfortable and productive workplaces, improve the energy performance of UK buildings and contribute towards meeting the Government's reduced carbon emissions targets. In order to facilitate the development of such guidance this research aims to establish the actual energy performance of air conditioning systems in practice within UK office buildings and identify some of the main factors affecting the energy performance of air conditioning systems in practice.

1.1 SCOPE

This research set out to measure the energy performance of various types of air conditioning systems *'as found'* in occupied UK office buildings, in order to provide insight into the actual energy performance of A/C systems *'in-practice'* and to identify the reasons behind variations in their energy performance.

However this research cannot consider all aspects of building services energy performance or indeed every combination of air conditioning systems currently used in the UK, and therefore this research only considers comfort cooling applications in UK offices. Space heating is considered only when provided from reverse-cycle systems, since it is difficult to differentiate between the heating and cooling modes of operation of the plant.

Furthermore, only system components associated with the provision of cooling services, and heating when from reverse cycle heat pumps, will be measured in order to enable fair comparison between different generic system types, since different system types provide different levels of service, often including secondary services such as ventilation or humidification. Therefore, the extent of monitoring required will be different for each system, depending on the system configuration and method of primary services delivery. For example the energy consumed by Air

Handling Units would be monitored if the air was the medium of delivery for the primary cooling services, as in an all-air system, but would not be monitored if the air was used solely for ventilation purposes.

This research would have ideally studied a large enough sample of buildings to be representative of the UK air conditioned building stock as a whole. However, within the resources available it was not possible to monitor a large enough sample to represent all the variations of buildings, systems and usage patterns. But instead monitored a series of case study air conditioning systems in-use within UK office accommodation, which is currently of particular interest because of the office sectors recent growth, as well as, increasing expectations of building occupants for thermal comfort leading to increased demand for air conditioning and legislative requirements to reduce carbon emissions which could be threatened by the increased us of air conditioning.

The detailed empirical data provided by this research, which takes into account 'real world' operation, is essential to assess the true energy performance, carbon emissions and operating costs of air conditioning. This information will be useful to provide updated design guidance and 'fact-based' design criteria, in order to improve the energy performance, life cycle costs and the environmental impact of our buildings.

1.1.1 Novelty

Traditionally, a number of different methods have been used in the assessment of air conditioning energy performance[12] including: the laboratory testing of system components, field measurement of energy consumption within buildings, and computer modelling of buildings and building services systems. However, none of these methods on their own can holistically assess all aspects of air conditioning energy performance when installed in occupied buildings. This research uses a field energy monitoring approach within occupied buildings in its assessment of air conditioning energy performance. This method is able to consider the entire cooling delivery system, not just individual components, and accounts for all the real-world environmental and operational conditions found in practice. Although this approach is not necessarily novel, due to the number of buildings and systems monitored the data will be able to draw direct comparisons between different air conditioning system types. This is unique in that, as far as the author is aware, such as comparison has not been done before in the UK using empirical data of this level of detail.

The efficiency of air conditioning systems has traditionally been rated using laboratory testing of system components, through standardised testing procedures. These tests rate system components in terms of their efficiency relative to similar components, but inherently do not to take into account usage and application variables influencing system performance in practice. In fact these test methods deliberately remove these "real-life" variables from the test equation, so that direct comparative performance can be assessed, since many of these variables are difficult to mimic in the laboratory environment. However, many of these "real-life" variables can also have a significant impact on energy efficiency, system performance and running costs.

Existing empirical building energy consumption data has been published by the Government for various market sectors, which include guidance relating to air conditioned buildings[9]. This guidance establishes benchmarks with which comparisons can be made to determine relative performance of buildings to the overall stock of similar building types. The principle advantage of these benchmarks is that they are derived from the performance of actual buildings and therefore account for all the variables encountered in practice. However, the current benchmarks do not differentiate between different types of air conditioning system, but only consider market sector and floor area. However, other Government guidance acknowledges that the energy performance of the different air conditioning system types can vary considerably[10]. This contradiction in the government's energy efficiency guidance is probably due to the lack of appropriate energy performance data and means that more information is required to set more selective energy consumption benchmarks which differentiate between different systems and building types.

Alternatively, many designers utilise computer modelling techniques in the design of their buildings and services. These models are numerous and can assess most aspects of building and services design including, equipment efficiency, occupancy patterns and environmental conditions. However, due to their 'design nature' they are only able to predict the relative performance of one design over another based on certain design assumptions, but their application is limited when required to determine the actual performance in practice, where conditions can vary substantially from design assumptions.

This research will measure the actual energy performance of a number of air conditioning systems 'as found' in occupied UK office buildings. Therefore the results will account for the interactions between the various system components, the environmental conditions, the buildings themselves, and the manner in which the buildings are operated. This data will therefore provide a unique insight into which air conditioning systems are the most efficient in practice and will enable some of the reasons behind any differences in energy performance of the various systems to be identified.

The resulting data will reduce the uncertainty that surrounds the current energy consumption benchmarks and design advice on the use of air conditioning systems in UK buildings. Improved guidance will enable designers to improve the energy performance of buildings and reduce their associated carbon emissions, while continuing to provide the comfortable and production working environment that business requires.

Furthermore, this research responds directly to a call for *"measured energy use figures for air conditioning"*[8] for use by Government researchers looking at the environmental impact of air conditioning[13] and its impact on the future UK energy and building markets, as well as, assisting in the development of future energy efficiency legislation to comply with the EU directive on energy efficiency[14].

1.1.2 Timeliness

Despite strong market growth driven by increasing demand for thermal comfort and productivity[11] the air conditioning market across Europe could be facing a serious crisis from the increased energy use and carbon emissions associated with the increased use of air conditioning. Growth in carbon emissions threaten the UK and EU G overnment's commitment to reduce carbon emissions and as such both Governments are currently implementing regulatory changes that aim to reduce the emissions resulting from energy use buildings and, air conditioning systems.

These trends alone would be cause for alarm, but compounding the problem is the prospect of climate change and the rate of growth in cooling energy demand. The international energy agency (IEA), while acknowledging that factual information is hard to find, estimates that cooling is currently the fastest growing source of new energy demand and greenhouse gases emissions in the world[15]. The IEA cites factors including increased hours of use, increased air conditioned floor area, and increased market penetration for this rapid growth which is likely to more than offset the impact of improved energy efficiency.

Climate change estimates predict an increase in global average temperature of 1.4 to 5.8 °C over the next century[1] and localised temperature increases are likely to be even greater, particularly in cities if you include “urban heat island effects”[16], as well as a greater incidence of extreme weather conditions[1]. Already, 8 of the 10 hottest years on record have occurred since 1990[15] and only serve to increase the perceived need for air conditioning in many peoples minds.

Consequently air conditioning will be more strictly controlled with future requirements for improved energy efficiency, stricter maintenance, energy monitoring, carbon based taxation, and even requirements to justify the use of air conditioning or limit the amount of cooling allowed for proposed installations. The two main legislative developments that have started to deal with these issues are the UK Climate Change Programme 2000[2] and the EU Directive on the Energy Performance of Buildings 2002[14].

The **UK Climate Change Programme** published in 2000 outlines the UK Government's approach to tackling the threat of climate change, which includes policies on energy, transport, and agriculture, among others. It states the Governments future policy intentions that affect the design and use of buildings, and air conditioning.

For example, it outlines future policy intentions towards hydro fluorocarbon (HFC) refrigerants as *"unsustainable in the long term"*[2] and states the Government's intention to phase-out HFC's as new technologies make it possible to do so, which will effect A/C systems which currently use these types of refrigerants, particularly as many of the alternatives are either more inefficient, flammable or toxic[17].

Furthermore, the Climate change programme also introduced the Climate Change Levy, which charges business, industry and the public sector a financial penalty for each unit of non-green energy they consume and has been in force since April 2001[2]. The levy has increased the operating costs of buildings and air conditioning; aiming to provide a financial incentive relating to building energy use, improve the relative cost effectiveness of 'green' alternatives, and at the same time generating funding for the development of new 'green' technologies and policies.

The climate change programme has also required that **Part L of the Building Regulations**[18], the provisions for energy efficiency in buildings, be updated to reflect the overall policies of the Climate Change Programme. The updated policy includes items which affect the running-cost and energy efficiency of buildings, including improved insulation and performance based testing, while also introducing the Carbon Performance Index (CPI)[18] which effectively limits the installed capacity of Air conditioning systems by setting a theoretical maximum carbon emissions level for air conditioning systems. These changes are due to be reviewed and tightened to bring

UK legislation into compliance with the EU directive on the Energy Performance of Buildings[14] which comes into force in 2006.

The **EU directive on the Energy Performance of Buildings** provides framework legislation focused on the ongoing energy performance of buildings through out their life and requires all EU member states, including the UK, to update their building regulations to comply with the new European standards by January 2006. Although the changes to the UK building regulations have yet to be finalised, they will have to comply with the EU requirements affecting air conditioning which include requirements for a methodology for calculating the energy performance of buildings, minimum requirements to be set for the energy performance of all new buildings and existing buildings undergoing major renovation, energy certificates of all buildings, and the regular inspection of air conditioning units over 12kW in capacity.

These policies underline the Government's commitment to reduce the UK's environmental impact, but will also significantly affect the UK air conditioning market. In addition the air conditioning market is also being affected changes to energy prices. Energy prices are projected to increase as a result of market deregulation, changes in taxation and as traditional energy sources become less secure[19], all will result in the increased running costs of air conditioning.

So providing energy-efficient low-carbon building services is in the interests of all parties including the building owners and occupants as well as government legislators and energy suppliers. If Government policy is to be successful it must be based on up-to-date and robust UK energy performance data in order to develop suitable legislation as well as realistic design guidance, which will enable buildings to be more energy efficient, comfortable and productive workplaces, as well as reducing overall carbon emissions.

1.2 TARGET AUDIENCE & END-USERS

It is envisioned that the empirical 'In-use' data resulting from this research will be useful to anyone making decisions relating to the design or operation of air-conditioned office buildings in the UK. These are likely to include:

- Building owners and managers who need reliable benchmarks to effectively judge the performance of their own buildings.
- Design professionals concerned about compliance with future energy efficiency legislation, reducing building lifecycle costs and improving comfort levels within buildings.
- Utility suppliers who need to accurately predict future electricity demand.
- The Government in formulating policies to combat Climate Change and the future development of the building regulations.

Clearly the list of possible end-users for this data is extensive, but the following sections detail a number of end-users that this work is specifically aimed toward. In some cases work is already underway for the application of this data. Dissemination of the results of this work through conference papers and academic or industry journals has progressively been undertaken to date and will continue as more results are available.

1.2.1 Good Practice Guidance

It is anticipated that the data obtained by this research will be used to underpin industry good practice guidance on the selection and operation of energy efficient air conditioning in the UK, as well as to update energy consumption benchmarks. There are various existing infrastructures for the application and dissemination of this type of advice, including the Government's own "Action Energy Programme[20]" run by the Carbon Trust which aims to provide independent, authoritative advice and assistance on all energy efficiency matters to UK based organisations. Professional bodies, such as the Chartered Institute of Building Services Engineers (CIBSE) and the American

Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE), also produce reference guides and journals for their members to keep their members up to date with the latest research and techniques in their respective fields. The *"Evaluation of Heat Gains*[21]*"* portion of this research has already been presented to CIBSE and ASHRAE and has been proposed for inclusion in the next generation of CIBSE guides.

Furthermore, a number of government intuitives responding to climate change issues, such as the Market Transformation Programme[22] and the technology support aspects of the UK Climate Change Programme[2] will benefit from access to improved energy profiles and benchmark data obtained by this research.

1.2.2 Energy Efficiency Legislation & Control Measures

It is anticipated that the data obtained by this research will be used to help underpin the Government's formulation of policies to combat Climate Change and the future development of the building regulations. Government's current proposed future changes to the building regulations are likely to introduce requirements for metering and energy reporting, as well as, other design carbon performance indices (CPI) for future non-domestic buildings[23].

In particular, the proposed CPI requires a maximum carbon emission target to be set for each HVAC system design. However at present the only available targets do not differentiate between different types of air conditioning system[9]. Ideally the CPI requires different standards to be set which account for the inherent efficiency of each system type. However, these require robust benchmark energy consumption targets for each type of system that accurately reflect the energy consumption of the building stock. These could be developed from the monitored energy consumption profiles obtained by this research.

Furthermore, the *"Evaluation of Heat Gains*[21]*"* portion of this research has already been proposed for inclusion in the next generation of the building regulations Part L for 2006.

1.2.3 Air Conditioning Equipment Manufacturers

The direct comparison of 'In-use' energy consumption profiles for the different A/C systems resulting from this monitoring research will provide excellent feedback to manufacturers on the energy performance of A/C equipment. This feedback will be useful in the development of new products, improvement of existing products and services, and therefore a benefit to sales and marketing of energy efficient products.

In particular, Toshiba Carrier Air Conditioning UK Ltd, who has partly funded this research, has already been using data from this work for the assessment of their products. So far Toshiba Carrier have used data from this research in order to rectify a controls fault in one system design, reinforce the energy efficiency message within staff training programmes, and included highlights in sales and marketing literature.

1.2.4 Utility Energy Suppliers

Utility suppliers are concerned by increasing energy demand from the growth of air conditioning use, especially during periods of warmer weather[24] and particularly when considering the prospect of climate change which could lead to increased frequency of warm weather[1]. Utility suppliers therefore have a need to accurately predict increasingly complex energy demand and in the longer term plan for new infrastructure to meet future energy requirements. For these reasons National Grid Transco plc., who have also partly funded this research, are currently using data from this research to better understand the relationship between ambient UK weather conditions and the energy consumption of air conditioning systems 'in practice'.

1.2.5 Further Energy & Building Performance Research

Since this data will ultimately end up in the public domain it will be available to underpin other research on the energy performance of air conditioning and help inform educators and practitioners in this field. Researchers at South Bank University in collaboration with The Welsh School of Architecture have already undertaken initial analysis, based on energy profiles collected from this monitoring study to develop improved application methods of cooling-degree days in UK buildings[25].

Furthermore, this research could be used in the development of a holistic interactive building and services design assessment tool. Such a tool could assess building & systems design integration, by bringing together the monitored energy and environmental data from this study with modelling of the thermal loads based within the buildings. This would allow assessment of the thermal loads, energy consumption, overall energy efficiency, and life-cycle emissions and cost analysis.

1.3 CONFIDENTIALITY

It is the intention of all parties involved with this research that the results will be published in the public domain. However, to effectively carry out the field work, strict confidentiality has been maintained to protect the interests of the owners and operators of the buildings monitored and to prevent the release of commercially sensitive information.

Therefore, the database of monitored data and survey information has been treated as confidential. This information includes the identities of the monitored buildings, the building occupants, and the brand-names of the air conditioning systems monitored. Instead, all references to specific buildings, occupants, product brands and specific equipment or systems have been done using generic descriptions throughout this work.

1.4 ACKNOWLEDGEMENTS

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Chapter 2: The Energy Performance of AC Systems

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2.0 THE ENERGY PERFORMANCE OF AIR CONDITIONING SYSTEMS

This chapter aims to review the aspects of air conditioning (A/C) affecting the energy performance and environmental impact of air conditioning use within UK office buildings, the expected performance of the various building and system types studied based on existing research and guidance, and the commercial and legislative issues currently influencing the UK A/C market.

This review is not intended to be a complete and authoritative guide on the energy performance of air conditioned buildings, as such guidance is already widely available, but instead aims to review the relevant information to the project and identify the expected outcomes of the work so that the findings can be put in context to the existing knowledge in this field of study.

2.0.1 DEFINITION OF COMFORT COOLING & AIR CONDITIONING

The Chartered Institution of Building Services Engineers (CIBSE) defines three general types of air conditioning differentiated by the level of control and conditioning provided to the conditioned space[1]. The three main types being Full Air Conditioning, Close Control Air Conditioning and Comfort Cooling[1].

The term 'Full' Air Conditioning implies *"control over the humidity within the conditioned space"* and 'close-control' air conditioning is further defined as the *"control over the humidity within the conditioned space to within +/- 5% of the set point of both temperature and humidity"*[1].

The term Comfort Cooling refers to systems that provide lower levels of control over space conditions and is defined as the *"use of mechanical cooling to maintain control over the maximum air temperature achieved within the conditioned space"*[1] where, as a consequence of the cooling process, some dehumidification of the supply air may occur but the system does not control humidity directly.

However in the UK the generic term 'air conditioning' is typically used in reference to systems that are in fact comfort-cooling systems. Comfort cooling systems account for the majority of 'air conditioning' systems used in the UK, since there are limited circumstances which require the use of 'full' or 'close-control' air conditioning, and this is certainly the case for most UK office buildings. Therefore, this study will limit its scope to consider only "comfort cooling applications" in UK office buildings and will also use the generic term of 'air conditioning' (A/C) when referring to comfort cooling air conditioning systems throughout this research.

2.0.2 DETERMINING AIR CONDITIONING ENERGY PERFORMANCE

The energy performance of air conditioning systems, i.e. the amount of energy that has to be supplied to get the desired environmental conditions to maintain occupant comfort, is dependant upon many variables which are often specific to individual applications. Therefore it is not possible to be prescriptive about air conditioning system design and selection for optimum energy performance, nor is it possible to be prescriptive about the actual energy performance of systems in practice.

However, whether considering a proposed system or an existing installation, the energy performance can be determined by the system efficiency under the particular set of conditions, the quantity of services required i.e. cooling load, and the period of time for which it is required. System efficiency is defined as equal to the total cooling output, in kilo-Watts *(kW)* of thermal energy, divided by the total power consumption *(kW)*. Similar efficiencies can be defined for either individual component, for example the coefficient of performance[2] *(COP)* of a chillers or for an entire system, referred to as the coefficient of system performance[2] *(COSP)*. This type of efficiency information is useful for comparing the relative performance of one system or component to another, but alone does not allow the energy consumption and therefore energy or environmental impact 'in-use' over a period of time to be determined since efficiencies are determined for specific conditions and for a set period of time. Actual operating conditions, required cooling loads and hours of use vary considerably due to the wide range of environmental, occupancy and building specific factors placed on the air conditioning systems in real buildings.

In practice this means that system efficiency under the corresponding ambient environmental and load conditions over the entire period of operation must be determined to assess a systems actual energy performance and environmental impact. Unfortunately, this means that the **assessment** of the actual energy performance and environmental impact of air conditionings, with an acceptable level of certainty, is quite difficult due to the number and variety of variables involved even for existing systems. Accordingly, the **prediction** of air conditioning energy performance is even more difficult and associated with higher uncertainty.

This research aims to establish the energy performance and environmental impact of UK air conditioning systems in practice, but to avoid the difficulties in determining actual system efficiency described above, this research has monitored the energy consumption of a number of air conditioning systems 'in-use' so that the relative performance of the different systems and their environmental impact can be determined very accurately for the case studies buildings chosen. This measured energy consumption inherently accounts for all the system and building design issues, operational and maintenance regimes, as well as the loads served and environmental operating conditions.

However, to say one system is better than another only because it uses less energy is an oversimplification, since the systems maybe serving different loads or required to operate for different periods of time, and systems might be very efficient even though consuming more energy. Therefore, this research will have to compare the energy consumption data at a number of levels including overall consumption, as well as normalise for the loads served and hours of operation in order to determine the relative performance of each system type.

2.1 FACTORS AFFECTING A/C SYSTEM ENERGY PERFORMANCE

There are many factors that affect the efficiency and overall energy consumption of an air conditioning system. This section briefly discusses the key factors relating to the energy performance of A/C systems in the UK. Definitive and detailed analyses of the subject are available from the CIBSE[3] and ASHRAE[4].

This section draws together the aspects relating to the energy performance of A/C systems in the UK from the various industry standards and guides, in order to identify the factors we would expect to influence the energy performance of A/C system in practice.

But based on first principals, the energy performance of an air conditioning system to provide comfort cooling should be determined by: the amount of cooling required to maintain comfort conditions within the occupied space, the efficiency by which the refrigeration components provide the required cooling, the efficiency by which the air conditioning system delivers the cooling to the occupied space, and the length of time that the cooling is required.

Where, the amount of cooling required is the total amount of heat that needs to be removed from the occupied space to maintain control on the upper temperature within the occupied space and thereby maintain the thermal comfort of the occupants. The total cooling load requires control over the maximum air temperature (sensible) and moisture content of the air (latent), but in 'comfort cooling' applications, as considered by this research, normally only directly control the sensible load. The cooling load is therefore determined by the net heat gains within the building from the various heat gains and loses. These typically include components from the building fabric via the conduction of heat through the materials of the building, the solar radiation entering the building through area of glazing etc, the out-door air entering the building through fabric infiltration and for ventilation, as well as, the gains from people and equipment occupying the building.

The efficiency by which the refrigeration components provide the required cooling is determined by the thermodynamic process of the refrigeration system. The refrigeration system uses the thermodynamic properties of a fluid i.e. the relationship between its temperature, pressure and enthalpy (energy content), to transfer heat from one substance to another[5]. In air conditioning applications this normally means removing heat from a medium that is used to cool the building and transfer it outside the building.

The thermodynamic cycle of refrigeration is based on basic physical principal that heat flows naturally from hot to cold, that heat energy is required to 'evaporate' a liquid into a gas, that heat energy is given out when a gas 'condenses' in to a liquid, and that the boiling and condensing temperatures of a fluid change depending on the pressure of the fluid[5].

The most common refrigeration cycle, vapour compression systems, use these basic principles to induce a repeating cycle of evaporation and condensation of a working fluid, known as the refrigerant, by mechanically changing the pressure placed on the fluid using an external compressor. Each time the refrigerant changes phase from liquid to vapour (evaporates) or vice versa (condensation) heat energy is absorbed or rejected from the refrigerant respectively. This heat energy is added or removed from the refrigerant cycle by heat-exchangers to other mediums, thereby transferring heat energy from one medium to the other.

The efficiency of this process, i.e. the amount of drive energy required on run the compressor and the amount of heat transferred, is highly dependant on the pressure enthalpy properties of the refrigerant used, as well as, the evaporating and condensing temperatures required to transfer heat to the exchange media. The evaporating and condensing, temperatures are determined by the heat-transfer properties of the exchange media (normally air or water), the size of the heat exchangers, and the required temperatures. This means that the efficiency of a given refrigeration system is determined by the difference between evaporating and condensing temperature, often referred to as the temperature lift, where the smaller temperature difference the higher the efficiency[5]. In building cooling applications this means the efficiency will be dependant on the difference between the required supply temperature to cool the building (air or water etc) and the out-door environment.

The efficiency by which the air conditioning system delivers the cooling to the occupied space is determined by the amount of energy used to transport and deliver the cooling in the building. However, the design of the air conditioning system will also influence the energy performance of the refrigeration plant by determining the supply temperature at which the chiller has to deliver its cooling (evaporating temperature) as discussed above.

The distribution system, whether air, water, or refrigerant based, will affect the energy performance of the system through the thermal properties of the distribution media itself, i.e. how much is needed to transport the required amount of cooling at the required temperature, the amount of energy used by the various fans and pumps to distribute the cooling media, which will depend on their performance properties of each fan or pump as well as the back pressure of the distribution duct or pipe work, and any heat lost throughout the distribution process.

The cooling delivery terminals affect the energy performance by the mechanism used of heat transfer used, i.e. convection or irradiation, whether or not they require any secondary heat transfers and the energy used by any terminal fan, controls or reheat systems.

Current UK Government energy efficiency guidance[6] identifies the six main categories of factors affecting the energy efficiency and power consumption of refrigeration plant, and therefore air conditioning systems, as: the load placed on the system, the environmental operating conditions, the component technology, the defrost method, the control of the system, the type of refrigerant used.

However, A/C systems generally consist of packaged components, and in particular chillers are commonly supplied as complete units[47]. It is therefore simpler to consider the type of refrigerant and method of defrost along with the component technology since each chiller unit would be designed for a particular refrigerant and defrost method. Importantly for the efficiency assessment undertaken by this research, the manufacturers design and testing data is normally provided for complete chiller units, taking into account all the factors involved with the whole chiller operation. Therefore throughout this research, the assessment of refrigeration component technology will be assumed to include refrigerant and defrost factors as part of the overall component technology of the packaged unit.

In addition to the factors affecting the refrigeration aspects of the system, the choice of services distribution and delivery system, i.e. the type of air conditioning system, can affect both the sizing of the refrigeration plant and the efficiency of the overall system[7]. This means that we must also consider plant sizing and system design as affecting the energy performance of A/C systems.

Finally, the refrigeration and air conditioning systems cannot be considered in isolation since the building and occupancy will also significantly affect A/C system performance though the buildings fabric, usage patterns, hours of use, control and maintenance of the various building and system components.

Therefore in this research we would expect the main factors affecting the energy performance of A/C systems to be the following:

- Load placed on the system
- Environmental operating conditions
- Refrigeration component technology (including refrigerant type and defrost method)
- Choice of distribution and delivery method (i.e. the type of A/C system)
- System design, control and maintenance

2.1.1 LOAD PLACED ON THE SYSTEM

The load placed on the system affects the energy performance of air conditioning plant by directly determining the amount of heating and cooling and the system has to provide, as well as affecting the efficiency of the system by influencing the design and sizing of the system[2]. The peak load is used to determine the capacity of the refrigeration equipment, as well as size of ancillary distribution and delivery components that in turn influence the choice of system, system configuration and building zoning.

However, even through air conditioning systems are sized for the peak load, actual building loads constantly vary and therefore refrigeration plant is rarely required to meet peak loads and must operate at less than full-load for the majority of the operational time. This means that in the UK chiller plant would typically operate at less than 50% capacity for nearly 90% of the time[8]. This in turn affects the overall efficiency because systems are often less efficient when operating under part-load conditions (see section 2.1.2).

The load placed on the system is therefore the total amount of cooling, or heating, required to maintain the desired environmental and comfort conditions within the occupied space. The load is a factor of the air temperature (sensible) and humidity (latent) difference between the ambient outdoor conditions and the desired indoor set point, as well as the net heat gains, or losses, from the various building, system and occupancy components. The component loads are most commonly a result of heat gains, or losses, from the buildings fabric, solar penetration, occupancy, small power equipment, and other building services such as artificial lighting and mechanical ventilation[1].

The component loads can be sensible or latent loads, where sensible heat gains are heat sources directly added to the conditioned space by conduction, convection, or radiation effects. Latent loads occur indirectly through the addition of moisture to the space i.e. vapour emitted from occupants, ventilation or air infiltration which affect the comfort conditions within the space. In order to maintain comfort conditions water vapour may have to be removed from the occupied space or incoming air, normally forcing condensation on cooling apparatus (whether by a dehumidification process or as a result of reduced air temperature from comfort cooling). The amount of energy required to remove this moisture equals the product of the rate of condensation and the latent heat of condensation[4].

The mechanisms of heat gain within the occupied space can be from direct solar radiation through transparent surfaces such as windows, conduction through exterior walls and roofs, as well as through interior partitions, ceilings, and floors. This is in addition to heat generated within the space by occupancy, equipment processes, as well as other building services, ventilation and infiltration of outdoor air. The following sections briefly describe many of the considerations and factors that affect the heating and cooling loads of a particular site.

Site considerations may dictate the built-form and orientation of the building, as well as, its services and operation. The building orientation affects the availability of daylight, heat gain and heat losses, wind effects all of which can be significant components of the loads placed on the A/C system.

Building fabric and solar loads, including the structure, materials, and installation will determine the amount of heat gained and lost through the building envelope, as well as, the buildings thermal response. Thermal response is a measure of the building's rate of heat exchange with the outside environment when subjected to cyclic variations.

It is beyond the scope of this review to discuss all the possible issues relating to specific building designs, although detailed technical guidance is available to designers from various sources. However CIBSE guidance[9] highlights the following issues that impact the fabric and solar loads for particular consideration:

- Building spacing and orientation and their impact on building shading and wind effects.
- Floor plan width to ceiling height ratio to achieve effective ventilation so that air flows across the zone in natural ventilation applications and sufficient height for stratification to lift heat and contaminants above the occupied space.
- Good solar control by sensible choice of glazing ratios and shading provision to limit direct solar penetration when cooling is required, but also allowing appropriate natural lighting levels and useful solar gains when heating is required.
- Openings in the external facades to provide appropriate access and air flow paths.
- Consideration of design utilising the buildings thermal capacity, exposed soffit design details etc, to absorb heat gains.
- Air-tightness to minimise energy losses and cold draughts in winter and to assist the controllability of ventilation.

Other **Building Services** including heating, lighting, and ventilation systems also contribute to the overall loads and can also impact on the operation of A/C systems. The design, operation, and control of all services, especially independent heating systems, must be carefully designed and operated to avoid conflicts between different systems.

Conflicts between different services can have a significant impact on the loads and therefore the energy consumption, running costs and thermal comfort of building services. Conflicts can occur when there is a wide variation in the requirement for heating and cooling between different zones or where independent heating and cooling systems are servicing the same space at the same time. Appropriate zoning, system selection and control should enable various loads to be serviced without systems conflicts. Furthermore simultaneous heating and cooling within a building can also afford opportunities for heat recovery and other energy efficiency measures.

Artificial lighting systems emit heat energy to the occupied space, by convective heating of the room air and radiation heating effects via other surfaces within the space, thereby increasing cooling loads. Artificial lighting systems are often a significant component of the total internal heat gains[10] and careful integration of electric lighting systems in to the overall design is essential to minimise its impact on the operation of the HVAC systems. Guidance recommends attention is paid to minimising internal gains from the lighting through:

- The selection of appropriate light levels, differentiating between permanently occupied workspace and circulation areas and the use of task lighting should be considered to provide individuals with the option to increase light levels locally[11].
- The selection of efficient light fittings with installed lighting power load in offices of 10-12W/m2 is considered best practice[9].
- The installation of an appropriate lighting control system, linked to a combination of time, occupant presence or light levels[12].
- Consideration of the impact of the lighting system on the ventilation strategy using up lighting with exposed thermal mass or ventilated light fittings to reduce internal gains[9].

Ventilation, fresh air must be introduced to conditioned spaces for ventilation purposes, but is typically at different temperature and humidity conditions to the conditioned space depending upon the external weather conditions. This will therefore have a varying effect on the internal conditions, as well as the heating and cooling loads depending upon the difference between the indoor and outdoor conditions, as well as the required ventilation rate.

However the introduction of ventilation air through mechanical ventilation systems can be used to offset cooling load at times when the external enthalpy conditions are below that of the conditioned space, providing so called "Free Cooling"[9].

Building usage factors including occupancy, small power loads and usage patterns contribute to the heating and cooling loads placed on the HVAC systems. Occupancy levels of the building result in internal heat gains from the heat and moisture given off from the occupants. These sensible and latent heat gains can constitute a substantial component of the total internal heat gains within a building[10].

In addition, any heat or moisture generating equipment, processes or activities that are contained within the space will contribute to the internal heat gains, as well as the overall sensible and latent cooling load placed on A/C systems. In office environments this type of load is often referred to as "small power loads" and includes heat gains from personal computers, printers and photocopiers etc[13].

2.1.2 ENVIRONMENTAL OPERATING CONDITIONS

The ambient weather conditions and microclimate at the building's location will affect the energy performance of air conditioning by imposing heating and cooling loads on the HVAC system. They also determine the operating conditions of refrigeration plant and the efficiency of heat rejection equipment, as well as the feasibility of energy saving measures such as 'free cooling'.

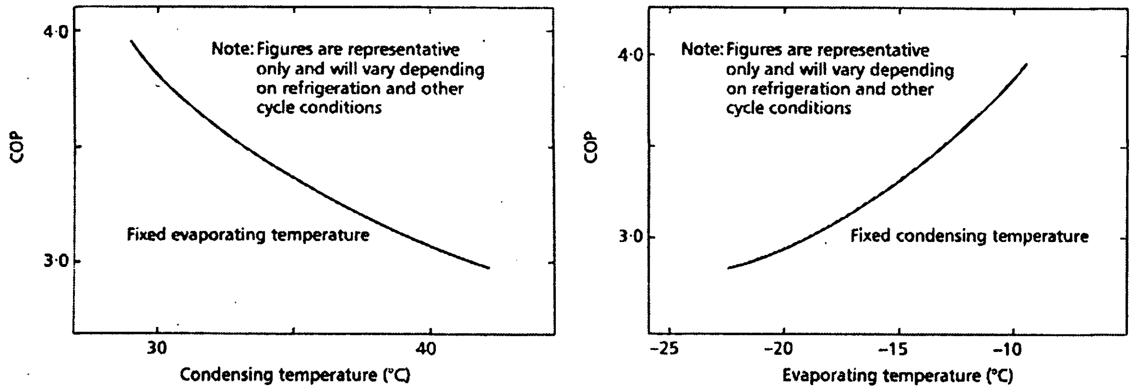


Figure 2.1.1 Condensing and evaporating temperature vs. COP[14]

The operating conditions of refrigeration plant affect the power consumption and thermal output of refrigeration plant, and therefore energy efficiency (usually stated as Coefficient of Performance - COP), through the temperature (and pressure) difference between evaporation and condensation of the refrigerant. This temperature difference is also known as the temperature lift. The temperature lift is related to refrigeration efficiency and system capacity[14], where larger the temperature 'lift' the lower the efficiency and system output, as shown in Figure 2.1.1. The smaller the temperature 'lift' between condenser and evaporator the higher the refrigeration efficiency and output. Typically a reduction of 1K in the required temperature lift reduces refrigeration energy use by around 3%[7].

In addition, the outdoor temperature and humidity affect the efficiency of heat rejection equipment by influencing the rate of heat transfer between the external environment and the refrigerant (or secondary cooling medium) aspects of an air conditioning system. The rate of heat transfer is a function of the size of the heat exchangers, the specific heat capacity of the exchange medium, the temperature difference, the humidity of the outdoor air, and the flow rates of both the delivery medium and the outdoor air[2]. These factors affect not only the efficiency of heat rejection from the system, but by doing so also influence the condensing temperature and required temperature lift. This affects the overall efficiency of the refrigeration system, limiting the maximum heat rejection potential and the cooling output of the system for a given system configuration and environmental conditions[15].

However, the temperature lift required of refrigeration plant can be determined (within limits) through the selection and design of the system components. Low condensing temperature can be achieved when ambient conditions are cold as a direct effect of the external weather conditions, or by installing larger more efficient condensers[15]. Similarly, higher evaporating temperatures can be achieved by raising the temperature of the fluid being chilled, as in chilled ceiling systems or with variable supply temperatures, or by installing larger more efficient evaporators[15].

Since the refrigeration components are normally a significant proportion of the total air conditioning system energy consumption[16], variation in refrigeration efficiency will impact the overall energy performance of the system.

In UK office buildings we might expect to have relatively long periods during the year when outdoor temperatures are relatively low but there is still a cooling demand due to internal gains. The resulting 'low' condensing temperatures and potentially 'high' heat rejection efficiency means that overall refrigeration efficiency should be relatively high during these periods if the plant is appropriately sized and operated for good part-load performance.

However, peak summer conditions will still determine the overall cooling capacity required of a system to meet the maximum cooling demand. During peak summer conditions the required high temperature lift and reduced heat rejection potential in theory lead to a reduced overall efficiency and output from the refrigerant system. However, this will not necessarily result in poor refrigeration efficiency due to higher system loads, where chiller plant is typically more efficient and the background energy consumption of the A/C system becomes proportionally less of the total system energy consumption.

2.1.3 REFRIGERATION COMPONENT TECHNOLOGY

This section reviews the relative impact of the different refrigeration component technologies commonly used in UK air conditioning applications. In general there are normally two main refrigeration cycles to consider, vapour compression which are mechanical systems normally driven by electrical motors and absorption systems which use chemical properties of solutions driven by heat. The choice of refrigeration cycle will have a significant impact on the overall system efficiency, since in terms of delivered energy vapour compression chillers can have a coefficient of performance (COP), typically up to 4.0 and absorption systems typically up to 1.2[15]. Although, the efficiency difference in carbon terms is not as great if you consider the primary energy of the different fuel types[15].

Whichever generic refrigeration type is selected the selection of efficient individual components including condensers, evaporators, expansion valves, compressors and fans is essential to achieve high overall efficiency. But because chiller systems are normally manufactured and their performance rated as packaged units[47] it is therefore simpler to consider the efficiency of the entire unit taking into account the net effect of the individual components, the type of refrigerant utilised and the method of defrost. A comparison of chiller energy efficiency is discussed in section 2.3.1.

This section will discuss the relative impact of different components on refrigeration efficiency. Guidance on the selection of refrigeration cooling and heat rejection systems is provided in British Standard 378[17], which summarises and classifies the main refrigeration types. Table 2.1.1 provides a summary of the main configurations of refrigeration systems and their relative advantages. In addition, the basic refrigeration configuration and evaporator or condenser type the compressors, choice of refrigerant etc also affect the efficiency of the system.

Table 2.1.1 Summary of primary refrigeration configurations

Cooling Systems	***Description***	***Comments***
(a) Direct Expansion	The refrigeration system evaporator is in direct contact with the space to be cooled	Most efficient cooling system but risk of refrigerant leaks in occupied areas and may have relatively large refrigerant charge.
(b) Indirect Open	A refrigeration system cools a heat transfer medium which is in direct contact with the space to be cooled.	May use an air washer or spray coil to cool air. However, hygiene risks mean these systems are not commonly used.
(c) Indirect Closed	A refrigeration system cools a heat transfer medium which passes through a closed circuit (heat exchanger) in direct contact with the space to be cooled.	Widely used with chilled water as heat transfer medium. However less efficient than (a) or (b) due to additional heat transfer process. Safer than (a) because refrigerant is isolated from occupied space.
(d) Double Indirect	A combination of indirect open and indirect closed systems, where a cooled heat transfer medium passes through second heat exchangers.	Two heat transfer processes mean these system configuration is not efficient. Normally only used for increased safety by keeping refrigerant out of occupied areas.
Heat Rejection Systems		
(e) Air-cooled Condenser	Fans induce air flow over finned tubes in which the refrigerant condenses.	Convenient and common condenser system. Free of hygiene risks and does not require secondary heat transfer medium. Can be adapted for free cooling from thermo-siphon system.
(f) Dry Air Cooler	Similar to air cooled condenser uses secondary heat transfer medium instead of refrigerant.	Less efficient than air cooled condensers due to secondary heat transfer process and condenser circulating pumps. Can be used to provide free cooling during cold weather periods.
(g) Cooling Tower	Evaporative cooling system, where water is sprayed over packing material and airflow over which evaporates some of the water.	More efficient than air cooled condensers or dry coolers because less air is required. Can be used to provide free cooling during cold weather periods. High maintenance.
(h) Evaporative Condenser	Water is sprayed over tubing in which refrigerant condenses. Airflow across the tubing evaporates some of the water causing the water and tubes to be cooled.	Most efficient method of rejecting heat from refrigeration plant. High maintenance similar to cooling towers. Can be adapted for free cooling from thermo-siphon system.

Source: British Standard 378[17]

In **vapour compression systems**, the compressors are an integral part of the refrigeration system and contribute to the overall refrigeration efficiency. There are a number of generic compressor types including reciprocating (piston, cylinder and valve assemblies similar to combustion engines), centrifugal (compression of refrigerant by centrifugal force created by rotating blades), screw (two counter-rotating and intersecting screws within a common casing) and scroll (interlaced coiled plates driven in eccentric motion on a crank shaft against a fixed scroll plate), which are commonly used in vapour compression systems[18].

However, which ever compressor type it is essential to match the selected compressor to the duty, required temperature conditions and refrigerant type, since compressor efficiency can vary by more than 20%[6] between different units of similar type due to pressure drops, restrictions to gas flow and unwanted heat transfer within the system.

Additionally, each generic type can be either Hermetic (drive motor and compressor are sealed into a common gas tight casing), semi-hermetic (sealed case with access for maintenance), or open (separate motor and compressor) as most systems utilise electric motors to drive the compressor. Whether a compressor is hermetic or not will have an impact on its potential efficiency and maintenance requirements as Hermetic and Semi-hermetic compressors are generally optimised with motors selected specifically for the compressor, duty and refrigerant utilised and therefore tend to operate relatively efficiently, while open compressors require the motor to be selected to match the compressor and the design load which can lead to reduced efficiency if improperly sized[7].

However, larger hermetic and semi-hermetic compressors (5kW+) often use suction cooling of the motor, by passing refrigerant over the motor windings, but this reduces the capacity and efficiency of the system in cooling mode and means externally cooled motors are usually about 8% more efficient[6]. This is the reason why many reverse cycle systems are more efficient and have a higher capacity in heating mode by utilising the heat from cooling the motor.

Absorption refrigeration, while not as efficient in terms of delivered energy use as vapour compression systems, can be practically applied if powered from waste heat sources or when combined with co-generation systems. The term 'sorption' refers to both 'adsorption' and 'absorption' refrigeration systems where a refrigerant is evaporated by heating and then absorbed in vapour form by a liquid absorbent solution or solid adsorbent material[7]. Absorption refrigeration is similar in principle to vapour compressor systems, expect the compressor is replaced by a heat operated generator and absorber assembly[7]. Absorption chillers come in a number of generic types which include single effect, double effect, and generator / absorber heat exchange (GAX) and double alternating absorption systems and all use working pairs of refrigerant and absorbent which include combinations of `Water (H_2O), Lithium Bromide (LiBr), Ammonia (NH_3) and silica-gel. The efficiency (COP) of the systems currently available on the market range from around 0.5 to 1.2 depending on the system type, working pair and application[19].

However, due to the low numbers of absorption air conditioning systems currently operated in the UK, this research has not studied their performance and is therefore to some extent beyond the scope of this review, but we would expect absorption driven air conditioning systems to be less efficient than equivalent vapour compression systems, at least in terms of delivered energy use.

Refrigerants are fluids which evaporate and condense under useful temperature and pressure conditions; and a wide range of fluids can be used in refrigeration systems[7]. However, no single refrigerant satisfies all the required properties and therefore a range of refrigerants are commercially available for refrigeration and air conditioning applications that meet various performance, safety, and reliability criteria. A number of standards are available which provide guidance on the selection of suitable refrigerants and will not be discussed here in detail, but because the thermal properties of refrigerants differ depending on the refrigerant used, the refrigeration equipment used and the operating conditions the refrigerant selection will have an impact on the efficiency of any given air conditioning application[6]. The energy efficiency implications of the various refrigeration components including choice of refrigerant will be assessed in a review of whole chiller performance (section 2.3.1).

Furthermore, refrigerants are increasingly becoming the target of policies restricting their use due to their tendency to be Ozone depleting materials, significant greenhouse gases, as well as, highly flammable or toxic. Therefore refrigerant use is restricted by legislation including international treaties on ozone depletion[20] and greenhouse gas emissions[21], as well as, national health and safety legislation which will have implications for the energy performance of future air conditioning technology, including the type of refrigeration equipment available. The legislative implications regarding refrigerants are discussed in more detail in section 2.6.

Traditional refrigerants used in air conditioning include Chlorofluorocarbons (CFC's), Hydro chlorofluorocarbons (HCFC), and Hydro fluorocarbons (HFC). However, CFC and HCFC refrigerants have, or are being, phased out and will no longer be available due to their ozone depleting and greenhouse gas properties. HFC refrigerants are typically also significant green house gases so their long term future is probably limited and are viewed by policy makers as transitional refrigerants only[21]. However, during the period of field monitoring, April 2000 to December 2002, most UK air conditioning systems and most of the systems monitored used HFC refrigerants (R407c, R134a, and R410a) and some older systems were using HCFC refrigerants (R22). However, in the long-term 'alternative' refrigerants will be increasingly used as their associated technology is developed[21] and as legislation continues to restrict the use of traditional refrigerants.

Natural refrigerants are fluids that naturally exist in the biosphere and generally have lower environmental drawbacks, i.e. low ozone depletion and global warming potentials, than traditional refrigerants. Therefore they are seen as long-term alternatives to traditional man-made refrigerants[21]. Natural refrigerants include ammonia (NH_3), hydrocarbons (i.e. propane), carbon dioxide (CO_2), air and water. Although there are some significant drawbacks which include lower efficiency, high flammability or toxicity which have to be over come before they are more widely used.

Ammonia (NH_3, R707) for example has excellent refrigeration and economical properties making it an excellent alternative to CFC and HCFC refrigerants but is highly toxic and must be used in specially designed plant for safety and materials compatibility[7]. The field monitoring undertaken in this research includes an example ammonia chillers system.

Hydrocarbons (HC) are well known refrigerants with favourable thermodynamic properties. They include propane, propylene and blends of propane, butane, ISO-butane and ethane, and are all regarded as promising hydrocarbon refrigerants for air conditioning applications[7]. However, due to their high flammability, hydrocarbons are normally only applied in systems with low refrigerant charge[17].

Water is an excellent refrigerant for high-temperature air conditioning and is neither flammable nor toxic. The major disadvantage with water as a refrigerant is its low volumetric heat capacity that requires large and expensive compressors, especially for low temperature operation leading relatively poor efficiency and high maintenance requirements especially in open systems[2].

Carbon dioxide (CO_2) is a good refrigerant that is attracting growing attention because it is non-toxic, non-flammable, has a nominal global warming potential and is compatible with most normal lubricants and equipment construction materials[22]. However, the theoretical efficiency (COP) of a conventional air conditioning cycle with CO_2 is relatively poor. Therefore practical application of CO_2 depends on the development of improved efficiency systems. Prototype CO_2 chillers are under development and continue to improve systems and component efficiency[22].

Method of defrost

Frost can build up on the outside of air-side evaporators when operating at refrigerant temperatures below 0°C which can significantly reduce the heat transfer efficiency and air flow across the unit leading to increased energy consumption and reduced capacity[6]. In building HVAC applications this is of particular concern for reverse cycle and heat pump systems when in heating mode, where the "cold" evaporator is exposed the outdoor air.

During periods of ice formation fin-tubes must be defrosted periodically to maintain adequate air flow over the evaporator. This process is achieved by the application of heat which requires extra energy and may place additional load on the refrigeration system[6]. Therefore unless carefully controlled to minimise the use of defrost cycles the overall system efficiency and energy consumption can be affected.

In practice it is hard to tell exactly how much energy is used for defrost and its relative effect is not likely to be identifiable from laboratory performance data or in field monitoring unless individually monitored.

Thermal storage systems, typically ice storage, are normally employed to enable 'load shifting', or the manipulation of energy demand profiles[7]. In building HVAC applications ice storage systems are typically employed over night, when energy demand and tariffs are lower, to store 'coolth' for use by air conditioning systems during the day. Their appropriate application can lead to reduced energy costs by avoiding peak tariffs, reduced greenhouse gas emissions by minimising peak generation load periods, and reduced chiller plant size[7].

However, Ice storage is inherently inefficient through the process of 'making ice' followed by 'melting ice'. In addition, lower evaporating temperatures are required to make ice compared to chilled water reducing the efficiency of refrigerant plant which maybe as much as 15-20%[23]. Although these efficiency losses can be minimised if the refrigeration system is controlled in a manner that allows the condensing temperatures to 'float' with the lower night time out-door air temperatures[24].

Most buildings that require cooling throughout the year have the potential to use **free cooling** to minimise or eliminate the need to operate chiller plant[15]. The term 'free cooling' refers to a number of techniques including environmental free cooling (direct use of ambient air or water source for building cooling), chilled water free cooling (use of separate dry coolers or water towers to directly cool chilled water system without running the chiller), condenser water heat recovery (use of dry cooler or cooling tower to pre-cool the return water to a chiller), and thermo-siphon chillers (use of temperature / pressure difference to operate a chiller without running compressors) which can all be used to provide cooling by drawing 'coolth' from the external environment during periods of relatively cool ambient conditions[7].

However, these techniques often require large quantities of air or water to be moved which can lead to substantial transport energy consumption. Therefore careful consideration of free cooling use must be given to ensure that the overall energy consumption not higher than would have been consumed had the refrigeration plant been operated instead. Therefore, the amount of time these techniques can be used through out the year is important to determining their impact on the overall energy consumption of the system and the economic viability of free cooling applications.

However, the selection of appropriate air conditioning system can maximise the opportunity for free cooling operation. Systems that require relatively high air or chilled water supply temperatures, such as chilled ceilings or displacement ventilation systems, are more likely to be able to benefit from free cooling techniques for longer periods throughout the year[9].

2.1.4 CHOICE OF DISTRIBUTION AND DELIVERY SYSTEM

The strategy for the distribution and delivery of cooling to the building occupants, or in other words the type of air conditioning system utilised, will affect the overall energy performance of the air conditioned buildings by influencing the sizing and operating conditions of refrigeration plant[7], indirectly due to the inherent efficiency of the delivery medium (air, water or refrigerant)[2] and by determining the type and quantity of secondary power loads associated with the distribution and delivery of cooling to the occupied space[9].

We would expect some generic system types are inherently more energy efficient than others, but definitive information on which systems are the most efficient in practice is difficult to determine because of the number of building occupancy and environmental variables involved, as well as, the different level of service provided by different generic systems types.

The Chartered Institute of Building Services Engineers (CIBSE) currently categorises the selection of air conditioning systems (cooling distribution) into the following three main categories[9]:

1. Centralised air systems.
2. Partially centralised air-water systems.
3. Local air conditioning systems.

The current CIBSE air conditioning classification system, as reproduced in Figure 2.1.2 is based on UK Government best practice guidance[54] updated to include other innovative systems from the International Energy Agency (IEA)[25]. However there is a wide range of air conditioning equipment available for a wide variety of applications which will not be discussed in this review. Instead, this review will focus on systems commonly used for comfort cooling applications in UK office building at the time when the field monitoring was undertaken, in line with the scope of this research (section 1.1). Therefore this review will not discuss in detail the 'innovative' systems as they were not included in the monitoring sample, although it is recognised that many of these 'innovative' systems have potential energy or environmental benefits over traditional systems.

2.1.4.1 Centralised air systems

Centralised air systems employ central conditioning plant and air distribution systems, is used to treat and move all the conditioned air to the occupied zones where it is mixed with the room air in order to maintain the desired comfort conditions and normally also supply fresh air for ventilation[27]. These systems are generally based around central plant rooms which typically containing air handling units (AHU), chillers, boilers and heat rejection equipment, although they can also be deployed as packaged system often located on rooftops.

The principle advantages of centralised air systems include relatively simple maintenance and control, as well as opportunities for 'heat-recovery' between different items of plant, since the majority of the equipment is located together centrally[26]. The centralised format also enables easier modulation of multiple chillers to match load conditions leading to reduced requirement for part-load operation. Centralised air systems can also benefit from 'free-cooling' through the careful use of mechanical ventilation of outdoor air into the occupied space during periods of cooler weather (see section 2.1.3).

The principle disadvantages of centralised air systems is the larger space required for the central plant and distribution ducts[15], the relative inefficiency of air as a delivery medium requiring more energy to temper the air to the desired condition compared to water or refrigerant[2], and the lower distribution efficiency of air when compared to water or refrigerant systems[2].

Common all-air system types include single and multi-zone constant volume systems (CV), variable air volume (VAV) systems and dual duct system variants. More innovative centralised air systems may employ desiccant, evaporative, or ground air cooling strategies[25] but these will not be discussed as none were included in the monitoring sample.

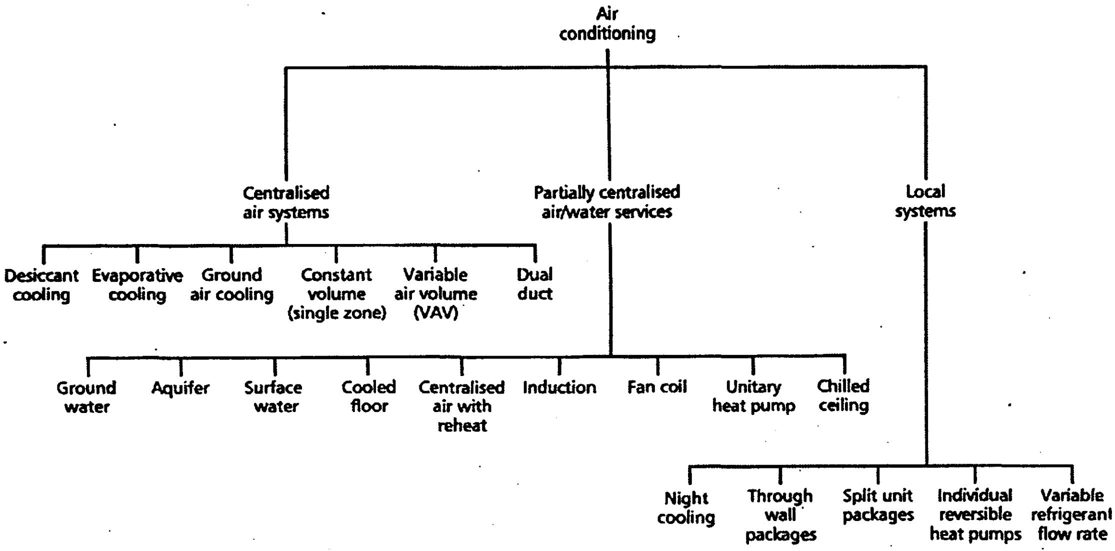


Figure 2.1.2 CIBSE classification of air conditioning systems[27]

Constant Volume (CV) systems supply conditioned air, and normally fresh ventilation air, to the occupied space from central air handling equipment and typically extract room air back to the atmosphere[27], as shown in Figure 2.1.3. The heating and cooling loads of the building are met by changing the temperature of the supply air. These systems are generally quite simple to commission and maintain, but are unlikely to provide adequate control for zones with widely differing heating and cooling requirements. Multi-zone re-heat CV systems can serve multiple zones with varying loads, where supply air is re-heated by heater batteries in the supply ductwork to each zone to the desired temperature. However, re-heat systems are generally inefficient, due to the energy used when centrally cooled air is subsequently reheated.

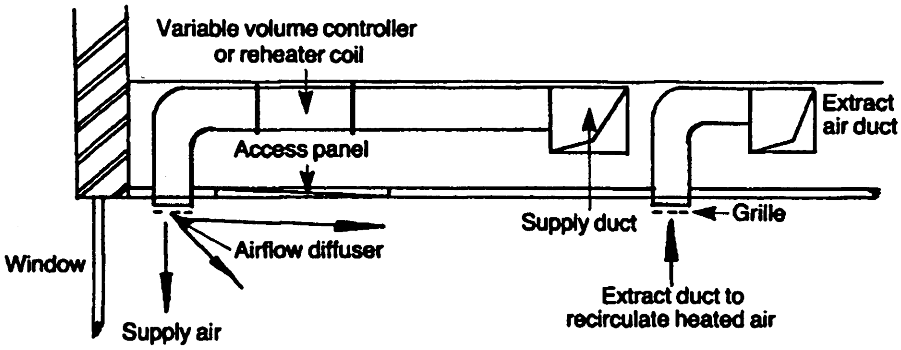


Figure 2.1.3 Single duct all-air system[27]

Variable Air Volume (VAV) air systems are often selected because of their perceived economy and controllability when applied to multiple zones of similar use for comfort cooling purposes[2]. Similar to CV systems, VAV systems supply conditioned air to the occupied space from centralised air handling plant, as shown in Figure 2.1.3. However, VAV systems meet differences in the loads by varying the volume of air supplied to each zone using thermostatically controlled dampers (VAV boxes), which reduce the airflow at the point of supply to the required level to meet the load within that zone. Therefore VAV systems can benefit from improved energy efficiency due to the reduced air supply requirements during much of the year compared to CV systems, but the individual VAV boxes do require some maintenance.

Variations of VAV systems include terminal re-heat, fan assisted VAV boxes, where terminal re-heat batteries are used to meet wide variations in load or simultaneous requirement for heating and cooling. Fan-assisted VAV systems use additional fans within each terminal unit to enhance room air movement (without the need to operate the central plant) improving control over localised conditions.

Dual duct air systems variants employ two ducts to distribute both cooling and heating air to each zone and can be employed in both CV and VAV systems. Mixing boxes located within each zone mix the heated and cooled supply air in appropriate proportions to meet the local load, as illustrated in Figure 2.1.4. Therefore, dual duct systems have the ability to deal with wide ranging heating and cooling loads simultaneously. However, the central plant and distribution systems tend to be much larger, more costly and energy intensive than other systems[27], because of the potentially large quantities of air required to conditioned and distributed.

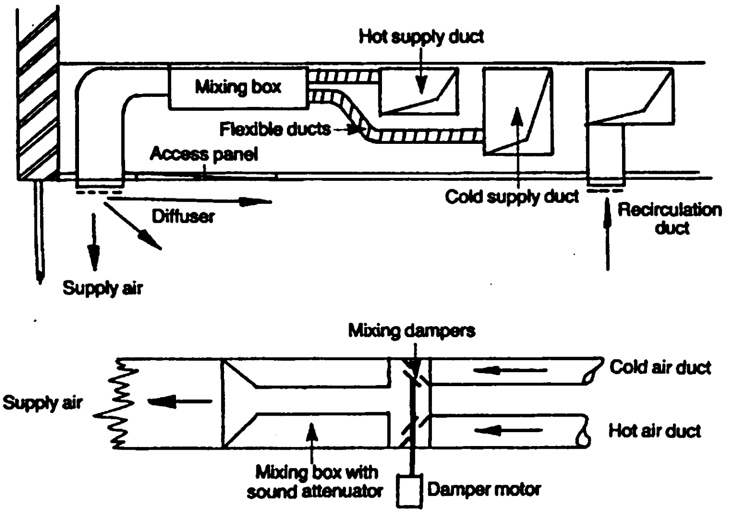


Figure 2.1.4 Dual duct all-air system[27]

2.1.4.2 Partially centralised Air-Water systems

Partially centralised Air-Water systems usually employ central plant to provide heating and cooling water to distributed terminal equipment which to condition the occupied room air. These systems normally operate in conjunction with separate mechanical ventilation systems to provide fresh ventilation, but alternatively natural or hybrid ventilation strategies can also be employed.

Principle advantages of partially centralised systems include the perceived ability of the systems to cope with varying loads and reduced space requirements for plant and distribution equipment, when compared to all-air systems, while also being able take advantage of 'free cooling' and 'heat recovery' between different items of plant[9]. In addition the use of water as the delivery media lead to greater heat transfer efficiency and lower distribution energy consumption when compared to air systems due to their better heat transfer and pumping properties[2].

However, due to the minimal fresh air ventilation rates normally associated with partially centralised systems limit humidification and dehumidification capacity[9], although close control of humidity is not normally an issue in comfort cooling applications within UK office buildings[1]. Additionally, partially centralised water systems that employ a '3-pipe' distribution strategy, with common return for heating and cooling water, are normally considered wasteful of energy[9].

Partially centralised systems include fan coil, induction, chilled ceiling and unitary heat pumps systems, but also technically include centralised air systems when 'water based' terminal re-heat is employed[9]. Innovative partially centralised systems include ground, aquifer, or surface water cooling strategies and cooled floor systems[25].

Fan-coil systems (FCU) are a generic type of partially centralised air-water systems that deliver conditioning via terminal fan-coil units located around the building. Fan-coil units re-circulate room air mixed with fresh ventilation air across water-air heat exchangers by means of a small fan, the heat exchangers provide either heating or cooling supplied by water circuits from central plant, as illustrated in Figure 2.1.5. Fan-coil systems come in two general types, 2-pipe 'changeover' that provide either heating or cooling depending upon their mode of operation, and 4-pipe 'non-changeover' systems which can provide both heating and cooling simultaneously from individual terminal units. However 2-Pipe systems often use electric reheat batteries to deal with variations in loads between zones.

Principle advantages of fan-coil systems include: reduced size or elimination of air handling component compared to centralised air systems, simplified control over temperature in individual zones, high cooling capacity and the flexibility to accept changes in load, system or building layout[27].

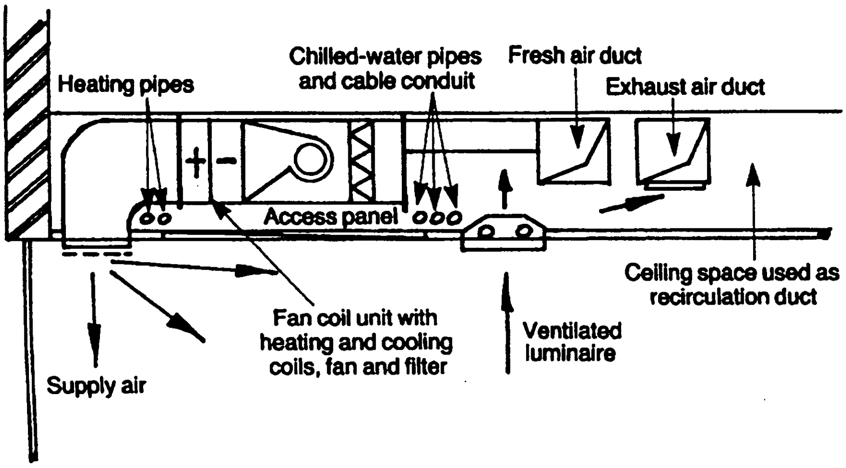


Figure 2.1.5 Example 4-pipe fancoil system (ceiling mounted) [27]

Induction systems are a type of partially centralised system that use terminal induction units that utilise high velocity primary air jet to 'induce' room air to flow over a heating or cooling coil[9]. Where the heating and cooling coils are supplied by a water circuit supplied from central plant equipment. There are two main configurations, 2-pipe systems which either change-over between heating and cooling mode or operate in conjunction with a separate heating system and 4-pipe non-change over systems that incorporate separate heating and cooling coils within each unit which are feed by separate heating and cooling circuits respectively[28].

The primary benefits of induction systems include individual zone control of temperature, as well as reduced size of ventilation plant and distribution ductwork. However, the high velocity of supply air required to induce sufficient room air movement means induction systems to operate at higher pressures than other all-air systems, resulting fan power and energy consumption penalties[9], and can lead to noise problems within the occupied space.

Chilled Ceilings are a generic type of partially centralised air-water comfort cooling system, which include three basic types, passive chilled beams, active chilled beams and radiant ceiling panels, as illustrated in Figure 2.1.6. All three basic types work on the same basic principle, where chilled water from central chiller plant, is pumped around the building to the 'chilled ceilings' (beams or panels etc) which are in direct contact with the occupied space. Cooling is delivered directly to the room air via a combination of direct irradiative effect and convection. The principle difference to other system types is the inclusion of the direct irradiative component in the cooling delivery.

'Passive' beams and chilled ceiling panels rely on radiation and natural convection in the transfer of cooling to the occupied space, with ventilation air is introduced separately. Active beams utilise forced convection to increase the amount of heat transfer from the chilled water circuit, in some cases with fans, similar to fancoil units, but normally by mechanically supplying ventilation air over the chilled beam elements.

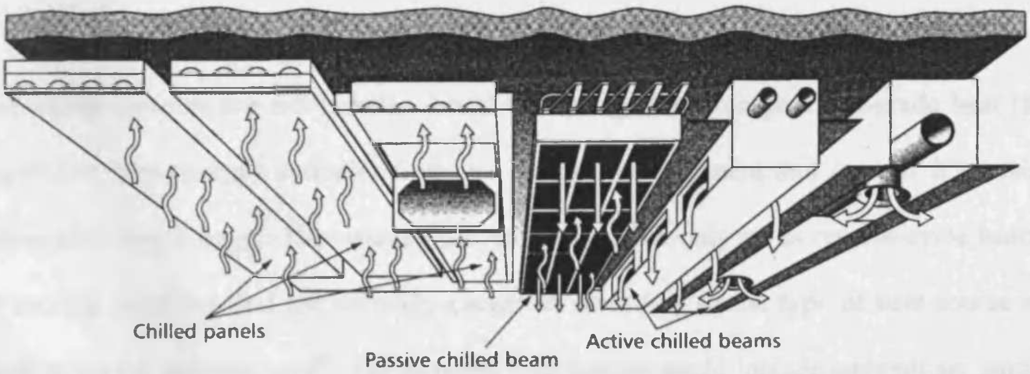


Figure 2.1.6. Dual duct all-air system[9]

Chilled ceiling systems are generally not able to meet high cooling loads, but typically can be used for cooling loads of between 40-120 W/m2 with active beams most suited to serving higher cooling loads in the 70-120 W/m2 range[29].

The principle attraction of chilled ceiling systems has been perceived superior comfort and air quality levels, and in theory, superior energy efficiency compared to other comfort cooling systems, although possibly at higher capital cost[29]. The superior energy efficiency results from the combination of a number of issues including the direct radiant cooling component which means comfort can be maintained at higher room air temperatures reducing the overall cooling load[2] and higher supply water temperatures, typically of 13-18°C for chilled ceilings instead of 4-6°C for other water or air systems, resulting in higher evaporating temperatures and improved chiller efficiency[30]. Research conducted in Hong Kong suggests this improved efficiency could be around 25%[31] from the chiller alone.

The risk of condensation on the surface of chilled ceilings elements has been a major design issue in the UK, with fears over the relatively wet climate of the UK. Various condensation avoidance strategies have been developed to minimise or eliminate the condensation risk[32], but in principle the selection of an appropriate system control strategy and set point should eliminate the risk of condensation.

Heat-pump systems are refrigeration based technology that transport low-grade heat (low temperature heat energy) normally from the external environment and convert it to useful (high-grade) heat energy. Heat-pumps can operate in heat-only or as reverse-cycle heating and cooling machines and are normally classified according to the type of heat source and heat distribution medium used[9]. For example heat sources could include ambient air, surface water or the ground using closed water loop and the distribution system could be air systems (CV or VAV etc) or water systems (radiators, under floor heating etc).

The theoretical efficiency of heat-pumps can be very high and are generally considered the most efficient method of providing heating in terms of delivered energy because of the additional energy drawn freely from the environment or waste sources[33]. In practice once all the associated fans, pumps and controls associated with the entire heat-pump and distribution system are accounted the actual efficiencies can be greatly reduced. A typical 'air-to-air heat-pump' in theory may have a COP of 5 but a system COP of 2.3 once all the system loads are taken into account, leading to a seasonal efficiency of 2.5 to 3.0 COP[9].

In building HVAC applications we would therefore expect buildings using heat-pumps to be more efficient than other heating systems. This should also be the case for building using reverse-cycle systems to provide heating and cooling, although albeit at slightly reduced efficient since the refrigeration components will have a configuration that comprises for both heating and cooling operations and will not be optimised for just heating or cooling[7].

However, heat-pump operation can be further improved by heat recovery operation or through the use of renewable primary energy sources[9]. Unitary heat-pump HVAC applications in buildings utilise the efficient heating advantages of heat-pumps but can also recover heat from different parts of a building when there is a simultaneous requirement for heating and cooling[34].

Unitary heat-pumps systems comprised of multiple terminal heat-pumps / conditioners linked to a closed water loop which is maintained at a constant temperature by central plant. Each individual 'heat-pump' provides either heating or cooling to the occupied space using a small refrigeration system drawing heat from, or rejecting heat to, the closed water circuit depending upon its mode. These systems can effectively handle wide variations in heating and cooling loads and when occurring simultaneously can result in significant energy savings by recovering heat from one area of a building that requires cooling to heat another reducing the operation of central conditioning plant.

However, each of the distributed terminals units is a refrigeration system in itself and can therefore sometimes be noisy and must be maintained individually, often incurring high maintenance costs, as well as, substantial disruption to occupants.

2.1.4.3 Local Air Conditioning Systems

Local Air Conditioning Systems include packaged 'through wall units', split direct expansion (DX) systems, variable refrigerant flows systems and packaged reverse cycle heat-pumps, which within building HVAC applications can be used to provide heating, comfort cooling and filtration[9]. Local AC systems often work in conjunction with separate ventilation, heating or humidification systems.

In general local systems may have lower efficiencies (COP) than centralised plant but can still be successfully used to provide energy savings through reduced distribution losses and simplified heat rejection, as well as, their ability to confine operation only to zones requiring serving and therefore control over operational periods[9].

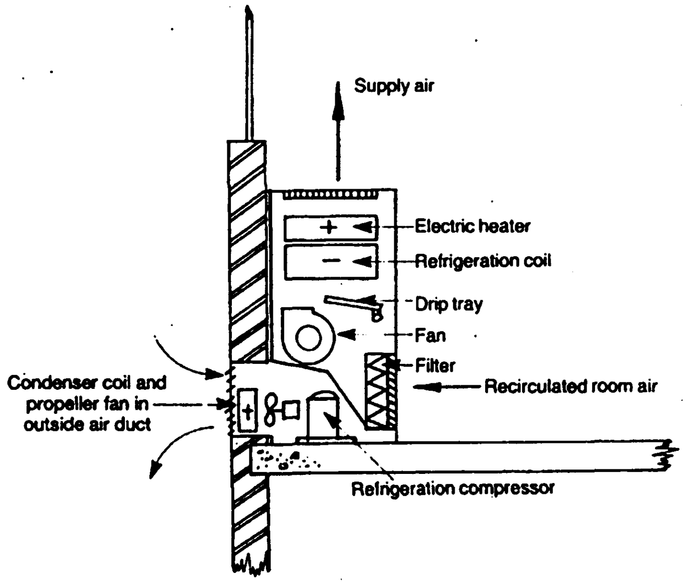


Figure 2.1.7. Packaged unitary DX system (thru-wall) [27]

Packaged and Split Unit Packages are a common format of direct expansion (DX) systems, which include mobile units, through-wall (as shown in Figure 2.1.7) or window box units and split system configurations. Where air conditioning is delivered to the occupied space directly from the evaporator of the refrigeration cycle itself located in contact with the room air, without the using a secondary distribution media with its associated heat transfer and distribution losses. The principle advantages of DX systems is their high cooling capacity, fast response and their theoretical 'system' efficiency achieved by not requiring secondary distribution media. Other advantages include being self-contained requiring only an appropriate power supply and outside side or wall space to be mounted requiring little or no plant-room space within the building.

The fundamental difference between splits and other format systems is in that the condenser and evaporator are split into separate units with connecting refrigerant lines, therefore not requiring an external wall or roof locations and keeping compressor noise from the occupied space. In some systems multiple internal units are linked to a single external condenser / compressor unit, which are refereed to as multi-split packages.

Variable Refrigerant Flow (VRF) systems are advanced variants of DX multi-split systems, where several internal units are connected to one external unit where refrigerant in various states (fluid, vapour, or mix etc) and temperatures can be supplied to the internal units depending upon the demand of heating and cooling required using single variable speed or multiple stage compressors and refrigerant mixing boxes. There are three basic figurations including cooling only, heating and cooling changeover, or simultaneous heating and cooling units. The latter is often refereed to as 'heat recovery' or 3-pipe system, which provides the additional benefits of each internal unit being able to heat or cool independently, leading to substantial energy savings when both heating and cooling are provided simultaneously as heat energy can be transferred between internal units.

2.1.5 SYSTEM DESIGN, CONTROL & MAINTENANCE

This section outlines the general issues that the current CIBSE guidance on the design of refrigeration[7], ventilation and air conditioning systems[9] indicate should be considered in the selection and strategy development of air conditioning systems in order to achieve energy efficient operation of comfort cooling or air conditioning systems. The underlying principles of this guidance is the identification of the 'minimum required services' and meeting the required minimum services with the most efficient system[54]. Guidance highlights a number of issues order to achieve energy efficient operation which include plant sizing, selective humidification and dehumidification, a considered control strategy, and zoning of the building, as well as the implementation of an active maintenance and monitoring programme.

In regard to **plant sizing** the guidance states that designers should ensure that primary plant, and in particular refrigeration chiller systems, are not oversized for the duty they are employed as this will increase the amount of time the chiller will be required to operate under part-load conditions resulting in reduced energy efficiency, increased capital and running costs[6] and comfort may also be compromised[35]. For example chiller plant operated at less than full-load is usually less efficient and can require 50% of full-load power consumption to meet 25% of a unit full-load capacity[6] which in effect halves the chiller efficiency, but to compound the problem in the UK it is expected that chiller plant will typically operate below 50% of its full load for nearly 90% of the time[8].

However, chiller part-load performance varies based on the actual plant used and some systems can actually be more efficient at part-load making the selection of appropriate chiller plant very important at the design stage, but part-load efficiency data is rarely published making the impact on the overall energy efficiency of plant over sizing very difficult to predict. However, one study from the United States indicated that when chiller plant was oversized by 50 percent, or more, it typically resulted in a 9 percent increase in annual cooling energy consumption[35]. Since the frequency of part-load conditions in the UK is normally higher than in the US[8], we would expect the increase in energy consumption due to over-sizing to be greater than 9% in the UK.

Furthermore, the relatively low average chiller load and resulting lower chiller energy consumption means that proportionally the energy consumption of the distribution system including fans and pumps are more important[8] to the overall system energy consumption in the UK than in other climates.

Selective **humidification and dehumidification** is highlighted for energy efficient operation of AC systems because of the energy intensity of the humidification and dehumidification process but also because there are many occasions where this facility is not required[1]. Close control of humidity may not actually be required for comfort cooling applications and designers are encouraged to allow humidity to drift between 40% and 65% relative humidity[9] and it is often acceptable to exceed this band for short periods. In comfort cooling applications it is usually satisfactory to supply air with sufficiently low moisture content to account for maximum latent gain and in the UK levels are unlikely to go outside comfort limits so long as sufficient ventilation rates are maintained[9].

A **considered control strategy** for comfort cooling and air conditioning applications should aim to consider all normal operational modes (e.g. winter, summer, night) as well as emergency and failsafe modes (e.g. smoke control, power failure), since, control failures tend lead to systems to being switched 'ON' by default and the energy consequences can be severe, particularly in the larger highly serviced buildings. Although detailed guidance[36] on the effective application of controls is available there are a number of generic control failure[2] issues that often lead to energy wastage which include:

- The 'tail-wags-the-dog' effect where whole systems have to operate in order to service small demands, e.g. a central chilled water system servicing a few 24-hour IT rooms.

- Unwanted operation when systems run long hours or constantly because controls have been overridden, automatic controls switch on systems unnecessarily or a lack of fault detection.
- Unintended operation when systems activate or fail to de-activate themselves when not required.
- Parasitic losses leading to increased consumption of one component due to the failure, reduced performance or inappropriate usage of another i.e. increased fan loads resulting from damaged or poorly maintained heat exchangers.
- Antagonistic losses where one system or service fights another system or service, common examples include heating fighting separate cooling systems, simultaneous humidification and dehumidification.

In addition to failures of control strategies there are a number of issues which are important to the overall efficiency of air conditioning control strategies. The control strategy should also consider how to economically maximise the utilisation of 'free cooling' techniques and minimise the need to frost protection and de-frosting processes (section 2.1.3).

Appropriate **set-points and dead-bands** must be selected consistent with comfort conditions for both temperature and humidity. The prime consideration is how wide a tolerance of the controlled environmental conditions is considered acceptable to maintain thermal comfort. Temperature control to within +/- 1 Deg C is normally more than adequate, while humidity can be allowed a greater range of variation. Tighter control will result in significant energy penalty and additional equipment operation without necessarily improving the thermal comfort conditions[2]. Appropriate set points and dead-bands are essential for energy efficient operation of air conditioning, as well as, control of the thermal comfort.

Advanced **Building Energy Management Systems** (BEMS) are computer based control systems which can automatically monitor and control a wide range of building services including, heating air conditioning, ventilation, boilers and lighting among others. Essentially they allow centralised control over the environmental controls of an entire building, but often monitor maintenance requirements and security issues as well. These systems can also provide data on energy performance to enable energy performance to be monitored and savings to be targeted. Typically energy efficiency improvements of 10 to 20% can be achieved by the installation of BEMS over individual system control.

Appropriate **zoning** of the building and air conditioning system is essential because the heating and cooling loads placed on a system are rarely constant due to changes in solar gain, occupancy and small power equipment loads (see section 2.15). Therefore, AC systems need to be zoned into areas with similar loads characteristics[2] in order to maintain comfort conditions, as well as, avoid many of the controls failures (listed above) which lead to increased and unnecessary system operation or even possible system conflicts (antagonistic failure) which result in reduced energy performance.

Most deep plan buildings require division into perimeter and internal zones based on daylight penetration and the building fabric loads as these 'zones' typically have different peak heating and cooling requirements and load profile characteristics. In office buildings space usage can also significantly affect the heating and cooling loads and should also be accounted for in the zoning of the system, for example, computer server and telecoms rooms often have large constant equipment heat-gains and may also have different requirements of thermal environment including close control over humidity[9].

The implementation of an effective **maintenance** programme contributes to the energy efficient operation of buildings and air conditioning systems by ensuring the efficient operation of plant equipment and system components, as well as helping to prolong the useful life of plant[15]. However, every building and air conditioning application will have unique maintenance requirements and maintenance regimes will have to be tailored accordingly and will have to take into account all facets of the buildings and systems operation and can therefore become very complicated. Guidance is available to encourage best practice in the operation and maintenance of air conditioning systems[37]. However in air conditioning systems a number of maintenance issues are of particular importance to the energy performance of the system which includes maintaining appropriate controls (see section), refrigerant leakage for refrigeration plant and filter replacement in mechanical ventilation and all-air AC systems.

Refrigerant leakage from chiller and refrigeration plant causes a gradual deterioration of system efficiency (COP) and a loss of capacity[38]. Some systems contain a 'buffer' or significant reserve refrigerant charge which can delay but not avoid the effects of refrigerant leakage on the systems performance. The impact of can be significant with a 20% loss of refrigerant in a typical system resulting in more than a 250% increase in power consumption, as well as, a 50% drop in system capacity[39], as illustrated in Figure 2.1.8.

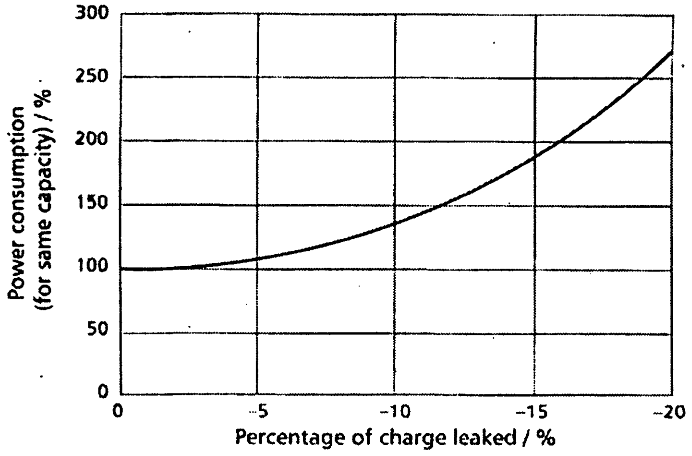


Figure 2.1.8. Refrigerant leakage Vs. Power consumption[39].

Filter maintenance in mechanical ventilations and all-air AC systems is essential to maintain good air quality through the efficient removal of airborne contaminants, but also because of the increased pressure drop of the air flow across the filter unit, resulting in increased fan energy consumption. Filters are normally replaced on regular time intervals or based on condition monitoring[9]. Filter condition is normally checked by monitoring the static pressure across the filter compared to their clean condition and usually replaced once a 20% increase in pressure in observed. However because of the 'fan laws'[2] any increase in the static pressure of a mechanical ventilation system can cause a significant increase in the power consumption of the fans.

2.2 BUILDING ENERGY ANALYSIS

This section aims to review building energy performance analysis methods, including their suitability for real world building services energy performance prediction, the tools currently available and existing research work already available.

2.2.1 GENERIC ENERGY ANALYSIS METHODS

The process of energy profiling and benchmarking of buildings, plant and equipment fall into either empirical or non-empirical methods. In general, non-empirical (non-instrumented) approaches predict energy performance from a mixture of modelling, previous monitoring studies and accepted wisdom and are generally simpler and less costly than empirical (instrumented) approaches that measure energy performance. But non-empirical 'predictions' are subject to more uncertainty and require more interpretation. Therefore the analyst must decide whether the extra cost of an instrumented approach is justified by the greater detail and accuracy obtained. However, in buildings due to the diverse nature of factors that affect energy performance (section 2.1) the difference between predicted and actual energy consumption can be substantial[40].

2.2.1.1 Non-Empirical methods

The most common form of non-empirical analysis of building energy-use is theoretical design and prediction methods, often in the form of computational models used in the assessment of building and building services designs. These models are numerous and are available to assess just about all aspects of a building design, but all generally suffer from the same drawbacks related to the 'design nature' of their intended use, making them very useful in predicting the relative performance of one design over another, but of limited application in determining actual performance in practice.

Firstly, design techniques tend to assume optimum operation of the building, its services and maintenance that are rarely accomplished in reality. Secondly, the models also tend to be used to predict peak conditions information that is required for the design process, but these are conditions to which the buildings will only occasionally be exposed in practice. Thirdly, the accuracy and reliability of these modelling techniques are dependent on the quality and accuracy of the input data, which must be assumed by the operator, but in practice this is often difficult because of the number of variables effecting the energy consumption of a building and certainly may not represent actual conditions imposed by real building users. For example the occupancy patterns, weather conditions, and controls of most buildings are highly varied and rarely reflect 'design' conditions. Research has shown that dynamic building thermal models can accurately predict measured conditions when corresponding measured input data is used, but accuracy is reduced when standard or design input conditions are used.[41]

These limitations tend to mean that predicted building performances reflect optimum building operation under design load conditions which by definition rarely occur resulting is simulated building performance which tends to be optimistic compared to actual system use. The Inland Revenue Building[42], in Nottingham, and the BRE's Low Energy Office[43], in Garston, both recent low-energy demonstration buildings, clearly show this discrepancy between their predicted and actual energy performance, where both buildings actual energy performance fell short of the design predictions.

2.2.1.2 Empirical Methods

Empirical methods refer to the direct measurement of all the parameters related to the performance of the monitored system and therefore the energy performance can be determined to a very high level of accuracy. The resulting accuracy would depend on monitoring variables such as the type of equipment used, the sampling period and the overall duration of monitoring. However, these empirical methods can be time consuming, costly, and unique to the building / systems monitored, while also requiring the building or system to already be in operation. However, in the determination of building and services energy performance, direct monitoring of existing sites by an empirical method leads to the highest level of certainty, since all the real-world influences are accounted for even if they are unknown or undeterminable.

2.2.1.3 Semi-Empirical Methods

Semi-empirical methods refer to the practice of analysing empirical and non-empirical data so that predicted results (non-empirical) can be compensated to account for real world conditions from measured empirical data, in effect benefiting on the strengths of both data types. Often energy performance benchmarks and many energy prediction tools such as Energy Consumption Guide 19[44] and the ESI-Check[45] model are based on whole-building energy-use, obtained from energy billing (empirical data) and assigned end-use consumption's for consumers within the building based on predicted performance of the system and building configuration (non-empirical data), which enable building performance to be estimated reflecting "real-world" conditions.

2.2.2 BUILDING SERVICES PREDICTION METHODS

Modelling (non-empirical) is often needed because systems that consume energy in buildings are non-linear, dynamic, and complex; few methods other than computer modelling are available for accurately calculating energy consumption. In particular, experts for determining energy use in buildings prefer simulation programs that assemble component models into system models and then exercise those models against weather and occupancy data. However, often, energy consumption must be estimated quickly to study trends, compare systems, or study building effects such as envelope characteristics for which simpler methods may be used.

Unfortunately there appears to be no accepted standard models or modelling systems for all energy prediction uses. However there is a wide range of products on the market from very simplistic steady-state models to highly sophisticated dynamic models each suited to particular type of use or regional applicability so choosing an energy prediction model is by no means a simple process. However guidance is available from organisations such as CIBSE[46] and ASHRAE[2] to assist in the selection of energy prediction tools for a particular need.

In the UK the new Building Regulations Part "L" covering provisions for energy efficiency published March 2001 grant completely free design of a building taking advantage of any energy conservation method as long as compliance is shown to the Carbon Emissions Calculation that the annual carbon emissions of the proposed building are no greater than a similar building designed to the Elemental Method of prescriptive energy performance specification. This carbon performance specification has to be calculated using a modelling technique or program documented in the CIBSE approved document Applications Manual 11: Building Energy and Environmental Modelling[46].

2.2.3 BUILDING ENERGY MONITORING METHODS

The collection of empirical data to determine building energy performance is an important but often complex and costly task. Although objectives and scope can differ building energy monitoring projects tend to have several issues in common, which allow methodologies and procedures to be standardised[4].

Monitoring projects can be non-instrumented, using utility billing data or instrumented billing data supplemented by additional sources of data, such as a building energy management system. Non-instrumented approaches are generally simpler and less costly than instrumented approaches, but they are subject to more uncertainty in interpretation[4].

Instrumented field monitoring projects generally involve data acquisition systems, which are typically comprised of various sensors and meters used in conjunction with some data recording devices such as an automated data logger or even pencil and logbook. Field monitoring projects may involve a single building or a sample of hundreds of buildings, and may be carried out over time periods ranging from days and weeks to years. Curr ent monitoring practices can vary considerably, for example a utility load research project tends to characterise the average performance of buildings with relatively few data points, whereas monitoring of a specific technology performance are much more focused and can become far more complex depending on the number of monitoring points and sampling intervals used.

Monitoring projects can be broadly categorised by the goals, objectives, experimental approach, and level of monitoring detail required. Other factors such as data analysis procedures, duration and frequency of data collection, and instrumentation are common to most projects. However three common types of monitoring project based on their uses are[2]:

- Whole building energy use
- Energy end-use
- Specific technology assessment

2.2.3.1 Whole-Building Energy Use

Whole-building energy use measures the total consumption for a building. Typically, these projects use a relatively small number of monitoring data points in each building and the data from a large number of buildings is statistically analysed to provide results with the desired level of accuracy for a representative sample of buildings or building systems. Examples of this type of project include utility load research projects that use whole-building data.

2.2.3.2 Energy End Use

Energy end-use projects focus on individual energy systems in particular buildings, typically for large samples. Monitoring usually requires separate meters or collection channels for each end use, and analysts must account for all factors that may affect energy use. Examples of this approach include detailed utility load research projects to evaluate building energy systems.

2.2.3.3 Specific Technology Assessment

Specific technology assessment projects monitor the field performance of specific equipment or technologies that directly use energy within a building or affect building energy use of other systems, such as the impact of envelope retrofit measures, major energy end-uses or mechanical equipment including air conditioning.

2.3 AIR CONDITIONING ENERGY PERFORMANCE DATA

So far this chapter has considered the various issues the might be expected to affect energy performance of and way to assess the energy performance of air conditioning in general. Where as this section reviews some specific air conditioning energy performance data for example air conditioning equipment in order to confirm the theoretical trends we expect to see in various air conditioning technologies. The data presented in the following sub-sections has been drawn from a number of sources including independent laboratory efficiency testing of various plant components, benchmark standards and design guidance and some modelling studies.

2.3.1 COMPONENT & SYSTEM EFFICIENCIES

Air conditioning system and component efficiency ratings are normally published by manufacturers or third party trade organisations to identify the performance of various AC system s and components under standard test conditions, which allow performance variations between similar products to be identified.

The energy efficiency data reviewed here is independently tested and published by the Eurovent-Certification Programme[47] and covers air conditioning systems and components technologies from leading manufacturers in the European market. The systems reviewed represent popular system types from leading suppliers including; Toshiba-Carrier, Daikin, Mitsubishi, Hitachi, Fujitsu, and Clivet brands. The Eurovent Programme[47] is an independent industry wide voluntary organisation that publishes results of independently conducted laboratory calorimeter type tests, conducted according to the relevant ISO standard relating to a particular equipment type[47].

The data reviewed here compares energy efficiencies in terms of Coefficient of Performance at full load against a number of issues including, differences in the manufacture of similar equipment, refrigerant used, condenser type, mode of operation, as well as, system configuration and capacity.

The laboratory testing data substantiates a number of the main theoretical factors that affect energy performance AC systems including:

- **Condenser Type;** this data has confirmed that water-cooled condensers are significantly more efficient than air-cooled units. Figure 2.3.4 shows the COP of example packaged chillers from a number of leading manufacturers with both air cooled and water cooled condensers.
- **Refrigerant Choice;** This data suggests the transitional blend HFC refrigerant R407c is not as efficient as R22 which it replaces in many smaller packaged and split systems, at least under laboratory conditions. Although in larger chillers R407c appears to be as efficient R22. However new refrigerants such as R134a and R410a are significantly more efficient than R407c and slightly more efficient than R22 even in the smaller packaged units, see Figure 2.3.5.
- **System Capacity;** The system capacity of refrigerant plant appeared to have little or no effect on the system efficiency under laboratory full-load conditions, as illustrated in Figure 2.3.6. Therefore equipment selection should focus on the matching the number and type of equipment to the load profile to minimise part-load operation and not necessarily steering towards certain sizes of equipment for efficiency reasons.
- **System Configuration;** The review also suggested that the efficiency of an AC system could also be affected by the configuration of the system (see Figure 2.3.2), e.g. packaged split or liquid chiller etc. The data suggests that under laboratory conditions packaged air cooled splits and multi-split systems are 16-17% more efficient than the liquid chiller packs in cooling mode with R22, once the proportional ancillary loads for conveying devices, fan's and pump's etc are accounted[47].

Although, this may not be the case for more modern liquid chillers that utilise new refrigerant such as R134a (Figure 2.3.5).

- **Mode of Operation;** The data confirms that reverse cycle air conditioning systems in heating mode are more efficient than in cooling mode, primarily due to the utilisation of the heat generated by the compressor. Significantly reverse cycle air conditioning systems in heating mode are also substantially more energy and carbon efficient than other common heat generation systems such boilers. This increased efficiency in heating mode is evident in all systems configurations as shown in Figure 2.3.2.

Overall, there were surprising differences in efficiency between similar equipment of the same general system configuration and capacity but from different manufacturers and emphasises the importance of choosing the most efficient system components, as the efficiencies range from a coefficient of performance (COP) of less than 2, to over 3.5 for

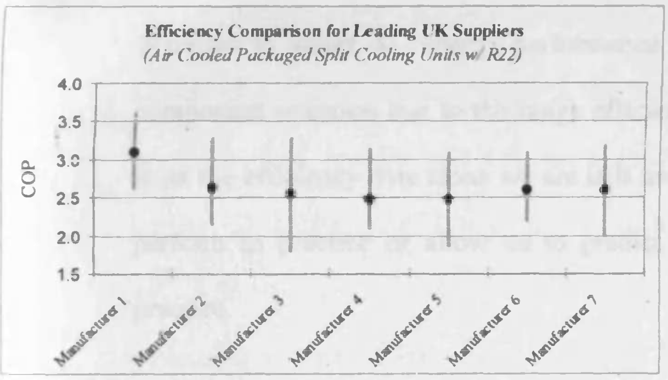
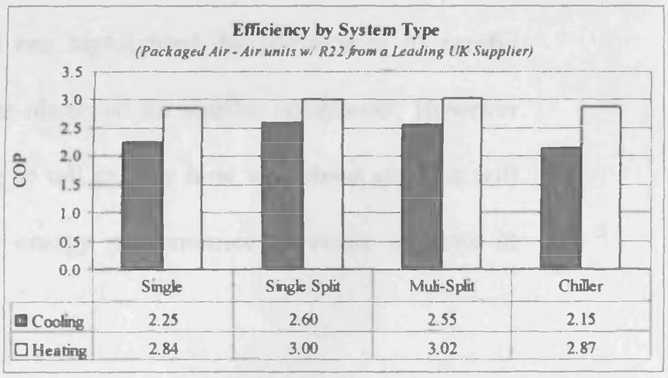
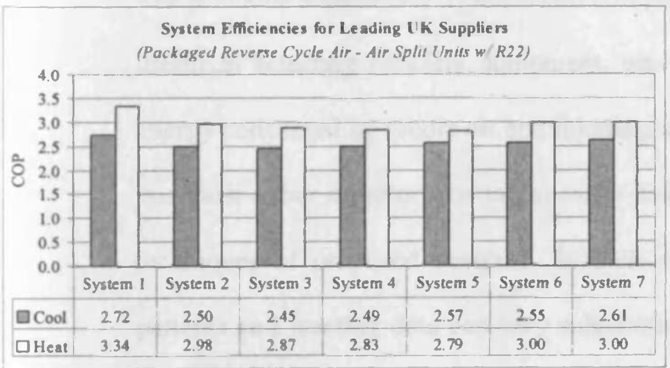


Figure 2.3.1 Efficiency comparison of similar equipment from leading UK manufacturers[47].



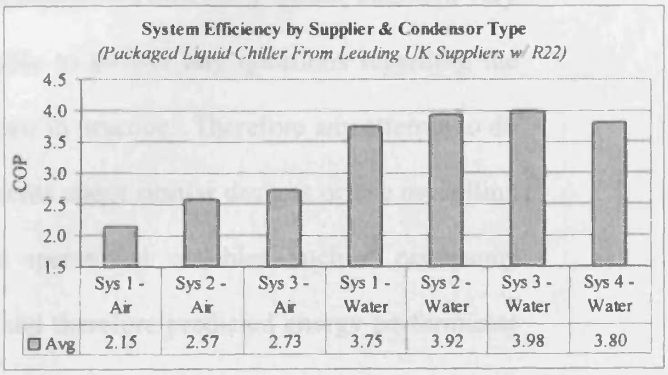
	Single	Single Split	Muli-Split	Chiller
▩ Cooling	2.25	2.60	2.55	2.15
☐ Heating	2.84	3.00	3.02	2.87

Figure 2.3.2 Efficiency comparison by generic system type[47].



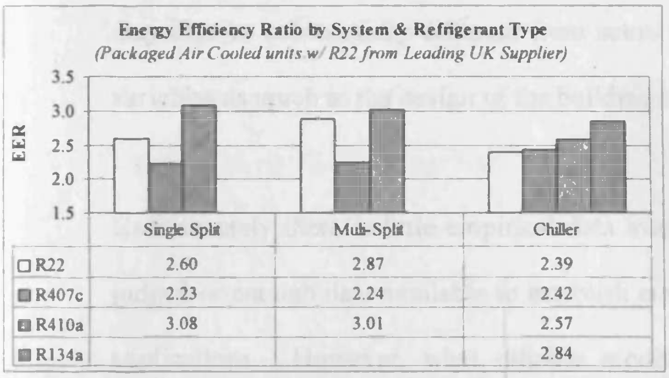
	System 1	System 2	System 3	System 4	System 5	System 6	System 7
▩ Cool	2.72	2.50	2.45	2.49	2.57	2.55	2.61
☐ Heat	3.34	2.98	2.87	2.83	2.79	3.00	3.00

Figure 2.3.3 Heating and cooling efficiency of reverse cycle systems of example systems[47].



	Sys 1 - Air	Sys 2 - Air	Sys 3 - Air	Sys 1 - Water	Sys 2 - Water	Sys 3 - Water	Sys 4 - Water
▩ Avg	2.15	2.57	2.73	3.75	3.92	3.98	3.80

Figure 2.3.4 Efficiency comparison by air and water cooled condenser[47].



	Single Split	Multi-Split	Chiller
□ R22	2.60	2.87	2.39
■ R407c	2.23	2.24	2.42
▨ R410a	3.08	3.01	2.57
■ R134a			2.84

Figure 2.3.5 Efficiency comparison by system and refrigerant type[47].

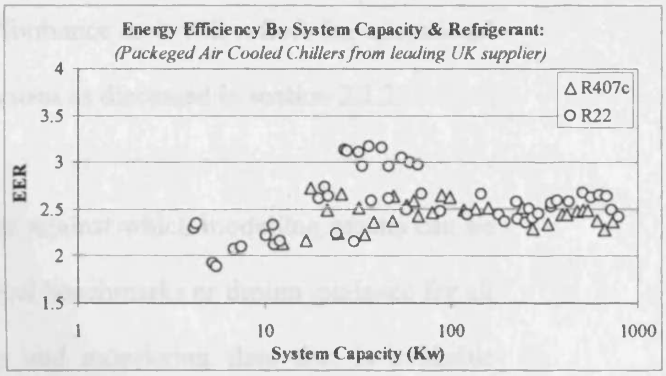


Figure 2.3.6 Efficiency comparison by system cooling capacity and refrigerant type[47].

similar equipment at full-load (Figures 2.3.1 and 2.3.3). This implies that the efficiency of systems on the market vary considerably and this is reinforced by results from independent research looking at equipment not part of the Eurovent-Certification Programme, which found systems with performance which fell 12 to 29% short of their own specification ratings[48].

This AC system and component efficiency data has confirmed some of the factors we expected to affect AC energy performance and has highlighted the importance of careful component selection due to the range efficiencies observed for similar equipment. However from the efficiency data alone we are still unable to tell exactly how well these systems will perform in practice or allow us to predict the energy performance of entire systems in practice.

2.3.2 BUILDING & SYSTEM ENERGY CONSUMPTION

The previous section (2.3.1) discussed component equipment efficiency which, although very useful in selecting efficient equipment, was unable to answer any questions regarding the energy consumed by whole air conditioning systems in practice. Therefore any attempt to do this must either monitor existing to make judgements about similar designs or use modelling techniques of proposed designs. In both cases operational variables, such as occupancy patterns and weather data can vary substantially and therefore predicted energy performance may also be substantially different from actual performance as it will reflect the operational variables as much as the design of the building or system as discussed in section 2.2.2.

Unfortunately there is little empirical data available against which modelling results can be judged or enough data available to establish empirical benchmarks or design guidance for all applications. However, what reliable modelling and monitoring data that is available regarding UK air conditioned office buildings is reviewed in this section in order to help identify the expected outcomes of the monitoring undertaken by this research, and ultimately also to judgments the application of benchmarks and modelling techniques compared to measured performance. This section reviews data from a number of sources including national energy consumption benchmark, .industry design guidance and some energy performance modelling studies.

2.3.2.1 Energy Consumption Benchmarks

Building energy benchmarks provide representative energy consumption values for common building types, against which actual building performance can be compared. The current benchmark standards of UK office buildings are provided by Energy Consumption Guide 19[44], which provides benchmarks for energy consumption, energy cost, and carbon dioxide emissions in four representative office buildings and a breakdown of their services with values for typical and best practice provided. Although this publication dates back to 1998 a number of subsequent industry guidance publications have replicated the data as recently as

Table 2.3.1 Energy consumption benchmarks for UK air-conditioned office buildings

	Type 3 – Standard Air Conditioned		*Type 4 – Air Conditioned Prestige*	
	Good Practice	**Typical Practice**	**Good Practice**	**Typical Practice**
	kWh/m^2 (KgC/m^2)	kWh/m^2 (KgC/m^2)	kWh/m^2 (KgC/m^2)	kWh/m^2 (KgC/m^2)
Whole Building	225 (23.5)	404 (41.9)	348 (39.5)	568 (62.4)
*Cooling System**	44 (6.3)	91 (12.9)	57 (8.1)	108 (15.3)
*Heating & Cooling**	129 (10.9)	249 (21.6)	152 (13.3)	289 (25.3)

**Excludes ventilation and domestic hot water services.*

September 2003[7], reaffirming this as the standard to which energy use in UK office buildings should be compared. In addition, these benchmark values have also been used to establish a standard "Energy Assessment and Reporting Methodology" [49] which standardises the energy benchmarking of offices, hotels and mixed-use buildings in the UK. The benchmark data energy consumption values are summarised as follows in Table 2.3.1.

The benchmarks values for typical practice represent median energy consumption and good practice values are based upon examples where significantly lower energy consumption has been achieved using widely available and well-proven energy efficient features[44]. So we would expect the energy consumption of the air conditioned office buildings monitored in the this study to be between 225 and 568 kWh/m^2 with the majority falling within the type-3 standard building range of values with energy consumptions up to 404 kwh/m^2 and only large highly serviced prestige office buildings recording higher energy consumptions.

This publication also provides indicative energy consumption values for non-air conditioned buildings which show that standard air conditioned buildings typically consume at least 50% more energy than mechanically ventilated (no cooling) buildings and twice as much energy than naturally ventilated office buildings.

Where the proportion consumed by the AC systems would be between 44 and 91kWh/m^2 for cooling only systems and between 129 and 249kWh/m^2 for reverse cycle systems in the standard air conditioned buildings. Therefore 16% to 23% of the whole building energy consumption for the cooling only systems and between 44% and 62% of the whole building energy consumption for the reverse cycle heating and cooling systems.

In general benchmarks based on in-use data, such as the Econ19 data, will suggest higher energy consumption than most design estimates[44], which tend to assume essentially perfect performance and operation and often ignore some end-user practices specific to individual buildings in the real world. This should mean that the building and A/C system energy performance measured during this study should more closely match these benchmarks rather than the modelling and testing data review in the chapter.

2.3.2.2 Building Services Industry Rules of Thumb

Current UK building services industry rules-of-thumb[50] provide indicative data on a wide range of building services related issues that provide an indication of expected loads, design levels and performance that we should expect to find in the monitoring of air conditioning systems in UK offices. Although this guidance provides information to a wide range of applications the relevant data regarding air conditioning in UK offices is summarised in Table 2.3.2.

Table 2.3.2 Rules-of-thumb relevant to air-conditioned UK office buildings

Cooling Loads:	
General Office	125 W/m^2 TFA
Internal zones	75 W/m^2 TFA
Perimeter(60-65% Glazing)	120-180 W/m^2 TFA
Heating load:	70 W/m^2 TFA
Occupant density:	12-17 m^2 TFA / person
Call centre / work stations	4-6 m^2 TFA / person
Cellular Offices	15+ m^2 TFA / person
Heat gains:	
Metabolic	10 W/m^2 TFA
Lighting	12-20 W/m^2 TFA
Office equipment	15-45 W/m^2 TFA
Installed Cooling Capacity:	
Central plant	125 W/m^2 TFA
Distributed Plant	140 W/m^2 TFA

Source: BSRIA Rules of Thumb: UK 3rd Edition[50]

The assumed cooling load of 125 W/m^2 for general offices and the total heat-gains adding up to between 37 and 75 W/m^2 TFA implies that the fabric and solar gains will amount to between 50 and 88 W/m^2 TFA taken over the whole treated floor area. Note, a more comprehensive review internal heat gains in offices is discussed in section 2.3.4.

In addition, the rules-of-thumb indicate the capital and maintenance costs of air-conditioned buildings to be £210-£410 per m^2 versus £170-£190 per m^2 for non-air conditioned buildings, which equates to between 60 - 110% increased overall costs for air conditioned buildings.

2.3.2.3 Energy performance modelling studies

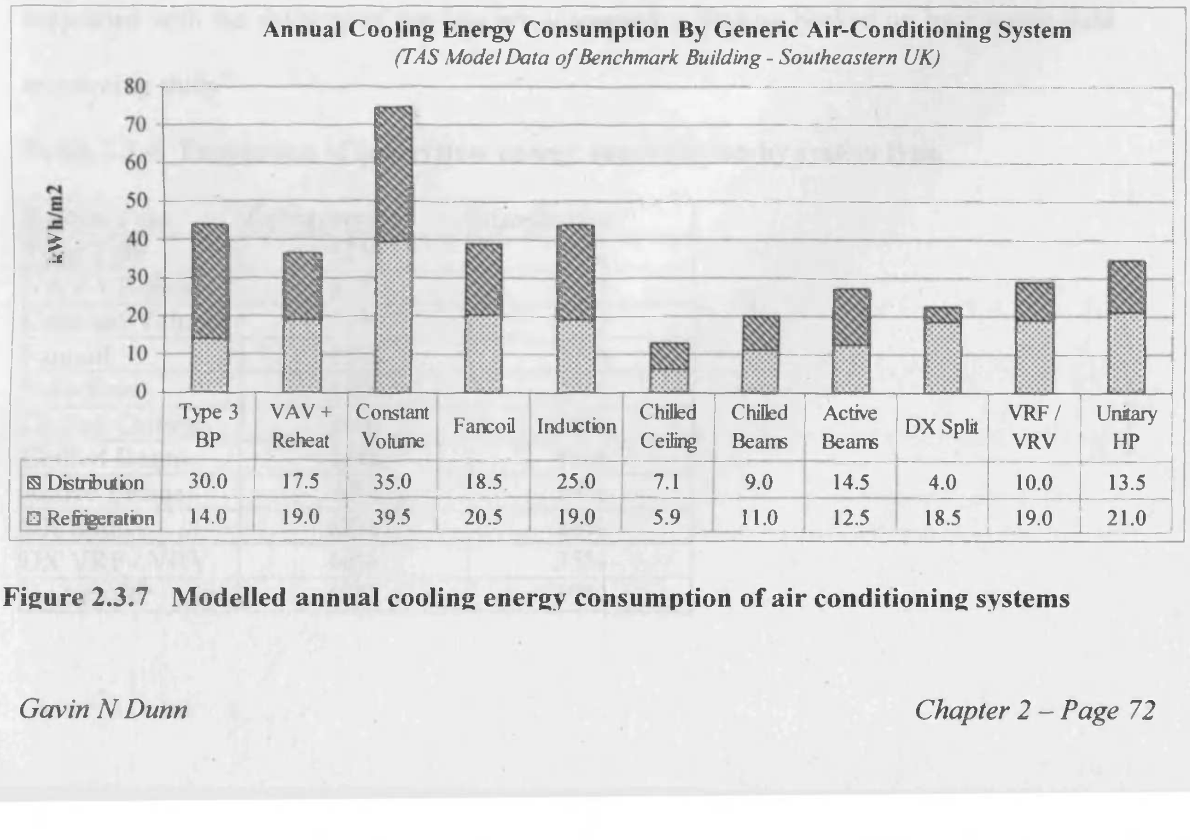
An older academic study using the BLAST energy prediction programme looking at energy consumption of common Air Conditioning systems with various control strategies in the USA[51] for different climatic regions concluded that in terms of annual energy consumption:

- Variable Air Volume (VAV) systems consume less energy than the other All-Air systems and the use of an economiser cycle (free cooling) improves the energy performance of all the all-air systems studied.
- However in larger offices hybrid systems using 4-pipe fancoil systems on the perimeter lead to the lowest predicted energy consumption of all systems configurations tested, implying that these systems meet the widely varying conditions of both heating and cooling requirements more efficiently than the other system types, although the study did NOT study fancoil systems on their own.
- In retail applications DX splits performed approximately the same as the best performing VAV with enthalpy economiser system study, and slightly better in areas with lower cooling degree days, which may favour DX systems in UK applications.

Due to the scope of this study with its limited types of system studied and geographic location for applications in the United States it has limited application to UK office buildings, due to the different climatic conditions, occupancy practices, and building techniques etc, and therefore is of little use to establishing the expected outcomes of this research. However, it is useful as a comparison of the relative performance of the specific systems studied and as an example of the limited applicability of "case study" research comparisons.

Far more recent UK based modelling work has been conducted by a UK environmental design consultant[52] on behalf of the Carbon Trust's Action Energy Programme using the TAS dynamic thermal building and services model. The findings provide an interesting insight to the comparative performance of different A/C systems employed in UK offices[53]. The work modelled the Standard type 3 Econ19 benchmark building[44] the same category of building predominantly studied by this research and modelled assuming a location in Southeast UK with a variety of different air conditioning systems commonly used in the UK.

Although comparison between these modelling results with the monitored data will have to be done cautiously due to the wide range of operational variables influencing the monitored buildings, the modelling of a standard benchmark allows many these variables to be assumed constant, so that any difference in predicted performance is due to the type of A/C system used, or other variables being studied, providing an insight to the relative performance of one system in terms of annual energy consumption and overall system efficiency. Furthermore, this modelling has enabled the relative impact on energy performance of common operating or design issues to be analysed, including plant over-sizing, poor maintenance and extended hours of operation.



	Type 3 BP	VAV + Reheat	Constant Volume	Fancoil	Induction	Chilled Ceiling	Chilled Beams	Active Beams	DX Split	VRF / VRV	Unitary HP
▨ Distribution	30.0	17.5	35.0	18.5	25.0	7.1	9.0	14.5	4.0	10.0	13.5
░ Refrigeration	14.0	19.0	39.5	20.5	19.0	5.9	11.0	12.5	18.5	19.0	21.0

Figure 2.3.7 Modelled annual cooling energy consumption of air conditioning systems

Figure 2.3.7 shows the modelled annual energy consumption of ten different air conditioning systems commonly used in UK office buildings in the fictional benchmark (Econ 19 Type 3) office building. The annual cooling energy consumption ranged from 13kwh/m^2, for passive chilled ceiling systems to 74.5kwh/m^2 for a Constant Volume (CV) system of the system types studied in the monitoring programme.

It is interesting that most of these figures are lower than the best practice benchmark values shown in the far left column of Figure 2.3.7and far lower than current typical practice benchmarks, indicating that in reality the actual energy consumption of these systems in real building are likely to be much higher than the modelling results suggest once all the 'real world' demands were imposed.

Table 2.3.4 show the proportion of energy consumed by the refrigeration and distribution aspects of the benchmark system and each generic system type. It is interesting to note that in all the centralised and partially centralised systems typically 40 to 60 % of the total energy consumption are by the distribution components of the systems. Significantly, these are the system types that utilise chillers and therefore it becomes clear that the efficiency ratings of the chiller plant as discussed in section 2.3.1 will be significantly reduced once all the loads associated with the delivery of services are accounted, a finding backed up by a recent field monitoring study[53].

Table 2.3.4 Proportion of sub-system energy consumption by system type.

System Type	*Refrigeration*	*Distribution*
Type 3 BP	32%	68%
VAV + Reheat	52%	48%
Constant Volume	53%	47%
Fancoil	53%	47%
Induction	43%	57%
Chilled Ceiling	46%	54%
Chilled Beams	55%	45%
Active Beams	46%	54%
DX Split	82%	18%
DX VRF / VRV	66%	35%
Unitary HP	61%	39%

Based on the TAS modelling data of the fictional benchmark building refrigeration and whole system cooling efficiencies were calculated as shown in figure 2.3.8 below. Refrigeration efficiency ranged from a CER of 1.6 to 3.1 but these dropped to between 0.44 and 1.45 once all the loads associated with the systems were accounted. In general the chilled ceiling systems and the direct expansion (DX) based systems had higher refrigeration efficiency and the system efficiencies than the other systems types making them substantially the most efficient systems for the delivery of cooling. This modelling suggests that the general ranking of air conditioning systems in terms of efficiency by which the systems deliver cooling from highest to lowest is as follows: Chilled Ceilings, DX Systems including VRF, Unitary Heat Pumps, Fancoils, All-Air systems.

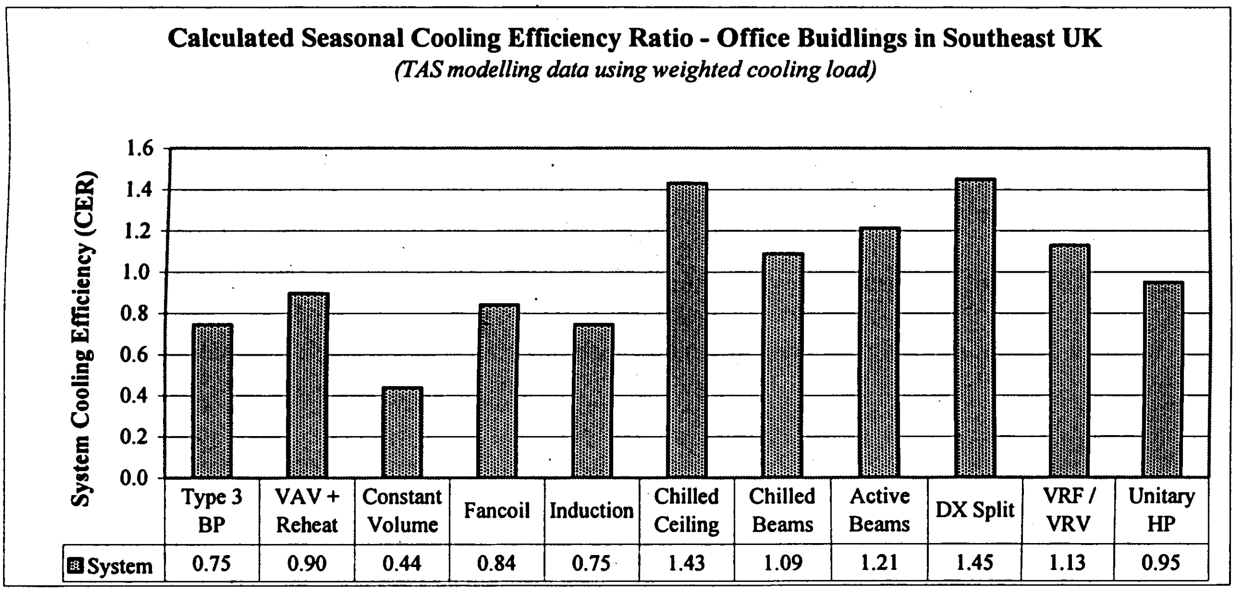


Figure 2.3.8 Calculated cooling efficiency of the modelled benchmark building.

The modelling data also included data on a dual-duct all-air system, which is not considered in this thesis due to its perceived un-common usage in UK office buildings and therefore the data is not shown, but the data suggests an annual cooling system energy consumption of 120 kWh/m^2, almost 3 times the good practice benchmark, leading to a cooling efficiency of only 0.27 CER.

Although, it is not possible to account for all the 'real-world' influences the modelling did assess the sensitivity to over-sizing, inappropriate controls leading to extended hours of use, and poor maintenance on the energy performance of air conditioning systems. Table 2.3.5 shows the percentage increase in energy consumption resulting from these three issues on their own and in combination with one another on a modelled example fancoil system.

Table 2.3.5 Energy Consumption Sensitivity to Common Operational Issues

Operational Issue	**Increased Energy Consumption**
	% Above Best practice
Poor Care& Maintenance	12.5%
Extended Use	53.1%
Extended Use & Poor Care	84.4%
Oversized	6.3%
Oversized & Poor care	37.5%
Oversized & Extended Use	68.8%
Oversized, Extended Use & Poor Care	112.5%

Extended hours of operation, essentially a user controls issue, had the single largest impact on the energy consumption resulting in a 53% increase in energy consumption, followed by poor care and maintenance resulting in a 13% increase and over-sizing resulting in a 6.3% increase.

The increased energy consumption resulting from each these operational issues is further increased when they occur in combination with one another as illustrated in the table leading to a 113% increase of energy consumption when all three issues in combination. So this data would suggest that even with a properly sized system the operational issues mean that the overall energy consumption could be expected to vary by around 84% and by more than 113% if the chiller plant was oversized as well.

These results compare to wider studies undertaken on a European level and case study field monitoring data looking at A/C energy efficiency in practice as summarised as shown in Table 2.3.6.

Table 2.3.6 Estimates of Seasonal System Energy Efficiency Ratio: Office buildings in south east of England[53]

Source of Estimate / System Type	*Measured[16]*	*TAS Simulation*	*DOE2 Simulations*
Constant volume		0.44	0.76
Variable Volume		0.81 to 0.91	1.19
Rooftop			0.87
Fan coil (4 pipe)		0.82 to 0.96	1.16
Fan coil	0.3 to 1.6		
Water loop heat pump		0.88	1.36
Room units (with ventilation)	1.3 to 1.7	1.15	1.95
VRF (with ventilation)		1.05	
Induction		0.55 to 0.75	
Dual duct		0.27 to 0.38	
Chilled ceiling and floor supply		1.37 to 1.51	
Chilled beams and floor supply		1.07 to 1.27	

The results of the monitoring can be compared with (roughly) equivalent figures from various modelling predictions. However the buildings modelled were not the ones monitored, nor was the weather the same and some differences are due to differences of definition between in the different simulation tools.

2.3.3 CURRENT GUIDANCE ON SELECTIING AIR CONDITIOING

Current advice from the government's energy efficiency best practice programme covers a wide range of energy efficiency issues, from refrigerant selection and usage to the effective procurement of refrigeration and air conditioning plant. However, the overall emphasis of these programmes is to encourage the designing out of air conditioning, and when not possible the selection of the most efficient AC plant available for the specific application. Good Practice Guide 71: Selecting Conditioning Systems[54], although dating back to 1993 and containing data up until only 1992, remains the main publication of the subject. Since then GPG71 has yet to be updated and has been republished in other guidance from the Chartered

Institute of Building Services Engineers (CIBSE)[55, 56, 9] as recently as 2001 with revisions (as discussed in section 2.1.4) thus establishing it as the current advice on the subject of AC selection.

The guide emphasises the benefits to the environment and running costs that avoiding use of air conditioning can provide by outlining the wide range of selection issues from the choice of refrigerants, thermal requirements, and running costs. As well as, an overview of each of the main system types available, their key features and rules of thumb for judging when each system is likely to be the most suitable option.

The following Tables 2.3.7 and 2.3.8 summarise the comparative performance of the system categories being considered in this project, from the data provided in GPG71. Note that in table 2.3.7 the categories of Chilled Ceiling and Heat Recovery systems are not represented in this source.

Table 2.3.7 Comparison of GPG71 Cost & Carbon Data[54]

System Types	*Capital Costs £ / m²*	*Energy Cost £/ m²*	*Carbon Emissions Kg CO_2 / m²*
All-Air Constant Volume (CV)	160	3.0	50
All-Air Variable Air Volume (VAV)	180	2.4	40
Fancoil System (Generic)	170	3.2	50
Direct Expansion (DX) Splits	85	3.5	75
Variable Refrigerant Flow (DX VRF)	130	2.8	50

This data suggests that in terms of capital costs, Splits are generally cheaper, but in their most advanced form (VRF multi-splits) there appears to be little difference between them and Centralised and the partially Centralised systems.

Table 2.3.8 Summary of current design advice[54]

System Type	Control	Filtration	Noise	Plant space	Office Space	Duct Space	Humindity Control	Air Distribution	Capital Cost £/m2	Energy Cost £/m2/year	Mainten-ance Cost	Carbon Emissions KgCo2/m2
Centralised												
Constant Volume (CV)	Good	Good	Low	High	None	High	Very Good	Very Good	160	3	Medium	50
Varible air Volume (VAV)	Very good	Good	Low	High	None	High	Good	Very Good	180	2.4	Medium to High	40
Dual Duct	Good	Good	Low	High	None	Very High	Good	Good	210	3.4	Medium	55
Partially Centralised												
Centralised w/ Reheat	Good	Good	Low	High	None	High	Good	Good	200	3.1	Medium to High	50
Induction units	Poor	Poor	Can be High	Low	None to Moderate	Moderate	Limited	Poor	160	3.2	High	50
Fan coil units	Good	Poor	Can be High	Low	None to Moderate	Moderate	Limited	Fair to Good	170	3.2	High	50
Unitary heat pumps	Good	Poor	Can be High	Low	Moderate	Low	None	Poor	130	3.2	Medium to High	55
Reversable Air-water Heat Pumps	Very good	Poor	Can be High	Low	Moderate	Low	None	Poor	160	2.5	Medium to High	35
Localised												
Through-wall Packaged	Local Only	Poor	High	None	Moderate	None	None	Poor	70	3.5	Low	75
Split Unit Packages	Local Only	Poor	High	None	None to Moderate	None	None	Poor	85	3.5	Medium to High	75
Reversable Heat pumps	Local Only	Poor	Can be High	None	Moderate	None	None	Poor	110	3	Medium to High	55
Varible refrigerant flow (VRF)	Good	Poor	Can be High	None	None to Moderate	None	None	Fair	130	2.8	Medium to High	50

However, in terms of energy costs and carbon emissions the VAV and VRF systems appear to be the better performing systems, but no particular category appears significantly better than the others, with the average energy costs slightly lower for the CV/VAV systems. The Range of performance for splits is much greater than for other types, which is likely to correspond to the sophistication of the systems and their capital costs.

2.3.4 INTERNAL HEAT-GAIN DESIGN GUIDANCE

The importance of the cooling load, and therefore internal heat gains, on air conditioning energy performance has already been established (Section 2.1) and therefore this section reviews the current guidance regarding the levels of internal heat gains within UK offices that we might expect to find in the buildings studied here.

No single source of guidance could provide all the information required to breakdown the overall loads by the different component sources, so the values shown are composite ranges of values derived from a number of sources including; the CIBSE guides[3], Government good practice guides[57], BSRIA rules-of-thumb[58] and a report from an energy monitoring study[59]. Composite ranges of current design guidance on internal gains in UK offices used in this study are summarised in Table 2.3.9 below.

Table 2.3.9: Summary of guidance heat gain design values

Guidance design values for internal heat gains in UK offices	
Source of heat gains	Design guidance values (minimum & maximum)
Occupancy	20 W/m^2
Artificial lighting	8 to 32 W/m^2
Small power equipment	7 to 45 W/m^2
Total internal heat gains	37 to 90 W/m^2

In addition this guidance also provides some insight to the density of office occupancy in the UK, which is expected to be between 8m^2 and 16m^2 of floor space per person[57] in typical offices, and down to around 4.5m^2 per person in 'clerical' offices[58].

2.4 UK AIR CONDITIONING MARKET

According to AMA Research[60] the overall UK non-domestic HVAC market was estimated to be approaching £1.2bn in 1998 and the market has exhibited strong growth since 1994, with the air conditioning sector demonstrating particularly rapid growth with its share of the overall market increasing to 35% of all UK non-domestic services.

There has been a general increase in demand for air conditioning, apparently driven by greater expectations of thermal comfort, combined with relatively low market penetration levels, resulting in substantial market growth, as more buildings become air conditioned. In the medium to long term this growth is expected to continue, reflecting construction trends, increased expectations of thermal comfort and air quality.

In particular, there has been dramatic growth in packaged air conditioning systems, which in 1999 accounted for 54% of the overall market and increasing at the expense of centralised systems, mainly due to their ease of retrofitting and lower unit prices.

BSRIA data from 2000[61] confirms these market trends and also shows changes within the market with regard to the uptake of different technology and equipment types. The following graphs show this data broken down by different technology type and covers UK sales figures from 1995 projected up to2005.

Figure 2.4.1 shows the UK non-domestic sales figures broken down between packaged and central plant equipment with both types showing expected growth over this period, but notably comparatively large growth of, smaller up to 200kW[62], packaged unit sales through 2005 by which point they will account for approximately two-thirds of the UK air conditioning market in terms of sales value. This is further detailed in figure 2.4.2, which shows the increased sales of ALL packaged system types, as well as, the increasing market share of packaged VRF/VRV systems. This shift towards decentralised systems appears to be driven by refurbishment projects where little space is available large units and increasing concern to provide partial back-up and redundancy[62].

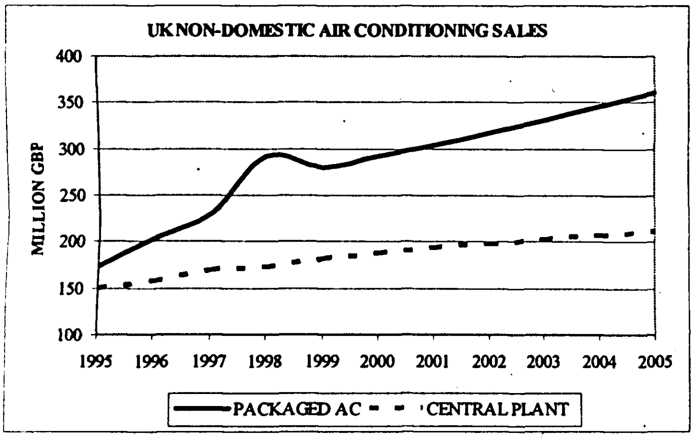


Figure 2.4.1 UK non-domestic air conditioning sales figures 1995 project to 2005[61].

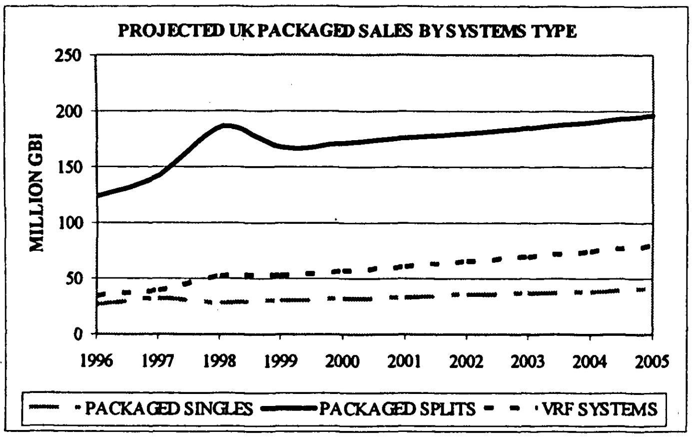


Figure 2.4.2 UK non-domestic packaged AC systems sales by generic type[61].

Figures 2.4.3 and 2.4.4 show chiller usage trends in the non-domestic HVAC market by method of heat rejection and compressor type, showing a shift away from reciprocating technology towards a large increase in the use of air-cooled rotary (scroll and screw) chillers which now account for 80% of the market[62]. While the market for water-cooled and remote-condenser, as well as centrifugal and absorption cycle chillers are expected to change little. Although many of these changes are likely to be a direct result of the markets increasing uptake of smaller packaged systems, it is perhaps surprising to see the continued move away from water-side systems due to continued concerns over legionnaire's disease despite their acknowledged energy efficiency advantages[62].

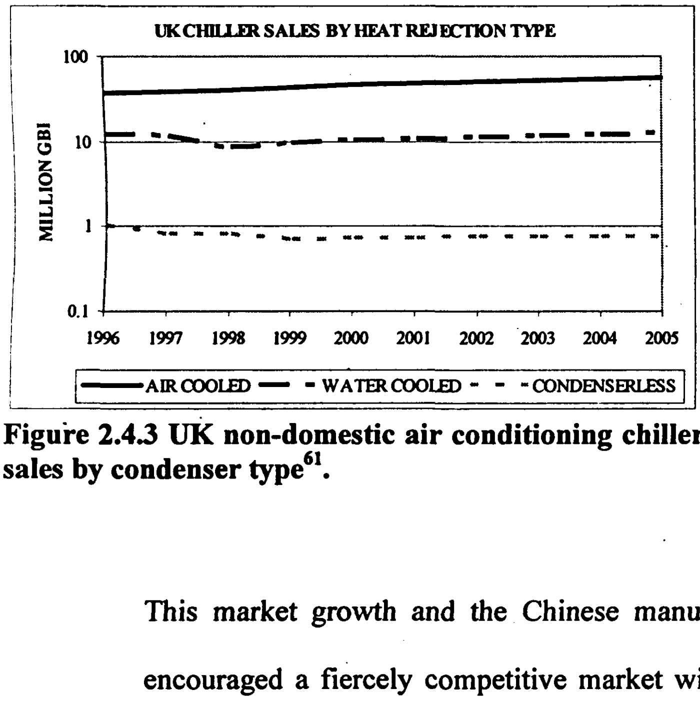


Figure 2.4.3 UK non-domestic air conditioning chiller sales by condenser type[61].

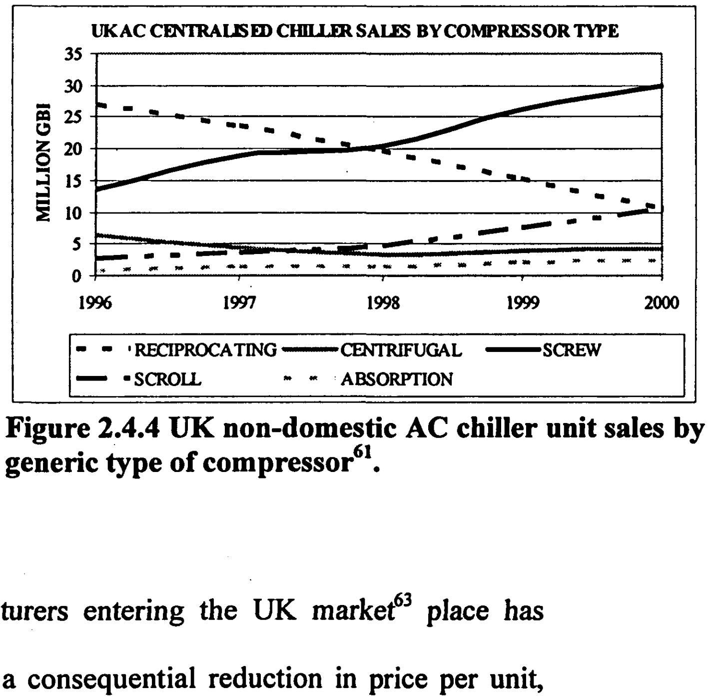


Figure 2.4.4 UK non-domestic AC chiller unit sales by generic type of compressor[61].

This market growth and the Chinese manufacturers entering the UK market[63] place has encouraged a fiercely competitive market with a consequential reduction in price per unit, particularly of packaged systems which is likely to keep prices down, but may also spawn initiatives to offer value added products, which focus on lifecycle costs, energy efficiency or environmental issues[60].

Significantly the increased uptake of air conditioning systems, particularly in the refurbishment of existing not previously mechanically cooled buildings, is leading to a significant growth in carbon emissions resulting from the use of air conditioning[64]. This trend is particularly worrying since the amount of air conditioning installed in UK non-domestic buildings is projected to more than double in the next twenty years[64].

Furthermore, recent changes to the UK energy supply market through the market deregulation and increased competition of the late 1990's, reduced energy prices below production costs[65] and thereby reduced the running costs of air conditioning systems and the effective payback of energy efficiency measures. However, recent consolidation of the industry towards a small number of large energy supply companies, concerns over carbon abatement and energy security increased the pressure on energy prices upward[65]. Furthermore, higher energy prices are predicted to continue for the coming year and in the longer term the EU Emissions Trading Scheme that intended to start from 2005 will help to push energy prices still higher[65]. Higher energy costs will inevitably increase the running costs of building services and in particular energy intensive services including air conditioning. However, higher A/C running costs may also provide increased emphasis on the attention paid to energy efficiency and will certainly improve the pay back period for energy efficiency technology in life cycle cost analysis.

2.4.1 INDUSTRY PERCEPTIONS OF SYSTEMS PERFORMANCE

A study into the future of office working environments in the UK[66] in 1998 surveyed UK building services industry professionals views of 18 different HVAC systems ability to meet a specified environmental criteria, the practical ease with which the criteria could be achieved, overall costs and environmental impact.

The survey covered a wide range of system types ranging in complexity from natural ventilation to advanced variations of Variable Air Volume (VAV) systems. The criteria by which their perception of system performance was judged included questions on environmental performance, user control, cooling capacity, environmental impact, lifecycle costs and integration within building design.

The results are summarised in the diagram shown in Figure 2.4.5 below.

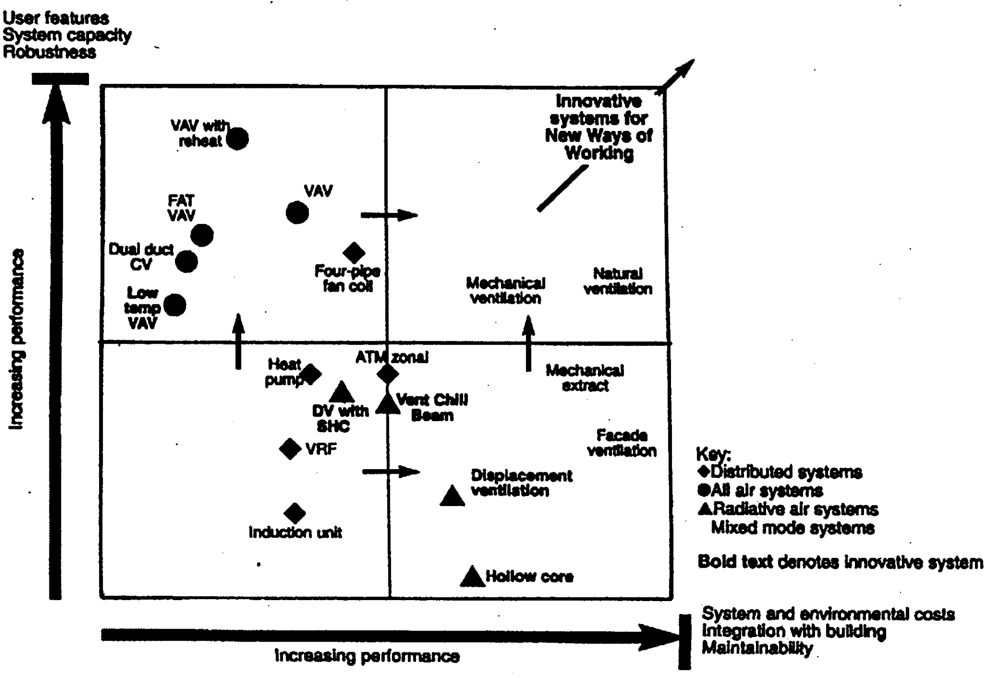


Figure 2.4.5 Industry perceptions of AC system performance [66]

The diagram shows the industry perception of the different A/C systems performance to provide the required conditioning against the costs and environmental impact. Where system performance increases towards the top of the chart and reduced costs and environmental impact improves towards the right hand side of the chart, so that the optimum solution or balance between performance, cost and environmental impact is located in the top right hand corner.

The results breakdown show a wide range of perceived performance broadly grouped around the different generic categories of systems, with ventilation-only systems perceived as having the lowest cost and environmental impact. While centralised all-air systems were viewed as providing the best comfort and operational performance, but with higher operating costs and environmental impact. The partially centralised systems including the fancoil and chilled ceiling systems were grouped towards the middle of the chart, perceived as having less operational robustness, as well as, reduced costs and environmental impact than the all-air systems, but better operational performance and increased environmental impact than the ventilation-only systems. Interestingly natural ventilation was overall the highest rated system i.e. nearest the top right hand corner and induction systems were rated the worst overall.

2.4.2 CARBON EMISSIONS IMPLICATIONS OF UK MARKET GROWTH

The carbon emissions resulting from Air Conditioning use in the UK currently accounts for around 5% of the total carbon emissions from non-domestic buildings[67], but only 10% of commercial floor space are currently air conditioned so the potential for growth is considerable[64].

Greater expectations of thermal comfort in the workplace, improved air quality and worker productivity demands, as well as, reduced air conditioning equipment prices, are all driving substantial growth of the UK air conditioning sector, as discussed in section 2.4. Significantly this growth is likely to more than offset the expected reduction of emissions per unit of electricity from cleaner energy generation, renewable energy sources and more efficient distribution, resulting in a net increase of energy use and carbon emissions[64].

The projected growth in UK building floor area which is air conditioned is illustrated in Figure 2.4.6.

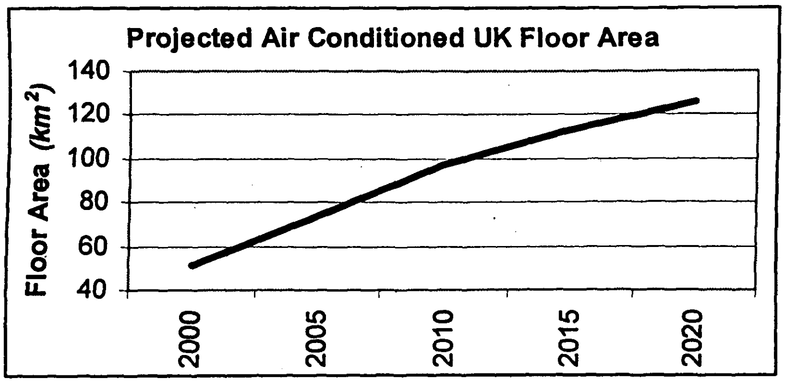


Figure 2.4.6 Projected air conditioned floor area in the UK[67]

Using this forecast for the growth of air conditioning use up to 2020 and the projected carbon emissions per unit of electricity[67] in the UK over the same period an estimate of the total UK carbon emissions resulting from air conditioning energy consumption were estimated to be 0.53 MtC in 2000, rising to 0.91 MtC annually by 2020 assuming a business as usual scenario[68]. This is a predicted increase of carbon emissions of 72% over the 20 year period, as illustrated in Figure 2.4.7.

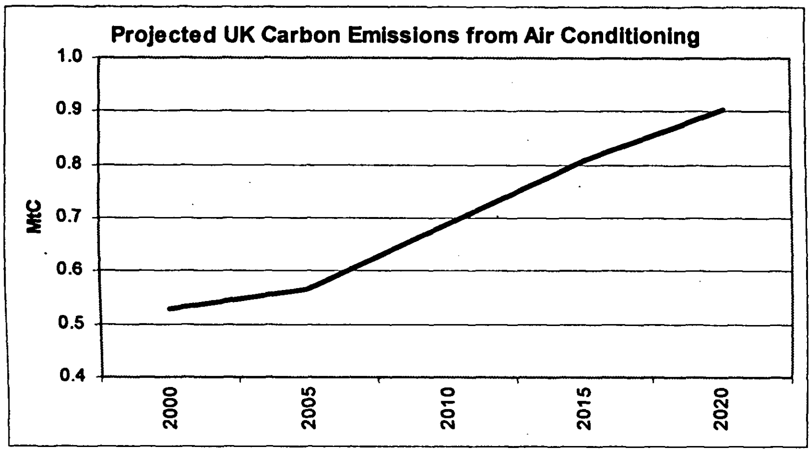


Figure 2.4.7 Projected UK AC carbon Emissions[68]

2.5 UNITED KINGDOM CLIMATE CHANGE POLICIES

Government has promoted energy efficiency with subsidies, advice and publicity campaigns during recent decades. During the 1990s the need to limit greenhouse gas emissions from burning fossil fuels have become the main driving force behind the UK Governments various energy efficiency programmes.

These polices affect the UK air condition market based on their requirements for increased energy efficiency and the environmental concerns over emissions of ozone depleting materials and greenhouse gases, in particular to meet its commitment to the Kyoto Protocol. The Kyoto Protocol once ratified will legally bind the UK to "reduce its annual emissions of a basket of six greenhouse gases in 2008-2012 to 12.5% below the 1990 level."[69] In addition the government has set a goal to further reduce the "UK's annual carbon dioxide emissions in 2010 to 20% below their 1990 level"[21].

Published in 2000 "The UK Climate Change Programme"[70] draws together all aspects of the government's strategy for tackling climate change in the UK. This program sets out a series of measures which aim to deliver the Government's greenhouse gas (equivalent carbon) emission reduction targets. The policies cover all aspects of the UK's society and economy so that the UK is prepared for the effects of climate change, in addition, to reducing countries overall emissions. The programme aims to change the way in which the UK generates, and utilises its energy, and will therefore impact all energy consuming services such as air conditioning.

The policies, which will directly impact the air conditioning market, are; the climate change levy, Future restrictions on the use of HFC refrigerants, Changes to the building regulations which aim to reduce energy use in buildings, and energy technology support programmes.

However, it is probably safe to assume that the current UK climate change polices are just a start since a more recent UK energy consultation paper[71] concluded that carbon emissions would need to be reduced by 60% from 1990 by the year 2050, a target which is three times what the current policies aim to achieve and is likely to become the Governments long term target. In which case, the Chartered Institute of Building Services Engineers (CIBSE) estimates that carbon emissions from buildings would have to cut by 50% for this is to be achieved[72]. Furthermore, since the projected growth in renewable energy would largely be offset by a possible reduction in nuclear energy production, a net reduction in carbon emissions will depend on achieving more efficient buildings[72].

2.5.1 CLIMATE CHANGE LEVY

The climate change levy aims to bring about reduction in energy demand, and associated greenhouse gas emissions, stimulate investment in renewable energy and energy efficiency technologies[69] through taxation on the energy used by industry; commerce and the public sector. Therefore organisations that use significant amounts of energy in their buildings could see increases in their tax costs, while organisations, which utilise low energy and energy efficient buildings, could benefit since organisations tax burdens are shifted to account for their energy use. The levy is likely to be of particular concern for organisations that have energy intensive building services such as air conditioning, which tend to use 50% more energy than other types of buildings.[56]

2.5.2 FUTURE HFC RESTRICTIONS

The Climate Change programme also details the government's future intention towards the use of Hydro fluorocarbons (HFC), which the Government considers "not sustainable in the long-term"[70] and that "HFC refrigerants are only necessary to replace ozone-depleting substances in some applications"[70]. Therefore as soon as alternative technologies are available to meet these applications Government policy is likely restricted the use of HFC refrigerants or phase them out all together. Other legislative issues regarding the use of refrigerants are discussed separately in section 2.6.

2.5.3 CHANGES TO THE BUILDING REGULATIONS

The Government aims to improve the energy performance of buildings through changes to the, Part-L of the building regulations, the regulatory provisions regarding the conservation of fuel and power[73]. The aim of which is to maximise the possible contribution of emissions reductions that can be achieved through the way in which we design, build and operate buildings, while also continuing to allow flexibility in design and avoiding unreasonable technical requirements or costs on the construction industry[74]. In Non-domestic buildings these policy changes aim to improve energy efficiency in buildings and their services by requiring appropriate design, construction and operation through legislation.

This legislation provides three methods for demonstrating that reasonable provision has been made for the conservation of fuel and power. These different methods offer increasing design flexibility in return for greater demands in terms of the level of calculations required. However the overall aim is to achieve the same standard in terms of carbon emissions[74]. The methods are the **Elemental Method** which considers the performance of each aspect of the building individually and a minimum level of performance must be achieved in each of the elements. The **Whole Building Carbon Index Method** where the performance of the proposed building is estimated from the installed capacity of the equipment and compared to a benchmark, and the **Carbon Emissions Calculation Method** where the carbon emissions from the proposed building and an equivalent reference building are estimated using an appropriate calculation tool and missions from the proposed building must be no greater than from the equivalent building that meets the compliance criteria of the elemental method.[74].

In addition to the general requirements of non-domestic buildings, air-conditioning and mechanical ventilation systems are also required to meet additional requirements which include:

- The form and fabric of the building do not result in a requirement for excessive installed capacity of cooling equipment, so that the suitable specification of glazing ratios and solar shading are an important way to limit cooling requirements[74].
- Components such as fans, pumps and refrigeration equipment are efficient and appropriately sized to have no more capacity for demand and standby than is necessary[74].
- Suitable facilities are provided to manage, control and monitor the operation of the equipment and systems[74].

- Continuity of fabric insulation and appropriate level of building air-tightness demonstrated through new requirements of construction and post-construction performance testing[74]. This should affect the performance of all building services, including air conditioning, through improved control over fabric and ventilation rates.

2.5.4 ENERGY TECHNOLOGY SUPPORT

Energy Technology Support a section of the UK Government policy which refers the energy efficiency best practice programme (now marketed as Action Energy) promotes energy efficiency in the manufacturing, services, domestic and transport sectors through good practice guides and case studies, demonstration projects and support for research and development[69] and the Market Transformation programme which aims to develop a consensus among manufacturers, consumers and government on achieving improvements in energy efficiency covering both domestic and offices appliances and some electrical equipment used by industry including refrigeration and air conditioning systems[69]. These programmes provide support and encouragement to various industries to enable energy conservation and the utilisation of energy efficient technologies. Therefore both these programmes are likely to increasingly target Air Conditioning systems as major energy users with the Non-domestic sector.

2.6 REFRIGERANT LEGISLATION

The use of refrigerants is increasingly becoming the target of policy restricting their use throughout the world, in the EU and the UK, due to their tendency to be Ozone depleting materials, significant greenhouse gases, flammable, and often toxic. The control and regulation regarding the use of refrigerants in air conditioning systems fall into basically two categories:

- *Legislation Concerning Ozone Depleting Substances*
- *Health and Safety Legislation concerning toxic and flammable materials.*

2.6.1 LEGISLATION CONCERNING OZONE DEPLETING SUBSTANCES

Governments, including the UK, aim to reduce and eventually eliminate emissions of man-made ozone depleting substances through the adoption of the Montreal Protocol on Substances that Deplete the Ozone Layer[75] in 1987. Since then the control provisions have been modified and strengthened five times (London 1990, Copenhagen 1992, Vienna 1995) Montreal 1997 and Beijing 1999)[75].

The Montreal Protocol came into European Law in 1994 in the form of EC Regulation No. 3093/94 and has already stopped the supply of new CFC refrigerants and frozen the quantity of new HCFC placed on the market within the European Union. This law will completely phase out the use of HCFC by 2015.[76].

2.6.2 HEALTH AND SAFETY LEGISLATION

Refrigerant safety issues are of particular importance with many refrigerants as many of them are highly flammable and / or toxic. However safer substances, such as air, water and carbon dioxide, can be used as refrigerants but practical systems using them are currently uneconomic or inefficient.[76]

Therefore a series of codes and recommended standards exist covering the design, management, transportation and handling of refrigerants. However compliance under law is not required to any specific code or standard. But "non-compliance could be viewed by a court of law as a failure to take reasonable care and precaution leading to criminal prosecution in the event of death or serious injury"[76] under the Health and Safety at Work Act 1974[77] or in subsequent civil action.

The two primary standard codes of practice are the Health and Safety Executive's (HSE) Specialist Inspector Report Number 48,[78] covering the occupational hygiene in the safe handling and selection of refrigerants" and British Standard BS4434[79]. BS4434 limits the hazards from refrigerants by stipulating how and where they may be used, and the maximum charge of a refrigerant in a particular application to maximise safety[76].

In addition to the Codes of Practice designers, installers and users of refrigeration equipment are required to abide by the following Health and Safety statutory requirements[76]:

- *Pressure Systems and Transportable Gas Containers Regulations 1999*[80].
- *Management of Health and Safety at Work Regulations 1999*[81].
- *Control of substances Hazardous to Health (COSHH) Regulations 1999*[82].
- *Construction Design and Management Regulations 1994*[83].

It is also recommended for good practice that in addition to BS 4434 all installations of refrigeration equipment conform to "The Institute of Refrigeration Safety Codes"[84], which give practical guidance on the inspection and maintenance of refrigeration systems.

2.7 RESEARCH HYPOTHYSIS

In conclusion from the review of the theoretical factors and existing performance data we would expect the energy performance of the air conditioning systems monitored by this research to vary based on the main factors identified in section 2.1 which are as follows:

- The load placed on the system, i.e. the net cooling load resulting from the building form and fabric, glazing and any internal heat gains.
- The environmental operating conditions, i.e. the weather conditions and required evaporating temperature.
- The refrigeration component technology (including refrigerant type and defrost method), i.e. the efficiency the chosen plant components of the chiller plant.
- Choice of cooling distribution and delivery method (i.e. the type of A/C system), i.e. the type of generic air conditioning system employed.

- System design, control and maintenance, i.e. how the air conditioning system is utilised.

But due to the number of building, system and occupancy variables influencing the performance of the monitored systems in practice, it is not possible to determine which of these factors will have a distinguishable influence on the monitored performance data or indeed which of the factors will overall have the most influence on the actual energy performance of the monitored systems in practice.

However we can speculate on the relative importance of these factors, by ranking them in order of their potential worst-case impact on the 'cooling' energy consumption based on the background issues discussed throughout this chapter. This speculation indicates that the factors identified above are rated in the following order of importance:

1. System design, control and maintenance, would appear have the largest potential impact of system energy consumption, since a worst case 'system running constantly' scenario would increase the operational hours, and therefore energy consumption, by 350% compared to 2,500 hours for typical annual usage.
2. The choice of cooling distribution and delivery method, i.e. the type of A/C system; based on the modelling work (Section 2.3.2) which showed that seasonal efficiency varied by as much as 320% between the different systems studied.
3. The load placed on the system; according to current building services design standards (Section, 2.3.2) indicate that the typical design load within UK office buildings could up to 187%.
4. The refrigeration component technology, which according to published chiller efficiency testing results (Section 2.3.1) the efficiency of refrigeration plant varied by as much as 168%.
5. The environmental operating conditions have been assumed to be the least important factor, because although clearly important all the monitored systems would have been

exposed to broadly the same climatic conditions since they were monitored over the same period of time, with only regional variations in climate not being accounted.

But overall due to the large number of variables involved we would expect to see a relatively wide range of measured energy consumption for both the buildings and systems monitored. Current benchmarks indicate that the annual building energy consumption should range between 225 and 404 kWh/m^2 and that between 44 and 91 kWh/m^2 of that would be attributable to the delivery of cooling services.

Therefore, although expecting wide range of monitored energy consumption cross the monitoring sample, we also expect to see a significant difference in the energy consumption depending on how the systems are operated and between the different generic types air conditioning. The modelling results would suggest that the Chilled Ceiling and DX based systems, including the VRF variants, followed by the unitary heat-pump systems to be noticeably more efficient in terms of their cooling energy consumption than the other generic system types.

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Chapter 3: Research Methodology

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3.0 METHODOLOGY OVERVIEW

The research aimed to determine the energy consumption, and atmospheric carbon emissions, currently associated with the use of air conditioning in UK offices, the relative energy performance of the different generic types of AC systems commonly used and the main factors which appear to influence AC energy performance in practice and their implications to UK atmospheric carbon emissions.

The method employed to achieve these aims utilised field energy monitoring techniques to measure the energy consumption, and therefore associated carbon emissions, of a number of air conditioning systems 'as found' within actual UK office buildings. In addition the research has undertaken surveys of each building, in order to estimate the loads served by each system monitored and therefore assess the relative performance of the different systems even when providing a different level of service or serving different cooling loads.

The research assesses the energy performance of the monitored air conditioning systems at a number of levels including:

- The measured annual energy consumption of each building and air conditioning system has been used to assess the relative performance of each building and AC system to one another, as well as, to national energy consumption benchmarks.
- The energy demand profiles of each air conditioning system over the monitoring period have been used to assess the relative peak energy demand, frequency of part-load operation and hours of operation for each system monitored.
- The internal loads served by the air conditioning system within each building from occupancy, lighting and small power equipment have been calculated, from information obtained by detailed building surveys, and used to assess the cooling load served and the chiller sizing of each system.

- An estimation of the efficiency of each system has been calculated from the measured peak power demand and calculated peak internal cooling loads for each building studied and used to assess the relative energy efficiency of the different generic air conditioning systems types.

Ideally, thermal modelling of each building should have been undertaken to determine the fabric, solar and ventilation loads placed on the systems over the monitoring period, but this was not possible with the resources available. So the fabric and solar component of the loads could not be reliably estimated. Therefore, the efficiency calculation used to normalise the measured energy consumption obtained from the field energy monitoring only considers the internal components of system load. Speculation of the total cooling loads including the fabric, solar and ventilation will be discussed based on rule-of-thumb values.

Each sample building and air conditioning system was studied 'as found', even if they were operated in a less than perfect manner, so that the results were consistent with the way the buildings and systems were designed, commissioned and operated over the monitoring period. Intervention to improve the performance of the air conditioning systems using feedback from the monitoring programme was avoided. Therefore, feedback from the monitoring was not provided to the managers of the host buildings until after monitoring was complete, so that the measured results represent the actual performance of each system and were not directly influenced by the monitoring programme, though the very act of monitoring the systems inevitably led to some attention being focussed on them and it is inevitable that some unintended improvements in performance were achieved in some instances. However, it is not thought that these improvements were very widespread or influential.

3.1 SELECTION OF MONITORING SITES

The selection of sites to be monitored during this research was undertaken to ensure that the appropriate parameters of each individual system could be monitored within the resources available to the project and within the limits of the cooperation of each buildings owner. While also ensuring that the overall sample was appropriately representative of the different air conditioning systems types and the national stock of air conditioned buildings. Chapter 4 describes in details the criteria by which each site included in the monitoring sample was selected and provides a summary of the sample of buildings monitored.

However, in the early stages of this research it was realised that one of the most challenging aspects of the research was going to be the recruitment of enough suitable buildings with owners and operators willing to allow monitoring of their systems over an extended period of time because the field monitoring approach required the cooperation of and commitment by all organisations involved with each building, as well as, finding enough buildings containing the right type of air conditioning systems.

3.2 MONITORING OF AC SYSTEM ENERGY PERFORMANCE

This research has used field energy monitoring techniques to measure the energy consumed by each air-conditioning system studied to deliver comfort cooling within each of the sample buildings over the monitoring period. The energy consumption was measured of all the component systems associated with the delivery of primary cooling services within each air conditioning system, so that direct comparison can be made of the efficiency by which the different system types provide comfort cooling.

Therefore number of parameters requiring monitoring and the amount of monitoring equipment required was different for each individual site, depending on the type of air conditioning system and its configuration within each building.

However the energy consumption of other building services not directly involved in the delivery of cooling, such as separate ventilation or humidification equipment were not monitored. Although it would have been interesting to assess all the services provided by the entire HVAC system in each building, it would have required monitoring resources beyond that available to the project.

Although this research is primarily concerned with the delivery of comfort cooling from air-conditioning systems it also had to consider space heating when provided by reverse-cycle heat-pumps, because it is difficult to differentiate between heating and cooling modes of operation with reverse-cycle systems.

In addition to the energy monitoring undertaken at each site the study also aimed to obtain enough additional information regarding the operation of each system in order to understand how each site was being operated, to help verify the quality of the monitored energy performance data, in order to provide feedback to the study on the main factors influencing energy consumption and in order to inform the building management on means to improve the performance of their air conditioning system at the completion of the study.

3.2.1 Categorisation of Generic System Types

This research considered six different generic types of air conditioning systems based on the definitions discussed in Section 2.1.4, as shown in Table 3.2.1 below.

Table 3.2.1: Categorisation of generic system types

System Category	***Description***
1 - All-Air Systems	Centralised Air-air systems, which centrally condition a mixture of fresh and return air, which is then delivered to the occupied space via ductwork and terminal devices.
2 - Fan-coil Systems	Partially centralised Air-water system that use centrally conditioned water to condition the air within occupied space via fan-assisted heat exchangers.
3 - Chilled Ceilings	Partially centralised Air-water system that uses centrally conditioned water to directly condition the occupied space by both radiant and convective cooling effects.
4 - DX Split Systems	Direct expansion (DX) system that condition the occupied space air directly from the evaporator of the refrigeration cycle.
5 - VRF/VRV Heat Recovery	Advanced multi-split DX system, using 3 refrigerant lines (3-pipe) that enable simultaneous heating and cooling, as well as, heat-recovery between internal cassette units.
6 - Unitary Heat-pumps	Partially centralised system, using multiple water-to-air heat-pumps located within the occupied space, which are served from a centrally conditioned water loop.

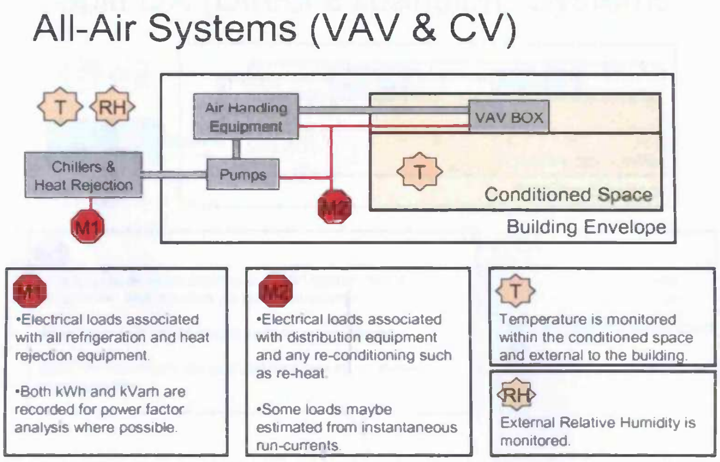
3.2.2 Measurement of System Energy Consumption

As previously stated the primary focus of the monitoring undertaken at each site was to measure the energy consumed by each air conditioning system to deliver comfort cooling to the occupied space of the building. To meet this aim the following parameters were recorded at each site:

- All refrigeration plant providing cooling and heating if provided by reverse-cycle heat-pumps, to the occupied space.
- All distribution equipment, i.e. fans and pumps etc, used to deliver cooling, and heating if provided by reverse-cycle heat-pumps, to the occupied space.
- Air handling equipment, but only if used to delver primary services to the occupied space as in centralised all-air systems and active chilled beam systems. Loads associated with air-handling plant providing only ventilation air even if tempered were not to be monitored, as they do not provide primary services based on the definitions used by this research.
- All controls equipment associated with the above systems.

Therefore, the type and quantity of monitoring equipment required to measure these parameters at each site varied depending on the type of air conditioning system and the specific circumstances of each building. Figures 3.2.1 to 3.2.6, show schematic diagrams which detail the monitoring undertaken for each generic system type studied by this work.

All this monitoring was conducted in accordance with ASHRAE guidelines for building monitoring protocols[1]. Details of the actual monitoring undertaken at each site monitored are provided in Appendix A, including the number of monitoring points and parameters measured.



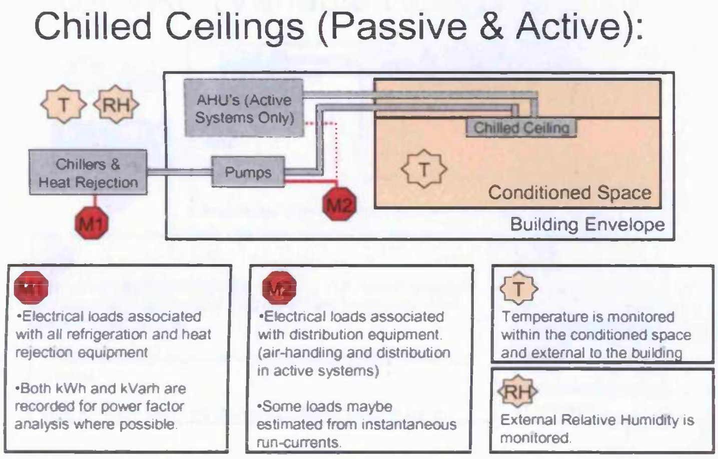
- Electrical loads associated with all refrigeration and heat rejection equipment.
- Both kWh and kVarh are recorded for power factor analysis where possible.

- Electrical loads associated with distribution equipment and any re-conditioning such as re-heat.
- Some loads maybe estimated from instantaneous run-currents.

Temperature is monitored within the conditioned space and external to the building.

External Relative Humidity is monitored.

Figure 3.2.1: Monitoring schematic for All-Air systems.



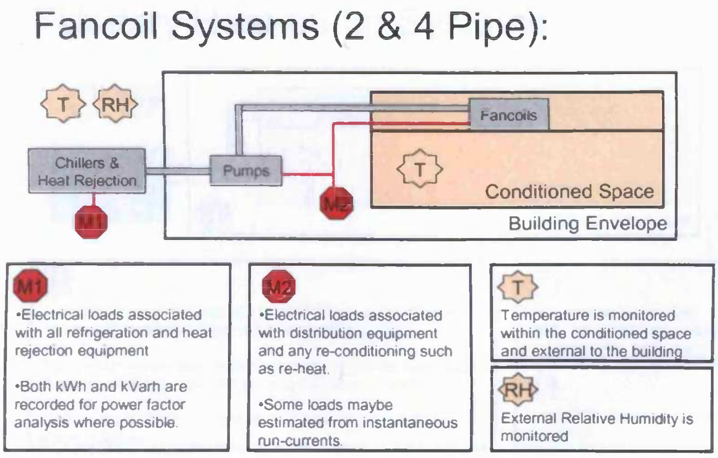
- Electrical loads associated with all refrigeration and heat rejection equipment
- Both kWh and kVarh are recorded for power factor analysis where possible.

- Electrical loads associated with distribution equipment. (air-handling and distribution in active systems)
- Some loads maybe estimated from instantaneous run-currents.

Temperature is monitored within the conditioned space and external to the building

External Relative Humidity is monitored.

Figure 3.2.2: Monitoring schematic for chilled ceiling systems.



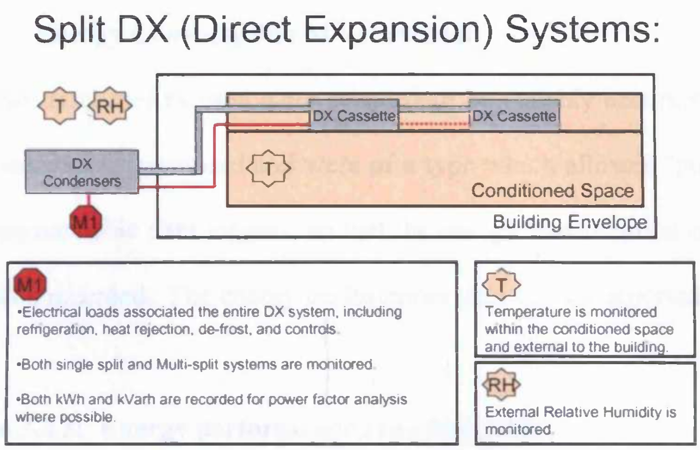
- Electrical loads associated with all refrigeration and heat rejection equipment
- Both kWh and kVarh are recorded for power factor analysis where possible.

- Electrical loads associated with distribution equipment and any re-conditioning such as re-heat.
- Some loads maybe estimated from instantaneous run-currents.

Temperature is monitored within the conditioned space and external to the building

External Relative Humidity is monitored

Figure 3.2.3: Monitoring schematic for fancoil systems.



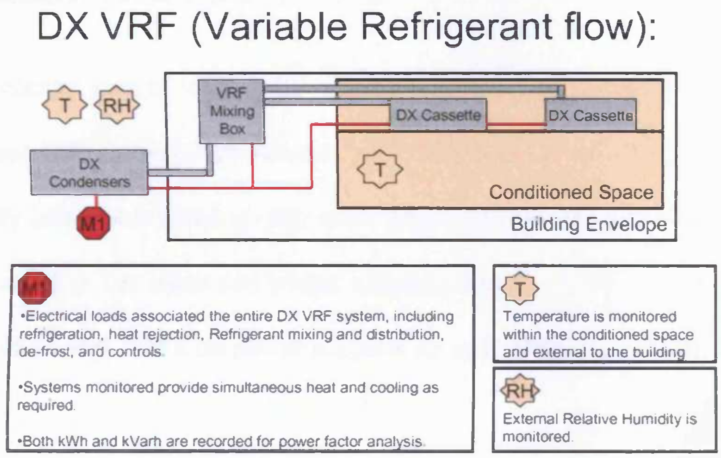
M1

- Electrical loads associated the entire DX system, including refrigeration, heat rejection, de-frost, and controls.
- Both single split and Multi-split systems are monitored.
- Both kWh and kVarh are recorded for power factor analysis where possible.

T — Temperature is monitored within the conditioned space and external to the building.

RH — External Relative Humidity is monitored.

Figure 3.2.4: Monitoring schematic for split DX systems.



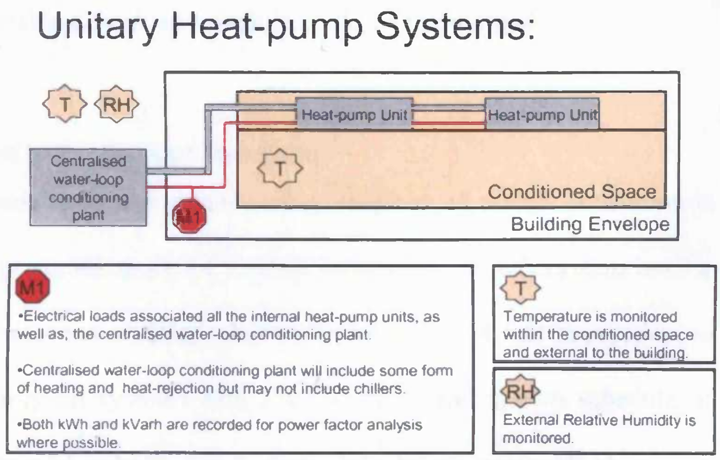
M1

- Electrical loads associated the entire DX VRF system, including refrigeration, heat rejection, Refrigerant mixing and distribution, de-frost, and controls.
- Systems monitored provide simultaneous heat and cooling as required.
- Both kWh and kVarh are recorded for power factor analysis.

T — Temperature is monitored within the conditioned space and external to the building.

RH — External Relative Humidity is monitored.

Figure 3.2.5: Monitoring schematic for VRF heat-recovery systems.



M1

- Electrical loads associated all the internal heat-pump units, as well as, the centralised water-loop conditioning plant.
- Centralised water-loop conditioning plant will include some form of heating and heat-rejection but may not include chillers.
- Both kWh and kVarh are recorded for power factor analysis where possible.

T — Temperature is monitored within the conditioned space and external to the building.

RH — External Relative Humidity is monitored.

Figure 3.2.6: Monitoring schematic for unitary heat-pump systems.

3.2.3 Energy Consumption Measurement

The electrical meters used were selected to be suitably accurate and appropriately sized for the loads being monitored and were of a type which allowed 'pulse-output' data connections to programmable data loggers, so that the energy consumption over a specified time interval could be recorded. The energy performance data will be reported to according to Table 3.2.2.

Table 3.2.2: Energy performance reporting units

Parameter	***Unit***
Electrical Power Demand	*Watts per square metre (W/m^2)*
Energy Consumption	*Kilowatt hours per square metre (kWh/m^2)*
Reactive power demand	*Kilo volt amp hours reactive per square metre ($kVarh/m^2$)*
Power Factor	*(n/a)*

The energy meters used were 'Sinergy KMF' brand multifunction energy meters[2], which utilised both current transformers (CT) and voltage inputs across all phases of the power supply being monitored so that any voltage variation or un-balanced loads was appropriately accounted in the measured power consumption and have a rated accuracy of +/- 1% with a resolution of 0.1kWh on power supplies up to 1.0kWh and of 800 to 3000 amps.

The data logging devices used were "Gemini Tinytag Plus" pulse-count loggers[3], which were selected to record the energy meter readings over the required recording intervals and had a 16,000 reading memory capacity which enabled the data to be saved for long enough so that a reasonable download schedule could be maintained.

Use of instantaneous Readings

In some instances instantaneous readings of power consumption were used to estimate the energy consumption of a plant component or sub-system over a period of time. However, instantaneous readings were only used when is was impractical to install permanent metering and only on systems with constant load and known schedule of operation. Instantaneous readings of voltage and current were taken across all phases so that the operational power rating (kW) could be calculated using the following equation:

$$Power\ (Watts) = \frac{\left(\sqrt{3} * voltage(volts) * current\ (amps)\right)}{power\ factor}$$

The equipment power consumption, resulting from this calculation, was then converted to energy consumption using the run-hours of the plant, before being added to the monitored energy consumption data from the rest of the system.

Use of Existing Sub-Metering Systems & Utility Billing Data

Whenever possible existing energy consumption data and utility energy bills were collected with the permission of the building management and used to establish the overall energy consumption of the whole building, its energy performance relative to national benchmarks[4], as well as, determining the proportion of HVAC services as a percentage of total building loads. See Chapter 5 for the results of this analysis.

Recording Intervals

All data parameters recorded by this research were collected at frequency intervals of no more than 30 minutes and where practical recordings were taken at much shorter intervals improving the resolution of the resulting data. Typically the primary results, i.e. the measurement of energy consumed by the air conditioning systems, were recorded at 15 minute intervals and downloaded at 90-day intervals.

The selection of recording intervals was assessed to ensure that all significant effects and fluctuations in power load are monitored, but at the same time taking into account the max-count and memory size of the data loggers to prevent 'flooding' the memory of the loggers resulting in lost data, but also allowing reasonable periods between downloads which could be met with the manpower and financial resources available to the project.

Details of the actual monitoring undertaken at each site monitored are provided in Appendix A, including recording intervals and dates when the data was downloaded.

Duration of Monitoring

The monitoring at each site had to continue for a period of time long enough to encompass all operating conditions and guard against untypical operation and weather conditions. This was anticipated to be a period of at least one calendar year and therefore the site selection process had to ensure continuous access for at least one calendar year (Section 4.1).

Details of the actual during of monitoring undertaken at each site monitored are provided in Section 4.2.1.

Quality Control

The quality of the initial monitoring set-up at each site was managed through the documentation and recording of all equipment and installation procedures used. Furthermore, all the energy monitoring equipment used was new factory supplied and tested equipment with guaranteed calibration. Checking of the initial results was carried out against existing benchmarks, other sub-monitoring data obtained from the buildings, and historical energy bills to aid the quality control and confidence in the monitored data.

The on-going quality of the measured data was periodically checked, normally during each download of data at each site. So that any problems that occurred during the monitoring were identified to enable effective remedial action to be taken. Such monitoring mishaps included missing data from failed, or stolen sensors, data points not monitored due to planning oversights not identified until after the monitoring had commenced, or monitoring equipment being mistakenly disconnected during routine maintenance.

Normalisation of floor areas

In order to make comparisons between the different buildings surveyed and published benchmark standards, all measured results and calculated parameters used during the analysis of this data have been normalised to treated floor area (TFA) based on the same definition as these standards[4].

3.2.4 Supplementary Environmental Monitoring

In addition to the energy consumption monitoring discussed above, for this research the environmental conditions to which the buildings studied were exposed during the monitoring period was also monitored. Although most of this environmental data collected has not been used in the analysis in this thesis, the data was used to aided in the quality control assessment of the monitored energy data, provided useful feedback to the building operators, by other end-users of the data (see Section 1.2) and importantly it enables further development of this data-set to be conducted beyond the scope of the analysis presented here, see suggested further research for further details in Chapter 12.

The monitoring of environmental conditions was undertaken at each site location on a basic level and on a more comprehensive level on a regional basis, as summarised in Table 3.2.3.

The localised environmental monitoring principally aimed to aid in the assessment of how the system was being operated, which was used when conducting the quality control assessment of the measured energy data (Section 3.2.3), as well as, to provide feedback to the building management which was often a often a key component in getting access to the buildings to carry out this research.

Regional meteorological data was obtained for a wider set of parameters and collected with the principle aim of enabling further development of this research in the future and for used by some of the other end-users of the monitoring data collected as identified in Section 1.2.

Table 3.2.3: Required environmental monitoring

Parameter Monitored	***Units of measure***
Localised monitoring at each site	
Internal Temperature (Dry-bulb)	*Degrees Celsius (Deg C)*
External Temperature (Dry-bulb)	*Degrees Celsius (Deg C)*
External Relative Humidity	*Percentage (% RH)*
Detailed Regional monitoring	
External Temperature (Dry-bulb)	*Degrees Celsius (Deg C)*
External Relative Humidity	*Percentage (% RH)*
Wind Speed	*Meters per second (m/s)*
Prevailing wind direction	*Degrees from north (Deg)*
Solar Irradiance (direct component)	*Watts per square meter (W/m2)*
Solar Irradiance (diffuse component)	*Watts per square meter (W/m2)*

Three regional metrological stations were operated located in Cardiff, Bristol, and Central London and in addition Met-office data was obtained courtesy of National Grid Transco Plc. For the Met offices' Birmingham site, as detailed in Table 3.2.4.

Table 3.2.4: Location and source of meteorological data

Sources of Meteorological Data:		
Site	***Location***	***Site operated by***
1	London (Central)	Welsh School of Architecture
2	Cardiff	Welsh School of Architecture
3	Bristol	University of West England
4	Birmingham (International Airport)	The Met Office

3.3 ASSESSMENT OF LOADS SERVED BY THE SYSTEMS

This section covers the assessment of loads served by the systems studied over the monitoring period, which will be calculated based upon the detailed information collected about each building during a building characteristics survey. The assessment of loads served by the systems over the energy monitoring period has been used to calculate the overall system energy efficiency for each of the systems studied, in order to understand the relative performance of the different systems, occupancy patterns and building types, as described in Section 3.4.

3.3.1 Building Characteristics Survey

The survey was based on the parameters required to complete the CIBSE TM22: an energy assessment and reporting methodology for offices[5] and conducted using a survey format developed for the UK Non-Domestic Building Stock Energy Database[7].

The building surveys aimed to establish detailed knowledge of the following issues at each sample building:

- Building identity and categorization
- Building structure and layout
- Building occupancy levels and patterns
- Type and details of HVAC systems
- Building and plant history

The level of detail required to collect all this information meant that at least one visit to each site was essential and where possible additional confirmatory visits were conducted to determine any variations in the building operation and occupancy, thereby ensuring the recorded values were typical of the building and not specific to the day of the visit. Typically these 'confirmatory' surveys were conducted on the various download visits to each building.

Details of each buildings structure, layout, HVAC systems, plant history, operation regimes and management were normally obtained from interview with building managers or from as-built plans and operation and maintenance manuals normally available in commercial UK buildings.

However, occupancy levels, lighting and small power loads were assessed by a walk-through survey of a representative office space within each building to assess the utilisation of the office area at any given time and to enable the internal heat-gains to be calculated as detailed below. The walk-through office survey recorded the following details; Number of personnel, Type and quantity of lighting fixtures, Type and quantity of office equipment.

The information gathered for each building in the monitoring sample has been summarised in Appendix A, including general information about each building and its occupancy, as well as, details of the building fabric, HVAC system and control.

3.3.2 Calculation of Internal Heat Gains

Internal heat-gains within each space studied are calculated using the CIBSE nameplate-ratio method[6]. In order for the calculated gains to represent the likely maximum gains, and therefore be comparable to loads used in the sizing of building services plant, worst-case power demand and nameplate ratios, as well as full occupancy without diversity factors are assumed. This method and the assumptions therein acknowledge that it is difficult to accurately account for the variation in usage between different users and that the calculated values are based only on the snap-shot of time during which the survey took place. However, so long as the method is applied consistently the relative impact of the different occupancy patterns will still be accounted for in the comparison between the different sample sites.

The calculated peak total internal heat gain is the sum of the calculated component heats gains resulting from; occupancy, lighting and small power loads and defined as follows:

$$\text{Total internal heat gains (W)} = \text{occupancy load (W)} + \text{lighting load (W)} + \text{small power load (W)}$$

Where the calculations used for each of the individual components are detailed in the following sub-sections.

3.3.3 Calculation of Occupancy Loads

The internal load resulting from the occupant persons within the space is calculated by:

$$\text{Occupancy load (W/m}^2\text{ TFA)} = \frac{\text{number of people x 130 Watts (W)}}{\text{treated floor area (m}^2\text{ TFA)}}$$

Where the number of people is that noted from the occupancy recorded during the survey and 130watts is the total heat emissions of one occupant based on 102 watts sensible and 28 watts latent heat emissions for a seated office worker undertaking moderate work[6]. This value has been adjusted to account for a mixture of men and women assuming that the number of women is 85% of the number of men[6].

3.3.4 Calculation of Electrical Lighting Loads

The internal load resulting from the electrical lighting within the office space is calculated by:

$$\text{Lighting load (W/m}^2\text{ TFA)} = \frac{\text{\# fixtures x \# lamps x lamp rating (W)}}{\text{floor area (m}^2\text{ TFA)}}$$

Where: '#Fixtures' represents the number of lighting fixtures within the sample office space, '#Lamps' represents the number of lamps per fixture and the 'Lamp Rating' is the lamp power rating in Watts *(W)*, as noted from the building survey.

Where lamp ratings could not be determined during the building surveys standard ratings[7] have been assumed as shown in Table 3.3.1.

Assumed Lamp Ratings	
Description	**Rating**
	(Watts)
Compact Fluorescent 2 tube	11
Compact Fluorescent 4 tube	18
Fluorescent 36mm 2 foot	18
Fluorescent 36mm 4 foot	36
Fluorescent 36mm 5 foot	65
Fluorescent 36mm 6 foot	72

** Source: Sheffield Hallam University*

Table 3.3.1: Assumed lamp ratings[7]

3.3.5 Calculation of Small Power Loads

The internal load resulting from the use of office equipment or so-called 'small power equipment' is the sum of the loads from each type of equipment within the office space. Where the loads from each type of equipment are calculated as follows:

$$\text{Small power (W/m}^2\text{TFA)} = \frac{\#\text{equipment x }\#\text{power (W) x nameplate ratio}}{\text{floor area (m}^2\text{ TFA)}}$$

Where: '#Equipment' is the quantity of a particular type of office equipment, '#Power' is the power rating in Watts *(W)* for the particular equipment type, and the 'Nameplate Ratio' is a constant factor for each equipment type derived from the average power demand *(W)* divided by the Peak rated power demand *(W)*.

Standard worst-case values[6] for both equipment power demand and nameplate ratios have been used throughout so that the resulting loads represent peak design conditions. The standard power demand and nameplate ratios used for each type of office equipment are shown in Table 3.3.2 below.

Equipment Power Ratings & Nameplate Ratios		
Equipment Type	***Worst-case Rated Power Demand***	***Worst-case Name Plate Ratio***
	(Watts)	*(n/a)*
Desktop Computer	187	0.7
Laptop Computer	55	0.7
Printer	150	0.2
Photo Copier	850	0.25
Fax	38	0.25
Desk Fan	60	0.7

** Source: CIBSE Guide A 1999*

Table 3.3.2: Standard small power ratings & nameplate ratios[6]

3.3.6 Normalisation survey floor areas

It is important to note that the sample floor areas recorded during the surveys were of representative office area, which did not include circulation and other service areas within the building, or in other words net-floor area (NFA). However, treated floor area (TFA) is more representative of the entire building and is the reference area used in this study. Therefore, the sample floor areas were converted into equivalent treated floor areas (TFA) using the benchmark assumption that TFA= 1.25 x NFA (8).

3.3.7 Consideration of Fabric & Solar Loads

In order to calculate the overall heating and cooling loads within the spaces served by the systems studied, the thermal loads resulting from building fabric and solar components need to be calculated for each time interval of energy consumption data for each building. The only practical method of assessing these loads is by computer based dynamic thermal models using the details of each buildings fabric layout i.e. size, shape, materials amount of glazing etc and the actual measured weather data for the same period of time as the energy data.

3.4 ASSESSMENT OF AIR CONDITIONING SYSTEM EFFICIENCY

The method used in this research to establish the relative energy efficiency of each of the air conditioning systems studied is based on the normal expression of efficiency used for building services, the co-efficient of performance (COP), but in this case calculated using the measured energy consumption obtained from the monitoring work and the calculated cooling loads served. Therefore the cooling system efficiency 'in-practice' for any given period of time is determined by the cooling load (kW/m^2 TFA) divided by the average power consumption of the whole system (kW/m^2 TFA).

The "System Load" is the total load served by the system, or the net sum of the all the component loads resulting from internal heat-gains, fabric, solar and ventilation gains or losses. The "System Energy Consumption" is the measured energy consumption of the entire system over the same period of time, including all the sub-systems involved with servicing the system load. Hence in order to establish the overall efficiency of a system based on the above ratio for a given period of time the following component factors will need to be determined:

- Internal Heat-gains within the occupied space serviced by the system.
- The fabric and solar heat-gains or losses to the serviced space.
- The energy consumption of the entire system meeting the system load.

Ideally, thermal modelling of each building should have been undertaken to determine the fabric, solar and ventilation loads placed on the systems over the monitoring period (Section 2.2). Unfortunately, resources were not available to this project to undertake the thermal modelling of these loads. So the fabric and solar component of the loads could not be reliably estimated, and could not be included in the efficiency calculations carried out. Therefore, the efficiency calculation used to normalise the measured energy consumption obtained from the monitoring for the different loads served has been modified to only consider the internal components of system load. In order to avoid confusion with other expressions of efficiency, the modified expression of efficiency used in this thesis will be referred to as the 'Internal Load Performance Ratio' (ILPR) and is defined below (Section 3.4.1).

3.4.1 Calculation of Internal Load Performance Ratio (ILPR)

In order to graph this normalisation it has been necessary to define a performance measure, which we have chosen to call the Internal Load Performance Ratio (ILPR). This is defined by the following equation for any given period of time:

$$\mathrm{ILPR} = \frac{\text{calculated internal load } (\mathrm{W/m^2})}{\text{power input to the AC system } (\mathrm{W/m^2})}$$

The ILPR is therefore a whole system Coefficient of Performance (COP) that does not include fabric, solar or ventilation components of the heat losses and gains of the overall load. Standard design methods are used for calculating internal component loads as defined in Section 3.3.2.

3.5 ACCURRACY OF MEASURED ENERGY PERFORMANCE

All the measured and calculated parameters used in the analysis presented as part of this thesis will have an error, or statistical uncertainty, associated with its value. Therefore the interpretation of these results must also take into account these error characteristics by assessing the degree of certainty associated with each result in order to draw valid conclusions. In order to quantify the certainty of the results the error associated with each result have been identified and calculated based on the following criteria.

3.5.1 Sources of Error and Uncertainty

The following sources of error or uncertainty have been identified which may affect the certainty of the results from this study. The sources of error can be grouped into basic types including parameters of a known accuracy and parameters estimated from instantaneous or sample readings.

Sources of error with a known accuracy are associated with all the energy and environmental monitoring equipment used in this study, i.e. energy meters etc, which all have certain accuracies to their measurements. This research has dealt with these monitoring accuracy issues by, firstly, selecting the most accurate monitoring equipment available within the resources available to the project, and secondly, by recording details of the equipment used to measure each parameter, and its accuracy rating from manufacturers calibration tests, so that the error associated of each result value could be calculated, see Section 3.5.2.

Sources of error and un-certainty from parameters estimated from instantaneous or sample readings used in this research include estimated energy consumptions of some secondary sub-systems included in the overall energy consumption monitoring (Section 3.2.2) and survey findings used in the calculation of internal heat-gains which are based on the conditions recorded on a number of spot-visit not continuous monitoring, and therefore may not be representative of conditions over the entire monitoring period. Although these methods are not ideal they have been used to assess issues which otherwise could not have been reliably quantified and their associated error has been assessed assuming extreme "maximum" and "zero" levels thereby assigning a theoretical error band and factored into the calculation of the error associated with each result, see Section 3.5.2 below.

3.5.2 Accuracy of the Energy Consumption Measurements

All results calculated from recorded values used in the analysis presented in this thesis have had their associated propagation error characteristics calculated. The following mathematical functions were used to calculate the propagation of error characteristics for each mathematical function used in calculating the results[8].

Addition & subtraction: $(\Delta Z)^2 = (\Delta A)^2 + (\Delta B)^2$

Multiplication & division: $\left(\frac{\Delta Z}{Z}\right)^2 = \left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta B}{B}\right)^2$

Where:

ΔA & ΔB = the error associated with their respective input parameters

ΔZ = the error associated with the resultant value of the function in question

The resulting calculated margins of error for the measured energy consumption data for each site are shown in Table 3.5.1 below. These indicate the maximum error as a percentage for total the total for any time internal. It is important to note that sites where estimations from instantaneous readings were made have high potential margins of error since the errors have been calculated based on the worst case scenario for all estimated component loads, i.e. a load is assumed when in fact the component in reality is switched off, or vice versa. Hence during periods when other parts of the system are operating at a low level the potential error can be a substantial proportion of the total system load. However, the majority of the time when the systems are operating the potential error resulting from the estimated loads will be far lower than the maximum indicated below, but nonetheless the potential it is important to highlight the potential error in the data.

Table 3.5.1. Calculated average error of measured energy consumption data.

Site ID Number	*System Type*	*Error (+/-)*	*Comment on potential error*	*Effective time control*
Cooling Only Systems				
1	*All-Air*	*1.0%*		*Yes*
2	*All-Air*	*0.8%*		*No*
3	*All-Air*	*1.0%*		*Yes*
4	*All-Air*	*0.3%*		*No*
5	*All-Air*	*0.6%*		*No*
6	*All-Air*	*0.6%*		*No*
7	*All-Air*	*0.5%*		*Yes*
8	*Chilled Ceiling*	*84.4%*	*Energy use by distribution pumps estimated from instantaneous readings*	*Yes*
9	*Chilled Ceiling*	*5.2%*		*Yes*
10	*Chilled Ceiling*	*1.0%*		*Yes*
11	*Chilled Ceiling*	*9.5%*		*No*
12	*Fancoil*	*0.9%*		*Yes*
13	*Fancoil*	*0.9%*		*No*
14	*Fancoil*	*51.7%*	*Energy use by Fancoil units, Primary, Secondary and condenser pumps estimated from instantaneous readings*	*Yes*
15	*Fancoil*	*0.6%*		*No*
16	*Fancoil*	*52.4%*	*Energy use distribution and condenser pumps estimated from instantaneous readings*	*Yes*
17	*DX Split*	*1.0%*		*No*
18	*DX Split*	*1.0%*		*Yes*
19	*DX Split*	*0.9%*		*Yes*
20	*DX Split*	*0.7%*		*Yes*
21	*DX Split*	*1.0%*		*Yes*
22	*DX Split*	*1.0%*		*No*
Reverse-Cycle Systems				
23	*Chilled Ceiling*	*51.0%*	*Energy use distribution estimated from instantaneous readings*	*Yes*
24	*VRF HR*	*1.0%*		*No*
25	*DX Split*	*1.0%*		*Yes*
26	*DX Split*	*1.0%*		*Yes*
27	*DX Split*	*1.0%*		*No*
28	*Fancoil*	*0.6%*		*No*
29	*VRF Heat Recovery*	*1.0%*		*Yes*
30	*VRF Heat Recovery*	*1.0%*		*Yes*
31	*VRF Heat Recovery*	*1.0%*		*No*
32	*Unitary Heat Pump*	*16.6%*		*No*

Note the error of systems that only required a single energy measurement point and no estimates from instantaneous measurements was equivalent to the error of the energy meter, in this case a rating of 1% recording error.

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Chapter 4: The Monitoring Sample

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4.0 THE MONITORING SAMPLE

This chapter discusses the sample of air-conditioned offices monitored in this study, including the requirements by which the individual sites were selected, the overall sample of sites required to achieve the projects aims, as well as, information on the actual sample of buildings monitored and how it compares to the selection criteria.

4.1 SAMPLE SELECTION CRITERIA

In order for conclusions to be drawn about the performance of the different generic system types and air conditioned buildings as a whole, the selection of sample sites had to consider the practical requirements to monitor each individual system, while also ensuring the overall sample was appropriately representative of the different systems considered in the study and also, as best as possible representative of the building types in the national building stock.

The criteria used to select the sample of buildings to be monitored were as follows and are further detailed in the following sections:

1. The largest possible overall sample of air conditioned buildings in order to be as representative as possible of UK air conditioned offices as a whole and of each generic system type studied.
2. Each sample building had to be located where appropriate meteorological data could be obtained and so that the regional distribution of the overall sample mimics that of the national stock as closely as possible.
3. Access to each site was available for a period of at least one calendar year.
4. The air conditioning system and refrigerant used were of a type that was not due to be phased-out and was expected to still be in operation in 5 to 8 years time.
5. The required monitoring parameters could be measured with the equipment and financial resources available to the project.

4.1.1 Sample Size and Representation of System Types

In an ideal situation, the overall monitoring sample would be large enough to be representative of the national stock of air conditioned buildings as a whole and have enough examples of each generic system type to be able to determine whether or not there were significant differences between the energy performance of the different system types as expected from the theory.

Therefore assuming a normal distribution and the aim of 90% certainty of the sample, i.e. 10% maximum margin of error, the required sample size can be obtained from the following equation[1]:

$$\text{Margin of error} = \frac{1}{\sqrt{n}} x100 .$$

Where: n is the sample size and the margin of error is expressed as a percentage.

Therefore to achieve a 10% margin of error from the sample relative to the national building stock as a whole the sample would ideally have included one hundred representative air conditioning systems.

However, the time and resources required to find and monitor, at the required level of detail, one hundred buildings for a period of at least one calendar year was substantially beyond the equipment, manpower and financial resources available to the study. Therefore the research had to study the largest possible sample within the available resources, albeit a sample much smaller than the ideally required and deal with the associated reduction in certainty of the results.

4.1.2 Monitoring of Required Parameters

The selection of each sample site had to ensure that it was possible to monitor the required energy consumption and local environmental parameters with the available resources. The monitoring parameters for each system type are detailed in Chapter 3, although the exact configuration of monitoring and required resources were unique at each site and as such, sites that required excessive amounts of monitoring equipment or required estimation loads on primary plant were not considered.

4.1.3 Duration of Monitoring

Monitoring at each site had to continue for a period of time long enough to encompass all operating conditions and guard against untypical operation and weather conditions. This was anticipated to be a period of at least one calendar year and therefore the site selection process had to ensure continuous access for at least one calendar year. Therefore only sites that anticipated constant occupancy of their building and use of their air-conditioning system over the proposed monitoring period could be considered. Sites whose management expected significant changes to their occupancy, building, or services were not considered.

Although the monitoring sites were selected to ensure access for monitoring for a period of at least one year, where the project resources and client buildings allowed the monitoring was extended to maximise the data obtained and to ensure overlapping periods of monitoring with the others sites.

4.1.4 Age of the Systems Monitored

Since this research aims to provide information to underpin future guidance, there was no point in studying out-of-date systems or systems operating in buildings of a unique type or operation that were unlikely to be encountered elsewhere. This is particularly relevant to the type of refrigerant utilised, as many refrigerants in operation at the out-set of the project were likely to be phased out of general use for legislative reasons (see Section 2.6).

Therefore the selection of sample sites aimed to study buildings and systems that were expected to still be in operation in the forthcoming 5 to 8 years (2005 to 2008).

4.1.5 Location of Monitoring Sites

All sample buildings were selected to be located where suitable regional meteorological data (as specified in Chapter 3) was available and so that the overall sample distribution mimics the current national distribution of air-conditioned buildings by region as defined by the Non-Domestic Building Energy Fact File[2].

Although it was unlikely that a close correlation of the monitoring sample and national stock regional distribution could be achieved, the sample buildings were selected to ensure basic trends, including the strong dominance of the southeast of England was carried through in the sample set monitored.

The current UK national distribution of air-conditioned buildings is summarised in Table 4.1.1 below.

Table 4.1.1. Distribution of air-conditioned buildings in England & Wales[2]

Region	*Number of premises*	*Percentage of total (%)*
East Anglia	*278*	*1.8*
East Midlands	*212*	*1.4*
Northern	*274*	*1.8*
North West	*833*	*5.4*
South East	*11870*	*77*
South West	*548*	*36*
Wales	*180*	*1.2*
West Midlands	*829*	*5.4*
York's & Humbs.	*396*	*2.6*

4.2 THE MONITORING SAMPLE

The final building sample monitored thirty-two air-conditioning installations throughout the UK including examples of each of system types considered for this study as detailed in Table 4.2.1 and further detailed information is provide for each individual site in Appendix A.

Table 4.2.1. Summary of systems in the final monitoring sample

Site ID Number	***System Type***	***Location***	***Region***
Cooling Only Systems			
1	*All-Air*	*Stafford*	*West Midlands*
2	*All-Air*	*London*	*South East*
3	*All-Air*	*Milton Keynes*	*South East*
4	*All-Air*	*Swindon*	*South West*
5	*All-Air*	*Swindon*	*South West*
6	*All-Air*	*Swindon*	*South West*
7	*All-Air*	*Gatwick*	*South East*
8	*Chilled Ceiling*	*Leicester*	*East Midlands*
9	*Chilled Ceiling*	*London*	*South East*
10	*Chilled Ceiling*	*Leicester*	*East Midlands*
11	*Chilled Ceiling*	*Chester*	*West Midlands*
12	*Fancoil*	*Bristol*	*South West*
13	*Fancoil*	*Bristol*	*South West*
14	*Fancoil*	*Bristol*	*South West*
15	*Fancoil*	*Guildford*	*South East*
16	*Fancoil*	*Walton on Thames*	*South East*
17	*DX Split*	*Nr Oxford*	*South East*
18	*DX Split*	*Cardiff*	*Wales*
19	*DX Split*	*Cardiff*	*Wales*
20	*DX Split*	*Wokingham*	*South East*
21	*DX Split*	*Cardiff*	*Wales*
22	*DX Split*	*Cardiff*	*Wales*
Reverse Cycle Systems			
23	*Chilled Ceiling*	*Slough*	*South East*
24	*VRF HR*	*Leatherhead*	*South East*
25	*DX Split*	*Wellingborough*	*East Midlands*
26	*DX Split*	*Huddersfield*	*Northern*
27	*DX Split*	*Huddersfield*	*Northern*
28	*Fancoil*	*Leatherhead*	*South East*
29	*VRF Heat Recovery*	*Lichfield*	*East Midlands*
30	*VRF Heat Recovery*	*Stafford*	*East Midlands*
31	*VRF Heat Recovery*	*Wellingborough*	*West Midlands*
32	*Unitary Heat Pump*	*Swindon*	*South West*

4.2.1 Monitoring Schedule

Due to the delays finding sites to monitor and logistic issues involved with monitoring thirty-two sites, it was not possible to maintain simultaneous monitoring of all the sites over the same period of time and therefore some of the monitoring had to be staggered. Table 4.2.2 shows the schedule of monitoring for each site, listing the first and last full month of data collected, as well as, the duration of energy consumption data collected.

Table 4.2.2. Schedule of monitoring by sample site

Site ID Number	*System Type*	*First Month Recorded*	*Last Month Recorded*	*Duration (Months)*
Cooling Only Systems				
1	*All-Air*	*September-00*	*October-02*	*26*
2	*All-Air*	*June-01*	*November-02*	*18*
3	*All-Air*	*February-01*	*December-02*	*18*
4	*All-Air*	*February-01*	*December-02*	*19*
5	*All-Air*	*February-01*	*December-02*	*19*
6	*All-Air*	*February-01*	*December-02*	*19*
7	*All-Air*	*April-01*	*December-02*	*16*
8	*Chilled Ceiling*	*March-00*	*August-01*	*18*
9	*Chilled Ceiling*	*May-00*	*September-01*	*17*
10	*Chilled Ceiling*	*March-00*	*September-01*	*19*
11	*Chilled Ceiling*	*March-00*	*July-01*	*17*
12	*Fancoil*	*December-00*	*April-02*	*17*
13	*Fancoil*	*December-00*	*April-02*	*17*
14	*Fancoil*	*March-00*	*April-02*	*26*
15	*Fancoil*	*September-00*	*October-01*	*14*
16	*Fancoil*	*April-01*	*December-02*	*21*
17	*DX Split*	*September-00*	*January-02*	*17*
18	*DX Split*	*August-01*	*August-02*	*13*
19	*DX Split*	*June-00*	*October-02*	*29*
20	*DX Split*	*September-00*	*December-02*	*23*
21	*DX Split*	*December-00*	*October-02*	*23*
22	*DX Split*	*March-01*	*July-02*	*17*
Reverse Cycle Systems				
23	*Chilled Ceiling*	*May-00*	*May-01*	*13*
24	*VRF HR*	*December-00*	*December-02*	*25*
25	*DX Split*	*March-01*	*November-02*	*21*
26	*DX Split*	*May-01*	*May-02*	*13*
27	*DX Split*	*May-01*	*June-02*	*14*
28	*Fancoil*	*December-00*	*December-02*	*25*
29	*VRF HR*	*September-00*	*April-02*	*20*
30	*VRF HR*	*September-00*	*October-02*	*26*
31	*VRF HR*	*March-01*	*December-02*	*22*
32	*Unitary HP*	*March-01*	*December-02*	*17*

4.2.2 Final Building Sample System Category Distribution

The following matrix in Table 4.2.3 shows the distribution of the thirty-two sites in the final monitoring sample for the project by the six system categories. The final sample meets or exceeds the minimum requirements of five examples of each system type in all the categories except DX-VRF and Unitary Heat Pumps. There are only four DX-VRF systems monitored and only one example of a unitary heat pump system.

Table 4.2.3. Numbers of systems by system category and operational mode

System Type	Cooling Only	Reverse Cycle	Total
All-Air (VAV & CV) systems.	7	0	7
Fancoil (2-pipe & 4-pipe)	5	1	6
Chilled Ceilings (Passive & active, beams & panels).	4	1	5
DX Split (Single and multiples)	6	3	9
DX VRF (3-pipe heat recovery)	0	4	4
Unitary Heat Pump	1	0	1
Total	23	9	32

Furthermore, the final sample has nine DX split systems including examples of both multiple and single DX split systems, which will allow comparison of these different configurations of DX split systems to be considered further.

4.2.3 Analysis of the Sampling Margin of Error

Based on the actual sample size achieved (Section 4.2.2) and the general formula for determining the margin of error (Section 4.1.1) the sample of 32 systems monitored during this research are therefore representative of the national stock of office air conditioning systems with an overall error margin of 17.7%.

However, the research also aims to draw conclusions about the relative performance of the difference generic types studied which obviously have much smaller samples size as detailed in Table 4.2.3 above and hence also increased margin of error. Based on the above general formula based on the sample size alone the margin of error associated with drawing conclusions from the system studied of any single generic type are as follows:

- 37.8% All-Air (VAV & CV) systems
- 40.8% Fancoil (2-pipe & 4-pipe)
- 44.7% Chilled Ceilings (Passive & active, beams & panels).
- 33.3% DX Split (Single and multiples)
- 50.0% DX VRF (3-pipe heat recovery)
- 100% Unitary Heat Pump (Single case study example only)

Therefore any conclusions drawn from this research on the performance of each generic system type studied are subject to relatively high levels of uncertainty, ranging up to 50%, due to the small sample sizes. In addition, no conclusions can be drawn regarding the performance of the unitary heat pump systems beyond pointing out the performance of the single system studied. Yet despite the relatively high margin of errors associated with the sample of an individual system type, the results are still part of the larger monitoring sample and may still be statistically significant depending upon the actual data values involved, but each conclusion has to be checked, or tested, to determine whether or not the conclusion is statistically significant using an appropriate statistically test and standard distribution for the sample sizes in question.

Therefore, in order to achieve the primary aims of this research and compare the relative performance of the different generic systems and without being overly circumspect due to the small sample size the key conclusions of the research have been subjected to statistical hypothesis tests in order to determine whether or not the conclusions are statistically significant using a hypothetical or null-test relative to the t-distribution appropriate the sample size. (Note: The normal distribution (Z) was NOT used since it applies only to samples sizes of thirty or more.)

For example, the conclusions of this research (Chapter 8) include that the chilled ceiling based systems were more efficient at providing comfort cooling in UK offices than the other generic system types studied. It was determined that this conclusion is statistically significant using the following formula to compare two separate population averages[3]:

$$\text{Test statistic (t-Score)} = \frac{(\bar{x} - \bar{y})}{\sqrt{\frac{{s_x}^2}{n_x} + \frac{{s_y}^2}{n_y}}}$$

In order to test that the null hypothesis $(H_o): \bar{x} = \bar{y}$ or $\bar{x} - \bar{y} = 0$

Where the average efficiency of chilled chilling systems $(\bar{x})$ and average efficiency of the other generic system types studied $(\bar{y})$ are values from the ILPR comparison (Chapter 6), and where (s_x) and (s_y) are the standard deviation of the respective samples whose size is denoted by (n_x) and (n_y), respectively.

The resulting test statistic (t-score) is 2.51 based on the t_3 distribution (3 degrees of freedom) and the ILPR efficiency data from Table 6.4.1. This value equates to a p-value of between 0.05 and 0.025 (between the 95th and 97.5th percentiles) meaning that based on the size and measured data of the sample tested, the likelihood of the null hypothesis being true is between 2.5% and 5%. Typically p-values of 0.05 (5%) are considered a reasonable cut-off point[3], and hence there is enough evidence to reject the null hypothesis $(H_o): \bar{x} = \bar{y}$ and conclude that a statistically significant difference exists between the cooling efficiency of the chilled ceiling systems and that of the other generic system types studied.

4.2.4 Regional Site Distribution

The final monitoring sample sites were recruited so that their regional distribution around the country mimicked the national distribution of air-conditioned office buildings in the UK as defined in Table 4.1.1 as closely as possible. The regional distribution of the final sample of buildings included in the monitoring programme is shown below in Table 4.2.4.

Table 4.2.4. Regional Distribution of Project Sample

Region	*Number of Premises*	*Percentage of Total (%)*
East Anglia	*0*	*0.0*
East Midlands	*5*	*15.6*
Northern	*2*	*6.3*
North West	*0*	*0.0*
South East	*11*	*34.4*
South West	*7*	*21.9*
Wales	*4*	*12.5*
West Midlands	*3*	*9.4*
York's & Humbs.	*0*	*0.0*

Figure 4.2.1 compares the regional distribution of the final monitoring sample as detailed in Table 4.2.4 to the regional distribution of air-conditioned buildings in the UK, from Table 4.1.1. It was not possible to closely mimic the existing regional distribution, but the overall trends were maintained and in particular the strong dominance of London and the South East of England. In the existing national stock, 77% of air conditioned buildings are located in the south east region, where as 34% of the monitoring sample was located in the south east.

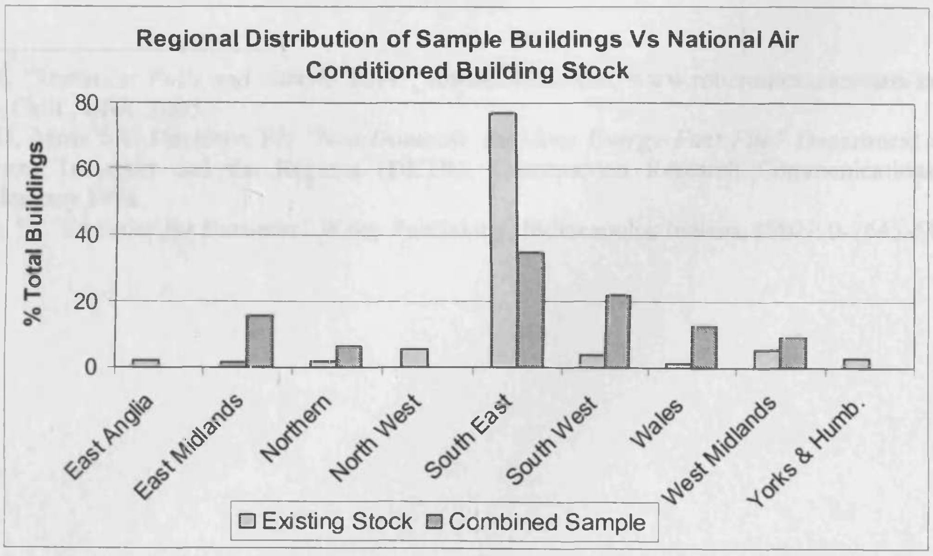

Figure 4.2.1.National and sample regional distribution of AC Buildings.

4.3 SAMPLE IMPLICATIONS TO THE RESEACH RESULTS

From the outset of the research it was realised that the recruitment of enough suitable buildings which were available for monitoring would be one of the most challenging aspects of the research because the field monitoring approach used was by its nature time and resource intensive, as well as, requiring the cooperation of various organisations associated with each building. Hence the undertaking this research involved far more than just finding enough suitable sites, and consequently the time and resources available to the project were stretched and the overall sample actually monitored was smaller than would have ideally been desired with the consequential drop in certainty of the results.

Yet this research is by far the largest and most detailed contemporary study of air conditioning system energy performance undertaken in the UK that the author is aware of at the time of submission. But despite the sample size being less than ideally desired, enough sites were found and monitored that met the selection criteria to enable the overall sample to be representative of the national stock of air conditioned buildings[2] with a 17.7% margin of error[1] and draws statistically significant comparisons[3] of the relative energy efficiency of the different generic AC system types studied.

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Chapter 5: Results of the Energy Monitoring

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5.0 MEASURED BUILDING AND SYSTEM ENERGY PERFORMANCE

This research set out to collect empirical data on the actual performance of air conditioning systems 'in practice' in order to aid the development of improved guidance on the appropriate use of air conditioning systems and help identify strategies to achieve our national carbon emissions reduction targets. As such this research has measured the energy consumption, and hence associated carbon emissions, of a number of air conditioning systems 'in use' within actual UK office buildings.

This chapter discusses the results of the field energy monitoring undertaken between April 2000 and December 2002. The implications of these results are discussed in terms of the associated carbon emissions; energy demand profiles; the part-load profiles and hours of operation of the systems studied compared to one another; benchmarks standards; and the research hypothesis from the theoretical review presented in Chapter 2.

The preliminary findings for this work have already been presented at a number of conferences[1,2,3] and further publicised in trade journals[4,5,6] and a project web-page[7]. In addition, a summary of the final findings of the field monitoring programme is also being peer reviewed and published by the Chartered Institute of Building Services Engineers[8].

Descriptions of the monitoring methods used are provided in Chapter 3 and information on the sample of air conditioned buildings monitored can be found in Chapter 4 and in Appendix A. Where Chapter 4 provides an overview of the whole building sample and Appendix A provides detailed information about each individual site by summarising information from the building characteristics surveys and notes from the field monitoring.

In summary the monitoring at each site included the measurement of air conditioning energy consumption, typically recorded at 15-minute intervals over a period of at least one calendar year, and in most cases more than two years. The monitoring focused on the elements within each

HVAC system used to provide comfort cooling to the occupied space within each building and as such measured the energy consumption of the following sub-systems at each site:

- All refrigeration plant providing cooling (and heating from reverse cycle systems).
- All distribution equipment i.e. fans and pumps etc used to deliver cooling (and heating from reverse cycle systems) to the occupied space.
- All controls equipment associated with the above systems.

5.0.1 Carbon Emissions Calculations

Throughout this analysis the carbon emissions associated with the energy consumption of each building and air conditioning system have had to be estimated from the respective measured energy consumption and standard rates of carbon emission per unit of energy for each respective fuel type. The conversion factors used are summarised in Table 5.0.1 below.

Table 5.0.1: Conversion factors for carbon emissions from UK delivered energy[9].

Fuel Type	***kgC / kWh***
Gas	0.055
Electricity	0.142

5.0.2 National Energy Consumption & Carbon Emissions Benchmarks

The energy consumption and carbon emissions benchmarks used to compare the measured performance obtained during this research have been drawn from the UK Government's energy consumption guide for energy use in offices[9]. The benchmark values used throughout are for a representative office building considered to be 'standard' air conditioned (Type-3) as defined by Energy Consumption Guide 19[9]. This benchmark design assumes a purpose built office building, probably speculatively developed, sized between 2000 to 8000m^2, and using an all-air Variable Air Volume (VAV) system with air-cooled water chillers to service its HVAC requirements.

The benchmarks used for the comparison of carbon emissions are drawn from the same guidance but converted into equivalent carbon emissions based upon the fuel type used for each service within the assumed typical building type again based on the representative 'standard' Type-3 office building[9].

The total delivered annual benchmark energy consumption values for the entire building energy consumption are 225kWh/m^2 for good practice standards, and 404kWh/m^2 for typical practice standard. These values include both electricity and gas energy consumption and equate to 23.5kgC/m^2 and 41.9 kgC/m^2 of treated floor area respectively.

The benchmark energy consumption values used to help assess the monitored air conditioning system performance account for the consumption of the following sub-systems; cooling, fans, pumps, where appropriate space heating, and their associate control systems. Table 5.0.2 summarises the annual energy consumption benchmarks used throughout this work, for the various building services sub-systems.

Table 5.0.2: Annual energy consumption benchmarks by sub-system.

	Good Practice	*Typical Practice*
Space Heating	85 kWh/m^2	158 kWh/m^2
Cooling	14 kWh/m^2	31 kWh/m^2
Fans, pumps & controls	30 kWh/m^2	60 kWh/m^2

The total annual energy consumption benchmark for the 'cooling-only' air-conditioning systems is 44kWh/m^2 for buildings designed and operated to 'good practice' standards, and 91kWh/m^2 for buildings of 'typical practice' standard. Whereas, the benchmark energy consumption for the reverse-cycle, heating AND cooling, systems is 129kWh/m^2 for 'good practice' and 249kWh/m^2 for 'typical practice' standard.

The corresponding benchmark carbon emission values for the cooling-only systems are 6.3kgC/m^2 of treated floor area for 'Good Practice' and 12.9KgC/m^2 for 'Typical Practice' standards. These values account for the following electrically driven sub-systems: cooling, fans, pumps and associated controls.

The benchmark carbon emission values used for the 'heating and cooling' reverse-cycle systems are 10.9kgC/m^2 for 'Good Practice' and 21.6kgC/m^2 for 'Typical Practice'. These values account for the following electrically driven sub-systems; cooling, fans, pumps, controls, and space heating assumed to be provided by centralised gas-fired boilers.

5.1 BUILDING ENERGY CONSUMPTION & CARBON EMISSIONS

This section discusses the whole building energy consumption, and carbon emissions, from the buildings in which the air conditioning systems have been monitored. The whole building energy consumption data has been derived from site energy bills, or monitoring and targeting (M&T) data, collected with the owner's permission at each site as described in Section 3.2.3.

This data was collected with the aim of determining the overall energy consumption of each site relative to national benchmarks and to determine the proportion of energy consumed by the different air conditioning systems. But although the overall energy consumption of each building may not be directly related to the performance of the air conditioning system, it does indicate each buildings energy signature, i.e. whether or not a building is a high or low energy consumer, and how much the air conditioning system is contributing to the overall energy performance of the building.

The overall whole building energy consumption, and calculated carbon emissions, for each of the buildings studied is summarised in Table 5.1.1 below. The Table shows the total annual energy consumption for each building by each fuel type, the total delivered energy consumption, and the associated annual carbon emissions. All these values have been normalised to the treated floor area (TFA) of each building as determined by the buildings characteristics survey described in Section 2.3.1.

Table 5.1.1 Summary of Annual Whole Building Energy Consumption & Carbon Emissions

Site # / System Type	**Electricity**	**Gas**	**Total Delivered Energy**	**Carbon Emissions**
	kWh/m^2	*kWh/m*^{2}	*kWh/m*^{2}	*KgC/m*^{2}
Cooling Only Systems				
Site 1 - All-Air	215.6	13.0	228.6	31.3
Site 2 - All-Air	284.4	51.5	335.9	43.2
Site 3 - All-Air	n/a	n/a	n/a	n/a
Site 4 - All-Air	389.5	232.4	621.8	68.1
Site 5 - All-Air	294.9	226.9	521.8	54.4
Site 6 - All-Air	290.0	235.7	525.7	54.1
Site 7 - All-Air	204.3	130.0	334.3	36.2
Site 8 - Chilled Ceiling	247.3	99.3	346.5	40.6
Site 9 - Chilled Ceiling	n/a	n/a	n/a	n/a
Site 10 - Chilled Ceiling	76.9	141.0	217.9	18.7
Site 11 - Chilled Ceiling	159.9	0.9	160.9	22.8
Site 12 – Fancoils	286.1	67.2	353.4	44.3
Site 13 – Fancoils	232.6	9.8	232.6	33.6
Site 14 – Fancoils	352.7	165.9	518.6	59.2
Site 15 – Fancoils	n/a	n/a	n/a	n/a
Site 16 – Fancoils	n/a	n/a	366.4	32.4
Site 17 - DX Split	n/a	n/a	n/a	n/a
Site 18 - DX Split	137.6	168.2	305.8	28.8
Site 19 - DX Split	438.2	85.0	523.2	66.9
Site 20 - DX Split	110.5	n/a	110.5	15.7
Site 21 - DX Split	112.1	42.8	154.9	18.3
Site 22 - DX Split	153.1	20.8	173.9	22.9
Site 32 - Unitary HP	147.6	166.3	313.9	30.1
Average	***229.6***	***109.2***	***334.0***	***38.0***
Standard Deviation	***102.0***	***81.1***	***149.1***	***16.3***
Reverse-cycle Heating & Cooling Systems				
Site 23 - Chilled Ceiling	407.7	n/a	407.7	57.9
Site 24 – Fancoils	252.6	n/a	252.6	35.9
Site 25 - DX Split	334.8	42.0	376.8	49.9
Site 26 - DX Split	558.5	n/a	558.5	79.3
Site 27 - DX Split	558.5	n/a	558.5	79.3
Site 28 - VRF HR	252.6	n/a	252.6	35.9
Site 29 - VRF HR	166.5	26.4	193.0	25.1
Site 30 - VRF HR	256.5	91.5	348.0	41.5
Site 31 - VRF HR	334.8	42.0	376.8	49.9
Average	***347.0***	***50.5***	***369.4***	***50.5***
Standard Deviation	***137.9***	***28.3***	***128.4***	***18.9***

Unfortunately, whole building energy consumption data was not made available by all the host clients for every building in this study. Reasons for this included; companies going out of business, lost or missing utility bills, and in at least one case a lack of cooperation from the staff involved. In total the overall building energy consumption data was obtained for twenty-seven of the thirty-two sites studied. Sites where this data was not collected are 3, 9, 15, 16, and 17.

The total annual delivered energy consumption of the buildings studied ranged from 110.5kWh/m^2 to 621.8kWh/m^2, which translates into associated carbon emissions of between 15.7kgC/m^2 and 79.3kgC/m^2. These measured values compare well to the range of energy consumption we expected, which was between 225kWh/m^2 and 568kWh/m^2 based on the benchmark standards as discussed in Section 2.3.2. Only Site 4 consumed more energy than expected and a number of sites consumed significantly less than expected indicating better than good practice energy performance.

It is interesting to note that on average the energy consumption of the buildings using reverse-cycle air conditioning systems was 10% higher than those using separate heating and cooling systems. The buildings with reverse cycle systems consumed 369kWh/m^2 and the buildings with separate systems consumed 334kwh/m^2 on average. Theoretically the reverse cycle air conditioning systems should provide heating more efficiently than gas-fired heating systems in terms of delivered energy[10], so it is slightly surprising that the buildings that used reverse cycle systems consumed more energy than those that used separate heating and cooling systems. However there are too many variables involved in the whole building data to draw conclusions on the performance of the reverse cycle systems compared to other types of heating system at this point.

In terms of annual carbon emissions the slightly higher energy consumption of the buildings using reverse-cycle systems is exacerbated by the higher emissions of their electrically driven energy, emitting more carbon emissions per unit of energy consumed, leading to 33% more carbon emissions on average than the buildings using separate gas-fired heating systems.

5.1.1 Comparison to Building Energy Consumption Benchmarks

The total annual delivered whole building energy consumption of the twenty-seven buildings for which data was available is shown in Figure 5.1.1 relative to the national energy consumption benchmarks for whole building energy consumption, as defined in Section 5.0.2, by fuel type.

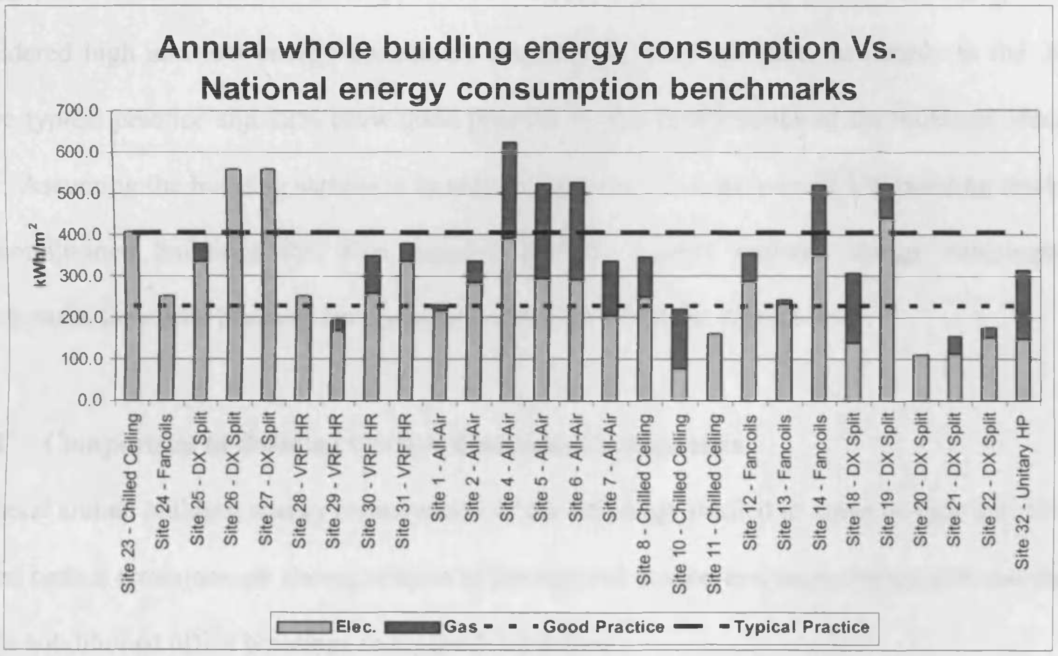


Figure 5.1.1: Comparison of annual whole building energy consumption to national energy consumption benchmarks for air conditioned office buildings.

When compared to the benchmarks it is evident that the buildings studied represent a broad cross section of the UK stock of office buildings in terms of their energy consumption, thus achieving one of the main aims of the building sample selection process (Section 4.1). The recorded building energy consumption ranged from only 49% of good practice (Site 20), indicating very low energy consumption by national standards, up to 154% of typical practice (Site 4), indicating high energy consumption by national standards.

The comparison to the benchmarks shows that eight of the twenty-seven sites (30%) were high energy consumers, with consumptions higher than typical practice, and six of the sites (22%) were low energy consumers with energy consumptions lower than good practice. The remaining thirteen sites (48%) of the buildings studied had energy consumptions between good and typical practice standards indicating 'normal' or 'typical' energy performance.

Since the benchmark standards assume upper and lower quartiles for typical and good practice energy performance, i.e. the consumption of the upper and lower 25% of the building stock are considered high and low energy consumers respectively, they compare favourably to the 30% above typical practice and 22% blow good practice energy performance of the buildings studied here. Assuming the building sample is broadly representative of the overall UK building stock of air conditioned buildings this also suggests that the current national energy consumption benchmarks for whole building energy consumption are set at the correct level.

5.1.2 Comparison to Building Carbon Emissions Benchmarks

The total annual building energy consumption of the buildings studied in terms of their associated annual carbon emissions are shown relative to the national carbon emissions benchmark standards for air conditioned office buildings in Figure 5.1.2 below.

Not surprisingly, the associated whole building carbon emissions data demonstrate similar relationships to one another, and the national benchmarks, as the energy consumption data discussed in the previous section. The exceptions are sites 20, 23, 24, 26, 27 and 28, which only used electricity and due to the higher emissions per unit of energy of electricity compared to natural gas meant that in terms of carbon emissions these building appear to perform less well compared to the other buildings and the national benchmarks.

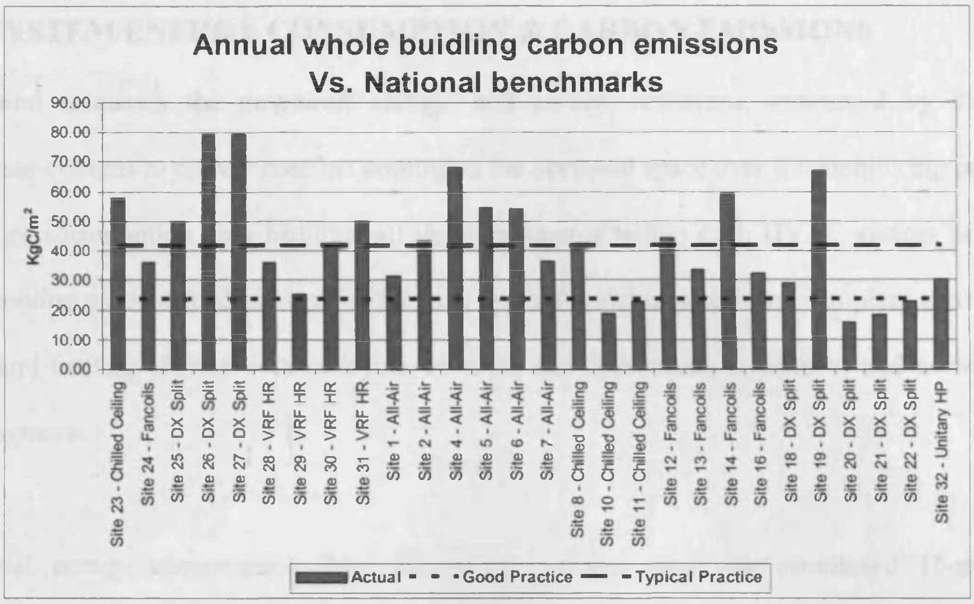


Figure 5.1.2: Comparison of annual whole building carbon emissions to national benchmarks for air conditioned office buildings.

5.1.3 Conclusions from the Building Energy Performance Results

The energy consumption of the entire buildings studied showed that the total annual delivered energy consumption of the air conditioned office buildings studied ranged from 110.5kWh/m^2 to 621.8kWh/m^2, which translates into carbon emissions between 15.7kgC/m^2 and 79.3kgC/m^2 of treated floor area.

These values are similar to the range of energy consumption expected from the current UK energy consumption benchmarks for air conditioned office buildings. This agreement between the monitored and benchmark energy consumption values suggests that the sample of buildings studied by the research is broadly representative of the UK stock of air conditioned office buildings, but also that the current national energy consumption benchmarks are probably correct since they were representative of the thirty-two buildings monitored in this study.

5.2 SYSTEM ENERGY CONSUMPTION & CARBON EMISSIONS

This section discusses the measured energy, and carbon emissions, consumed by the air conditioning systems to deliver comfort cooling to the occupied space over the monitoring period. This energy consumption data includes all the components within each HVAC system used to provide cooling as described in Section 3.2, and typically includes refrigeration plant providing cooling, and heating if from reverse cycle systems, the distribution equipment and associated controls systems.

The annual energy consumption data shown are derived from the monitored 15-minute measurements summed over a calendar year. In cases where more than one year of data was recorded the value shown is the average annual energy consumption over the entire period of monitoring. Details of the actual period of monitoring at each site are provided in Section 4.2.1.

The measured energy consumption data of the systems using reverse–cycle refrigerant plant also include the energy used to provide space heating as well as cooling, since it is difficult to determine the proportion of energy used for heating or cooling separately. Therefore, the annual data from the reverse-cycle heating and cooling systems has been separately compared to their appropriate benchmarks, but not directly to the cooling only system energy consumption.

The measured annual air conditioning energy consumption, and carbon emissions, for each of the systems studied has been summarised in Table 5.2.1 normalised by the treated floor area of the building as determined from the building characteristics surveys (Section 2.3.1).

Table 5.2.1: Measured annual AC system energy consumption and carbon emissions

Site # / System Type	**Annual Energy Consumption** *(kWh/m^2)*	**Annual carbon Emissions** *(KgC/m^2)*
Cooling Only Systems		
Site 1 - All-Air	36.0	5.1
Site 2 - All-Air	37.8	5.4
Site 3 - All-Air	41.7	5.9
Site 4 - All-Air	164.4	23.3
Site 5 - All-Air	90.3	12.8
Site 6 - All-Air	104.2	14.8
Site 7 - All-Air	99.0	14.1
Site 8 - Chilled Ceiling	22.8	3.2
Site 9 - Chilled Ceiling	17.1	2.4
Site 10 - Chilled Ceiling	6.8	1.0
Site 11 - Chilled Ceiling	23.3	3.3
Site 12 - Fancoils	102.2	14.5
Site 13 - Fancoils	55.3	7.8
Site 14 - Fancoils	38.1	5.4
Site 15 - Fancoils	108.1	15.4
Site 16 - Fancoils	151.6	21.5
Site 17 - DX Split	57.2	8.1
Site 18 - DX Split	23.0	3.3
Site 19 - DX Split	35.9	5.1
Site 20 - DX Split	47.8	6.8
Site 21 - DX Split	44.5	6.3
Site 22 - DX Split	69.4	9.8
Site 32 - Unitary HP	98.2	13.9
Average	***64.1***	***9.1***
Standard Deviation	***43.0***	***6.1***
Heating & Cooling Systems		
Site 23 - Chilled Ceiling	70.5	10.0
Site 24 - Fancoils	104.6	14.9
Site 25 - DX Split	160.4	22.8
Site 26 - DX Split	128.3	18.2
Site 27 - DX Split	230.3	32.7
Site 28 - VRF HR	159.1	22.6
Site 29 - VRF HR	131.1	18.6
Site 30 - VRF HR	102.7	14.6
Site 31 - VRF HR	92.6	13.1
Average	***131.1***	***18.6***
Standard Deviation	***47.6***	***6.8***

The total annual energy consumption of the thirty-two air conditioning systems ranged from 6.8kWh/m^2 to 164.4kWh/m^2, which translates into carbon emissions of between 1.0kgC/m^2 and 23.9kgC/m^2 for the cooling only air conditioning systems. The energy consumption of the reverse-cycle heating and cooling systems ranged from 70.5kWh/m^2 to 230.3kWh/m^2 which equates to carbon emissions of between 10.0kgC/m^2 and 32.7kgC/m^2.

When compared to the expected energy consumptions of between 44kWh/m^2 and 91kWh/m^2 for the cooling only systems and between 129kWh/m^2 and 249kWh/m^2 for the reverse-cycle heating and cooling systems (Section 2.3.2), it showed that the overall range of measured energy consumption was wider than we would have expected from the benchmark standards. In particular, the cooling only systems had a measured range of performance significantly wider than expected.

On average the cooling only systems consumed 64.1kWh/m^2 annually while the reverse-cycle systems consumed just over twice as much with an average consumption of 131.1kWh/m^2 annually. But significantly the range of measured annual energy consumption appears to vary depending on the generic type of air conditioning system used. This is illustrated in Table 5.2.2, which shows the range of annual energy consumption by generic system type and mode of operation.

Table 5.2.2: Range of annual energy consumption by generic system type and mode of operation in kWh/m^2 TFA.

System Type	*All-air Systems*	*Fancoil Systems*	*Chilled Ceilings*	*Split DX Systems*	*DX VRF/VRV*	*Unitary Heat-pumps*
Cooling Only	36 – 164	38 - 152	7 – 23	23 - 69	n/a	98*
Reverse Cycle	n/a	105*	71*	128 - 230	93 - 160	n/a

* Only site of this system type

There were not enough sites to compare all systems for each operational mode, i.e. unitary heat-pumps, reverse-cycle fancoil and reverse-cycle chilled ceilings were only represented by one example system each, and no examples of reverse cycle all-air systems were represented.

However, the data does suggest that as a generic group the chilled ceiling systems, and to a lesser extent split direct expansion (DX) systems, consume less energy than other generic types of air conditioning system to deliver comfort cooling services in UK office buildings.

In addition to the reverse-cycle systems studied the one example of reverse-cycle chilled ceiling systems was also the lowest energy consumer of all reverse-cycle systems studied. However, due to the low sample representation of different types of reverse-cycle system it is not possible to draw any firm conclusions about the relative performance of the different generic types in reverse-cycle operation at this point.

Although the performance of the split DX systems were relatively good in cooling-only form, their reverse-cycle energy consumption was relatively high and included the highest recorded annual energy consumption of any system in the study (Site 27 consumed 230.3kWh/m^2 annually).

A speculative explanation of the relatively high reverse-cycle DX split systems energy consumption could lie in the application of separate split systems with independent control within the same space, which was common within the buildings studied. We know that such applications, can easily lead to conflicts between the individual units, although this is difficult to prove without actually witnessing the event occurring.

The following sections expand on this discussion of the annual system energy consumption by comparing the measured data to national benchmarks for energy consumption and carbon emissions, consider the proportion of the energy consumption used for air conditioning and discuss further implications of the relative energy and carbon performance of the systems studied.

5.2.1 Comparison to System Energy Consumption Benchmarks

This section compares the measured annual energy consumption of each air conditioning system to the national energy consumption benchmarks defined in Section 5.0.2. This comparison for the cooling-only and reverse-cycle systems is shown in Figures 5.2.1 and 5.2.2 respectively.

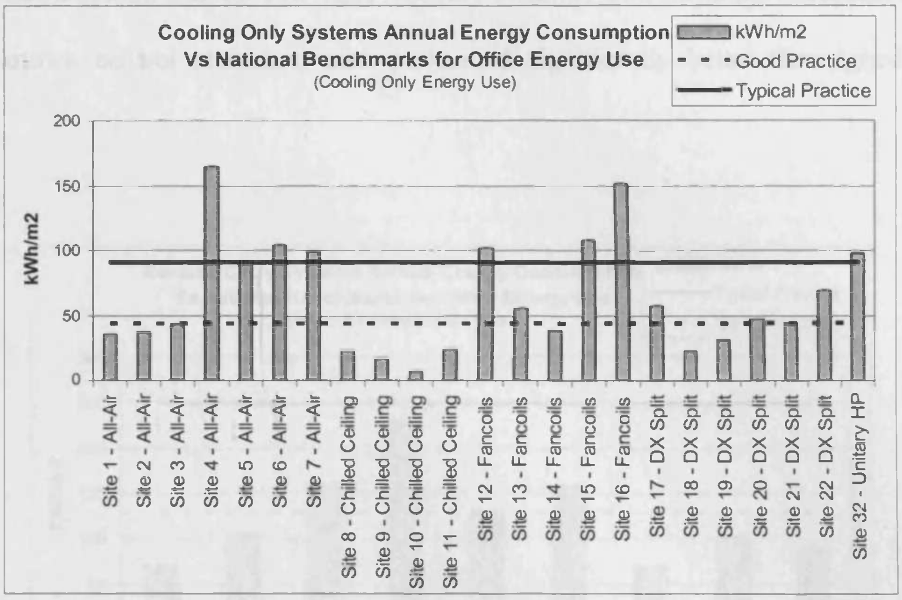


Figure 5.2.1: Comparison of cooling-only systems annual energy consumption to national benchmarks

Figure 5.2.1 shows that the majority of the ‘cooling-only’ systems studied (17 out of the 23 sites), met or exceeded current ‘typical practice’ standards for annual energy consumption. More than half (12 of the 23 sites) met or exceeded current ‘good practice’ practice standards. The annual energy consumption data shown also illustrates the chilled ceiling systems significantly lower energy use than other generic types as previously discussed.

The data also shows that individual ‘non-chilled ceiling’ sites were also capable of achieving very good energy performance, since at least one example system from each generic system type achieved an annual energy consumption that met or exceeded current good practice standards. The one exception is the unitary heat-pump system, but since there is only one example of this system type it is difficult to judge how these systems will perform overall. But it is interesting to note that the annual energy consumption of the one system studied was above typical practice levels indicating that it was a relative high energy consumer.

The reverse-cycle systems all performed better than current ‘typical practice’ standards, as shown in Figure 5.2.3, and the majority (7 out of 9 sites) exceeded current ‘good practice’ standards. Once again the chilled ceiling system had the lowest energy consumption, but in addition the example fancoil system and the VRF heat-recovery systems; with the noted exception of one site that had known control problems, also performed significantly better than 'good practice' standards.

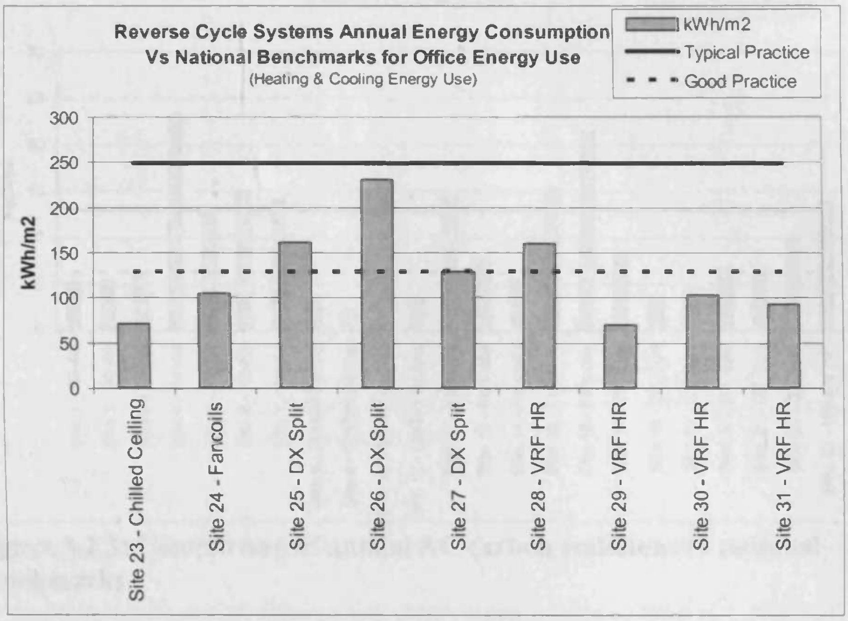


Figure 5.2.2: Comparison of reverse-cycle systems annual energy consumption to national benchmarks

This reinforces the conclusion that chilled ceiling based systems, as a generic group; appear to be the most energy efficient performers in both heating and cooling applications. Furthermore it also suggests that the use of reverse cycle air conditioning systems to meet the heating as well as cooling loads appears to be more efficient in terms of delivered energy compared to gas-fired heating systems with separate cooling systems, since all of the reverse-cycle systems monitored performed better than the typical practice benchmarks which are based on buildings with gas-fired heating systems.

5.2.2 Comparison to System Carbon Emissions Benchmarks

This section considers the previous sections findings but in terms of carbon emissions and compares the annual carbon emissions of the studied systems to their respective benchmark for annual carbon emissions. The measured annual carbon emissions for the monitored 'Cooling-only' sites compared to their respective carbon benchmarks are shown in Figure 5.2.3.

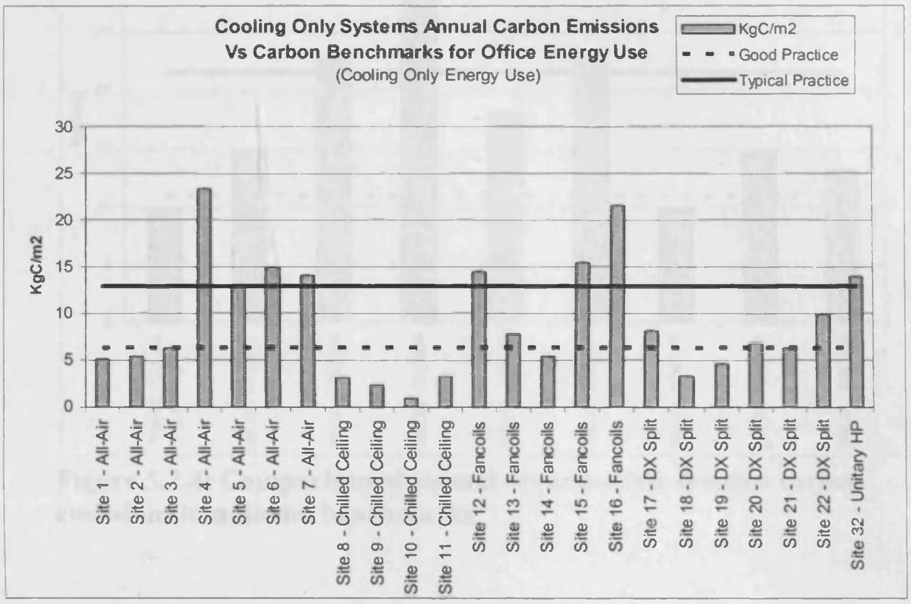


Figure 5.2.3: Comparison of annual AC carbon emissions to national benchmarks

The annual carbon emissions ranged from 0.97kgC/m^2 to 27.3kgC/m^2 and the Chilled Ceiling systems again performed significantly better than the other systems types. Not surprisingly, the relative performance of the 'cooling-only' systems in terms of carbon emissions shows the same relationship as in the comparison of energy consumption since all the sub-systems in this comparison are electrically driven and therefore also account for the same proportion of carbon emissions as energy consumption.

The measured annual carbon emissions for the reverse-cycle systems compared to their respective carbon benchmarks for 'good' and 'typical' practice are shown in Figure 5.2.4.

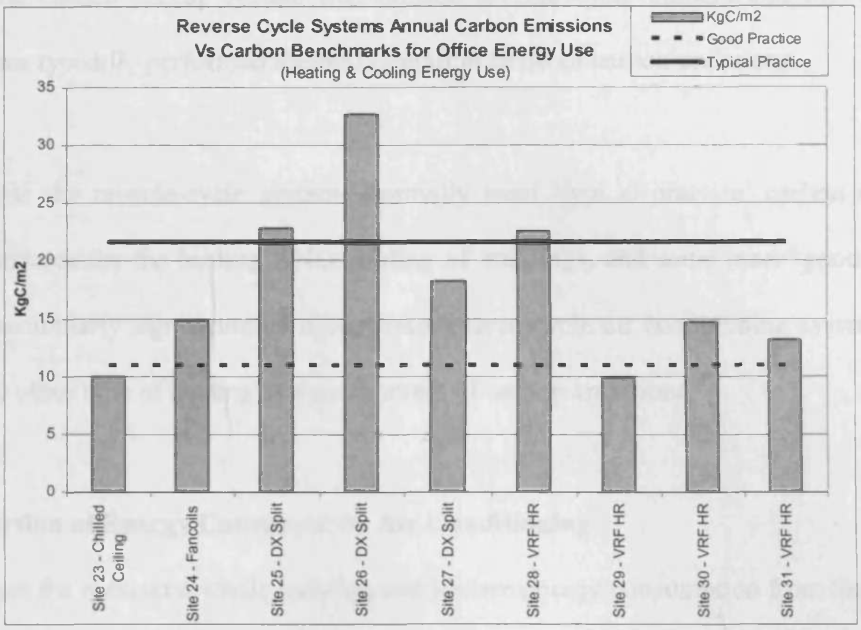


Figure 5.2.4: Comparison of annual reverse-cycle systems carbon emissions to national benchmarks

This comparison of the annual carbon emissions of the reverse cycle systems to the national benchmarks is significant, since we expect the reverse-cycle systems to provide heating very efficiently per unit of energy, which was born out on the energy consumption data, but are driven by electricity which has higher carbon emissions per unit of energy than natural gas, which means that the relatively good heating energy performance of the reverse-cycle systems may not result in reduced carbon emissions once the current fuel mix and emissions rates are accounted.

This in fact meant that a number of systems that in terms of their energy consumption had better than typical or good practice performance as shown in Figure 5.2.2, performed less well in terms of their carbon emissions as shown in Figure 5.2.4. Out of the six systems that exceeded good practice for energy use only two of these systems exceed good practice from a carbon emissions view point.

With the exception of site number 26, the carbon emissions from the reverse-cycle systems typically ranged from just over 'typical practice' to slightly better than 'good practice' standards. In general the direct expansion (DX) split systems performed less well than the other system types, while the chilled ceiling system that utilised reverse cycle chillers and the VRF heat recovery systems typically performed the best overall in terms of carbon emissions.

But the fact that the reverse-cycle systems normally meet ‘typical practice’ carbon emissions benchmark standards for the heating AND cooling of buildings, and some meet ‘good practice’ standards, is particularly significant as it suggests reverse-cycle air conditioning systems are as efficient as any other type of heating system in terms of carbon emissions.

5.2.3 Proportion of Energy Consumed by Air Conditioning

This section uses the measured whole building and system energy consumption from the previous sections to assess the proportion of energy consumed by the air conditioning system in each building studied. The proportion of building energy consumption, and carbon emissions, of the buildings studied used by each air conditioning system is shown in Table 5.2.3 expressed as a percentage of the whole building consumption and emissions.

Overall the proportion of energy consumed by the cooling only systems ranged from 3% to 43% of the whole building energy consumption and 21% on average. The proportion of energy used by reverse cycle air conditioning systems was 39% on average and ranged from 17% to 67 % of the whole buildings energy consumption.

This compares favourably to the expected proportion of energy consumption (Section 2.3.2) which ranged 16% to 23% for the cooling-only and 44% to 62% for the reverse-cycle systems. The only systems that proportionally used less than 16% of the whole building energy consumption for cooling were ones that had better than good practice energy consumption.

Table 5.2.3: The proportion of building energy consumption and carbon emissions resulting from the air conditioning system.

Site # / System Type	Proportion of energy consumption	Proportion of Carbon Emissions
	% kWh	*% KgC*
Cooling Only Systems		
Site 1 - All-Air	16%	16%
Site 2 - All-Air	11%	12%
Site 3 - All-Air	n/a	n/a
Site 4 - All-Air	26%	34%
Site 5 - All-Air	17%	24%
Site 6 - All-Air	20%	27%
Site 7 - All-Air	30%	39%
Site 8 - Chilled Ceiling	7%	8%
Site 9 - Chilled Ceiling	n/a	n/a
Site 10 - Chilled Ceiling	3%	5%
Site 11 - Chilled Ceiling	14%	15%
Site 12 - Fancoils	29%	33%
Site 13 - Fancoils	24%	23%
Site 14 - Fancoils	7%	9%
Site 15 - Fancoils	n/a	n/a
Site 16 - Fancoils	41%	67%
Site 17 - DX Split	n/a	n/a
Site 18 - DX Split	8%	11%
Site 19 - DX Split	7%	8%
Site 20 - DX Split	43%	43%
Site 21 - DX Split	29%	35%
Site 22 - DX Split	40%	43%
Site 32 - Unitary HP	31%	46%
Average	***21%***	***26%***
Standard Deviation	***13%***	***17%***
Heating & Cooling Systems		
Site 23 - Chilled Ceiling	17%	17%
Site 24 - Fancoils	41%	41%
Site 25 - DX Split	43%	46%
Site 26 - DX Split	23%	23%
Site 27 - DX Split	41%	41%
Site 28 - VRF HR	63%	63%
Site 29 - VRF HR	68%	74%
Site 30 - VRF HR	30%	35%
Site 31 - VRF HR	25%	26%
Average	***39%***	***41%***
Standard Deviation	***18%***	***19%***

The proportion of carbon emissions attributed to the air conditioning systems are slightly higher than the proportion of energy consumption, because they are electrically driven with higher emission per unit of energy than other types of fuel. On average these accounted for 26% and 41% of the emission of the buildings with cooling only and reverse-cycle air conditioning respectively.

Current energy consumption standards lead us to believe that air conditioned office buildings typically use at least 50% more energy than similar non-air conditioned buildings[9] as discussed in Section 2.3.2 but, based on these results, the provision of cooling by air conditioning systems on average only accounted for 21% of total building energy consumption. Therefore air conditioning systems on their own do NOT account for all the extra energy typically consumed by air-conditioned buildings compared to non-air conditioned buildings.

The measured data also indicates that the low energy consuming air conditioning systems lead to a reduced proportion of building energy used for cooling, but not necessarily also to reduced whole building energy consumption. For example, Site 19's air conditioning system had a better than good practice energy consumption, and accounted for less than 7% of the total building energy consumption, but the whole building was a high energy consumer with annual energy consumption 30% above typical practice.

This indicates that the underlying reasons for 'air conditioned' buildings consuming more energy, and hence producing more carbon emissions than 'non-air conditioned' buildings, is NOT necessarily, or inherently, due to the use of air conditioning to provide cooling. The relatively high energy consumption of 'air conditioned' buildings compared to 'non air conditioned' buildings appears to be as much to do with other energy-use and not just air conditioning.

This issue is illustrated in the buildings monitored in this study by that fact that 46% of the air conditioning systems performed at good practice level or better, but only 22% of the buildings also performed at good practice levels. Air conditioning as a major energy user in buildings is clearly important to achieving good overall energy and carbon performance, but as the last point emphasises air conditioning systems cannot be considered in isolation from the building and its other energy uses.

5.2.4 Comparison of Measured and Predicted Energy Consumption.

This section compares the measured annual cooling energy consumption of the air conditioning systems studied to the theoretical 'modelling' results discussed in Section 2.3.2.3. The modelling results are from a recent UK study conducted on behalf of the Carbon Trust's Market transformation Programme[11] using the TAS dynamic thermal building and services modelling tool[11] to compare the performance of different air conditioning systems in the same benchmark "Standard Type 3"[9] office building used as the benchmark throughout this study.

The modelling predicted that the annual cooling energy consumption of the generic system types studied during this monitoring work ranged from 13kwh/m^2 for the passive chilled ceiling system to 74.5kwh/m^2 for the Constant Volume (CV) all-air system.

However the modelling results also suggested that design and operational issues such as the over-sizing of chillers, extended hours of operation and poor maintenance could raise the annual energy consumption of air conditioning systems by 113% above predicted good practice levels. This would mean that the predicted range of annual cooling energy consumptions could be as high as 28kwh/m^2 for passive chilled ceiling system, and up to 159kwh/m^2 for the Constant Volume (CV) all-air system.

Table 5.2.4 shows a comparison of the predicted cooling energy consumption of the benchmark building and measured annual cooling energy consumption from this monitoring study by system type. The indicated range of predicted energy consumptions are given by the values obtained for modelled 'good practice' (lower) and the predicted performance accounting for the maximum combination of 'operational issues'(upper) which included over-sizing, extended use and poor maintenance.

Table 5.2.4: Comparison of the predicted and measured range of annual cooling energy consumption by system type.

System Type	**Predicted** (Benchmark Building)	**Measured** (32 Real Buildings)
	kWh/m²	*kWh/m²*
All-Air	37 – 151	36 – 164
Fancoil	40 – 85	38 – 152
Chilled Ceilings	13 – 57	7 - 23
DX Splits	23 – 49	23 – 69
DX VRF / VRV	29 – 62	n/a
Unitary HP	35 – 74	98*

**Only one example system available*

Meaningful comparisons could only be made for four system types including the All-air, Fancoil, Chilled Ceilings and DX splits systems, since no comparison could be made for VRF/VRV due to the need to separate the energy used for heating and cooling which could not be done from the monitored VRF/VRV data and the Unitary heat-pump system type only had one unitary heat-pump in the sample.

But the comparison of the four system types shows a relatively close correlation between the predicted and measured cooling energy consumption. This is particularly notable since the TAS models were of the benchmark building and not of the actual monitored building designs and the weather data was assumed standard CIBSE design data[12] which did not necessarily represent the conditionings actually encountered over the monitoring period.

In particular, the predicted 'Good Practice' (lower) values were remarkably close to the lowest measured energy consumptions for three of the four systems types where comparison could be made with predictions of 23-40kWh/m^2 compared to 23-38kWh/m^2 in practice.

Once again the chilled ceiling systems' previously noted exceptional performance in practice resulted in a lower range of annual cooling energy consumption at 7 – 23kWh/m^2 compared to the predicted 13 – 57kWh/m^2.

The upper predicted 'operational' energy consumption, again with the exception of the chilled ceiling systems, were generally lower than the maximum measured energy consumptions in the sample of actual office buildings. This might be a factor of the 'design nature' of the model discussed in Section 2.2, but since the other data correlates quite well, it might also indicate that the modelling study was overly conservative in its assumptions as to the extent of plant over-sizing, extended hours of operation and poor maintenance found in practice. If this is the case, the actual impact of the design and operational issues on the energy and carbon performance of these air conditioning systems could be substantially higher than the 113% that the modelling study concluded.

This comparison also reinforces the conclusion that the chilled ceiling systems are in theory, and in practice, more energy efficient than the other generic system types studied, since they had the lowest predicted and measured energy consumption of any generic system type. Furthermore the chilled ceiling systems actually performed better in practice than their predicted performance, i.e. the range of measured cooling energy consumption is lower than the predicted range of energy consumption.

5.2.5 Comparison of Reverse-cycle and Gas-fired Heating Systems

Using the measured energy consumption of the reverse-cycle systems and the benchmark standards for heating energy consumption we can assess how the reverse-cycle systems fare in terms of energy use and carbon emissions compared to gas fired heating systems. It is known that heat pumps are the most efficient method of heating a building in terms of kWh of heating provided per unit of fuel[13]. Since reverse-cycle air conditioning systems operate in the same manner as a heat pump when in heating mode, albeit at reduced overall efficiencies, from an efficiency point of view the reverse-cycle systems should compare favourably to traditional gas-fired heating methods. A comparison of the annual energy consumption of the monitored reverse-cycle systems and benchmark values for traditional 'wet' heating systems in office buildings is shown in Figure 5.2.5.

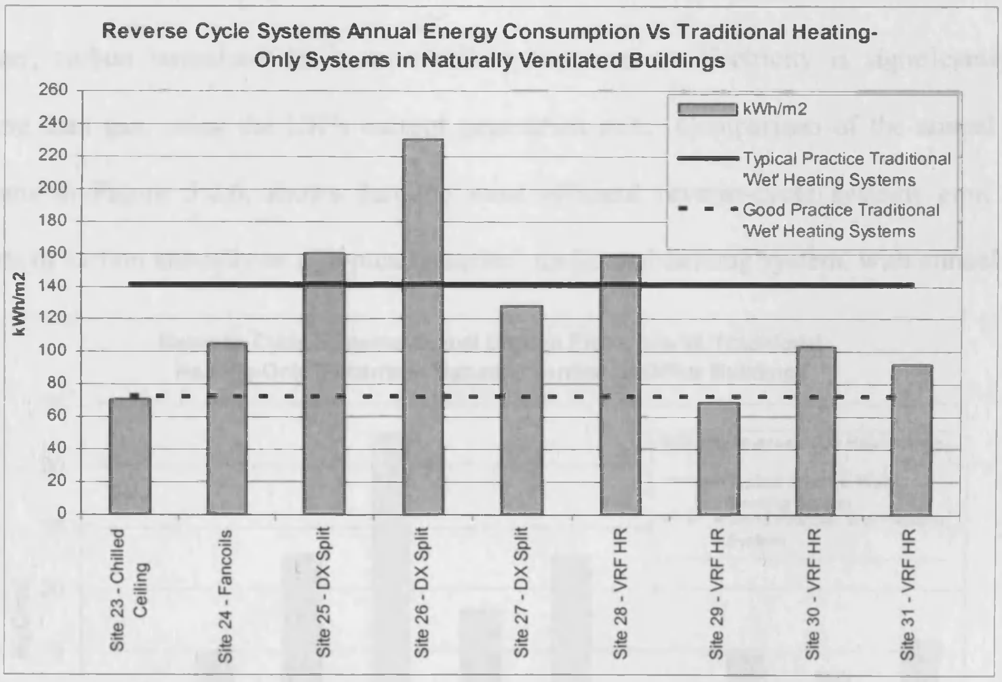


Figure 5.2.5: Annual energy consumption of reverse-cycle AC systems and traditional 'wet' gas-fired central heating systems.

The benchmark values used are 72kWh/m^2 for 'Good Practice' and 141kWh/m^2 for 'Typical 'Practice' standards[9]. These are based on the energy consumption of a representative heated only, open-plan, naturally ventilated office building (Type 2, ECON 19). Included is the energy consumption for space heating, fuelled by natural gas, and electrical systems including pumps, controls and any nominal cooling.

This comparison shows that the electrically driven reverse-cycle systems perform similarly in terms of annual delivered energy consumption to the gas-fired boiler heating systems in naturally ventilated buildings, but reverse-cycle systems also provide cooling, in addition to heating, over the year. Out of the nine reverse-cycle systems monitored, two consumed less energy than current 'good practice' standards and only three exceeded 'typical practice' standards for the traditional heating-only systems in naturally ventilated buildings. It therefore seems that reverse-cycle systems are capable of matching the energy consumption performance of traditional heating-only systems.

However, carbon emissions are a more telling measure, as electricity is significantly more polluting than gas, using the UK's current generation mix. Comparison of the annual carbon emissions in Figure 5.2.6, shows that the most efficient reverse-cycle systems emit similar amounts of carbon annually as a 'typical practice' traditional heating system, with annual carbon

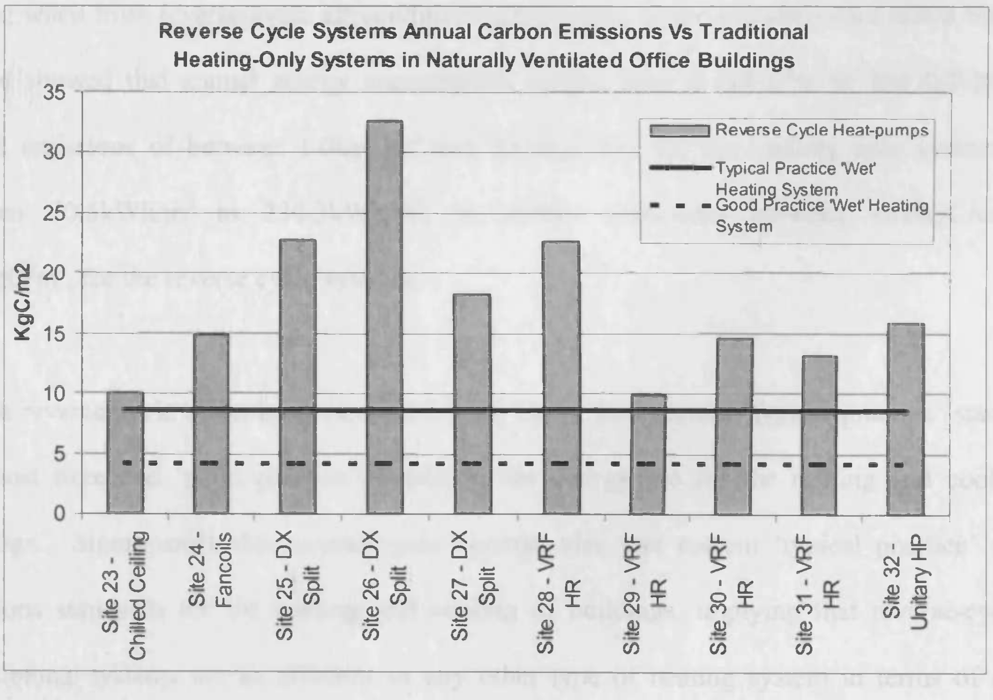


Figure 4.2.6: Annual carbon emissions of reverse-cycle AC systems and traditional gas-fired 'wet' heating systems.

emissions of the best reverse-cycle heat-pump systems being around 10kgC/m^2 and a 'typical practice' heating-only system in a naturally ventilated office building emitting 9kgC/m^2. However, carbon emissions from a 'good practice' traditional heat-only system would be down as low as 4.3kgC/m^2, a level of emissions that none of the monitored reverse-cycle systems appear capable of matching if we include the cooling element as well. We are unable to state whether electrically driven heat pumps designed for heating only would fare any better, but would expect a significant improvement over the systems we have tested.

So to conclude reverse-cycle air conditioning systems and traditional gas-fired heating systems perform similarly in terms of delivered energy consumption when considering heating-only, but because they are electrically driven reverse cycle air conditioning systems currently emit around 50% more carbon per annum than gas-fired heating systems on average. However they also provide cooling within this figure.

5.2.6 Conclusions from the Measured System Energy Consumption Results

Monitoring of the energy used by the air conditioning systems to deliver comfort cooling, (and heating when from reverse-cycle air conditioning systems), within the thirty-two office buildings studied showed that annual energy consumption ranged from 6.8kWh/m^2 to 164.4kWh/m^2, or carbon emissions of between 1.0kgC/m^2 and 23.9kgC/m^2, for the cooling only systems, and between 70.5kWh/m^2 to 230.3kWh/m^2, or carbon emissions between 10.0kgC/m^2 and 32.7kgC/m^2, for the reverse cycle systems.

All the reverse-cycle systems studied performed better than current 'typical practice' standards, and most exceeded 'good practice' standards, for energy use for the heating and cooling of buildings. Significantly the reverse-cycle systems also met current 'typical practice' carbon emissions standards for the heating and cooling of buildings, implying that reverse-cycle air conditioning systems are as efficient as any other type of heating system in terms of carbon emissions and more efficient in terms of delivered energy.

Significantly the annual system energy consumption appeared to vary depending upon the generic type of air conditioning system used. In the buildings studied the Chilled Ceiling, and to a lesser extent the cooling-only DX split, systems typically consumed significantly less energy than the other generic air conditioning system types for the cooling of office accommodation.

5.3 MONITORED ENERGY DEMAND PROFILES

This section discusses the measured energy consumption of the various air condition systems monitored studied but focusing on the energy demand profile of the systems over various time periods during the overall period of monitoring. The previous section discussed the monitored energy consumption of the air conditioning systems over an entire calendar year, where as this section uses the same data to look at the energy demand of each system, in terms of Watts per square meter of treat floor space (W/m^2 TFA), for each interval of recorded data. Recording intervals were typically 15-minute and the energy demand discussed in this section here represents the average 'instantaneous' energy demand for each recording interval.

The energy demand profiles are shown over an entire year for both the cooling only and reverse cycle systems separately, as well as, the cooling energy demand profiles of ALL the systems during peak summer cooling periods. This analysis aims to determine whether or not the systems studied are responding appropriately to variations in daily and seasonal weather conditions and the occupancy schedule of the building. But furthermore, the relative energy demand of all the systems (including both reverse-cycle AND cooling-only) to meet peak summer weekday cooling loads within each building has also been compared, since under these conditions we can be pretty sure the reverse-cycle systems are only providing cooling and no heating services. This assumption has been verified by another field monitoring study of four UK office buildings[14]. Therefore comparison of this demand can indicate the relative efficiency of all the systems to provide cooling including both the reverse-cycle and cooling only systems.

5.3.1 Annual System Energy Demand Profiles

This section looks at the energy demand profiles of the systems studied cooling services, and heating when from reverse cycle systems, over the course of an entire calendar year. The energy demand profiles are drawn from the same monitored data used in the previous section, but expressed in terms of Watts per square meter of treated floor area (W/m^2 TFA) for each recoding interval over the year. At sites where more than one calendar year of data was collected the values used are averages of the data for each corresponding time interval for each year of data collect.

Figures 5.3.1 to 5.3.6 show the average energy demand of each generic system type of air conditioning system studied over an entire year, with the energy demand of the systems providing only cooling graphed separately to reverse-cycle systems providing both heating and cooling. These graphs show data collected from 2000 to 2002 as detailed in Section 4.2. Note there is only one example unitary heat pump system in the sample.

The maximum cooling energy demand and variation by generic system type are summarised in Table 5.3.1 and shows that the peak energy demand of the systems on average ranged from $11W/m^2$, for the chilled ceiling systems, and up to $46W/m^2$ for the all-air systems in the cooling only systems, as indicated in blue on the graphs. The reverse-cycle systems, indicated in red on the graphs, ranged between $46W/m^2$ for the chilled ceiling systems and $101W/m^2$ to provide both heating and cooling.

Table 5.3.1: Summary of maximum cooling only energy demand and maximum variation between systems for each generic system type.

System type	Peak cooling only energy demand	Peak reverse-cycle energy demand
All-Air Systems	46 W/m^2 TFA	n/a
Fancoil Systems	37 W/m^2 TFA	101 W/m^2 TFA
Chilled Ceilings	11 W/m^2 TFA	46 W/m^2 TFA
DX Split Systems	31 W/m^2 TFA	89 W/m^2 TFA
DX VRF/VRV Systems	n/a	55 W/m^2 TFA
Unitary Heat Pump	28 W/m^2 TFA	n/a

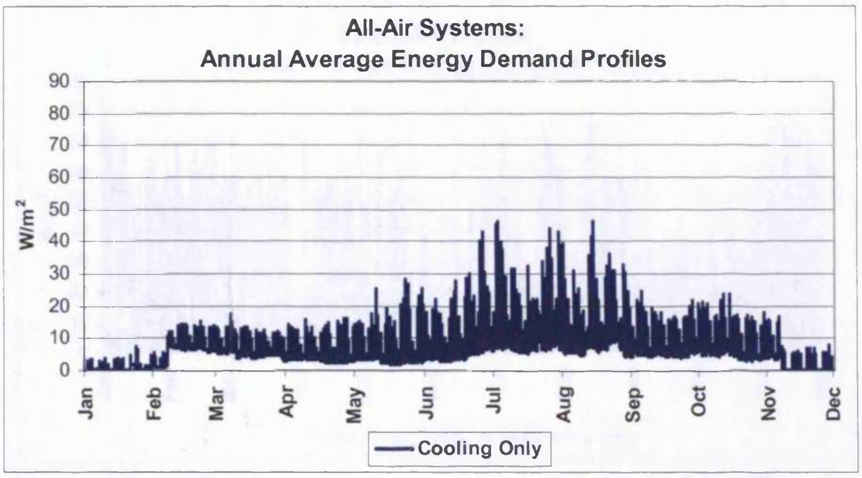


Figure 5.3.1: All-Air systems – annual energy demand profile.

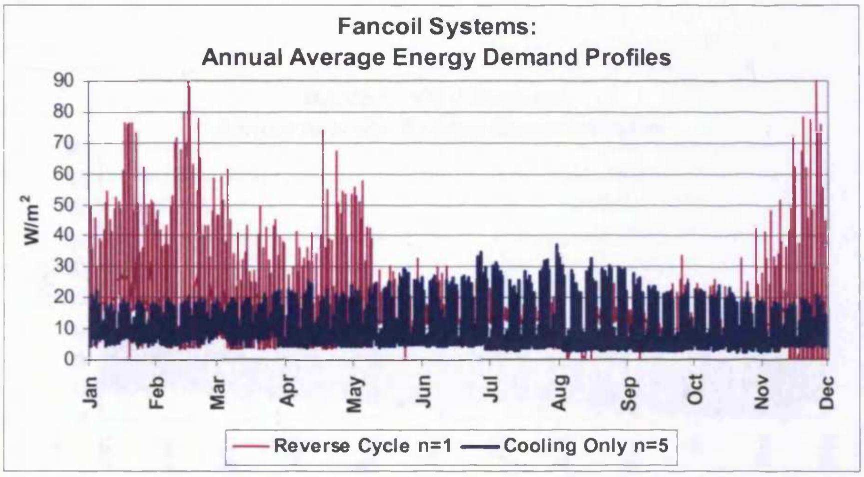


Figure 5.3.2: Fancoil System– annual energy demand profile.

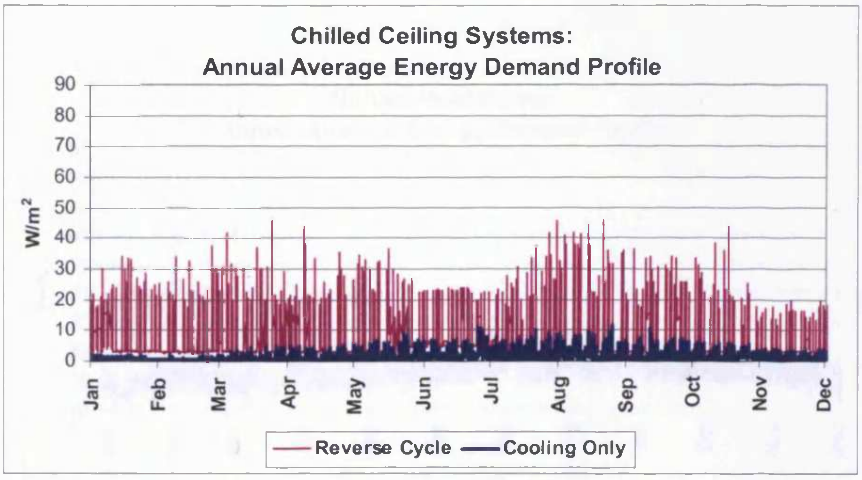


Figure 5.3.3: Chilled ceiling systems – annual energy demand profile.

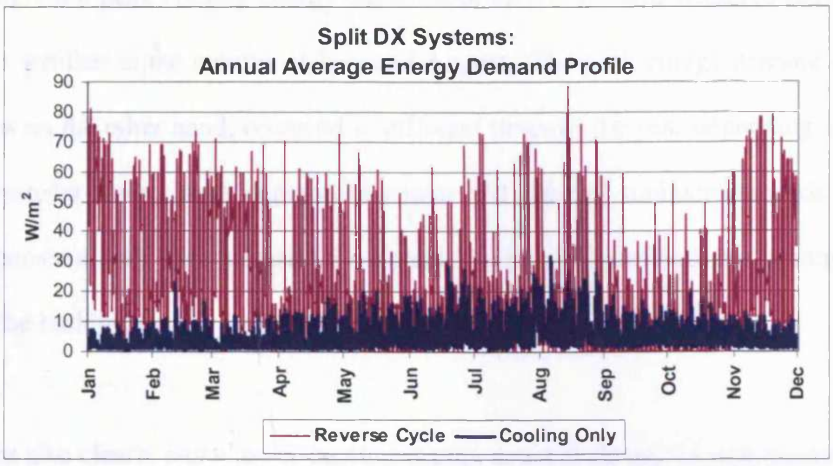


Figure 5.3.4: DX split systems– annual energy demand profile.

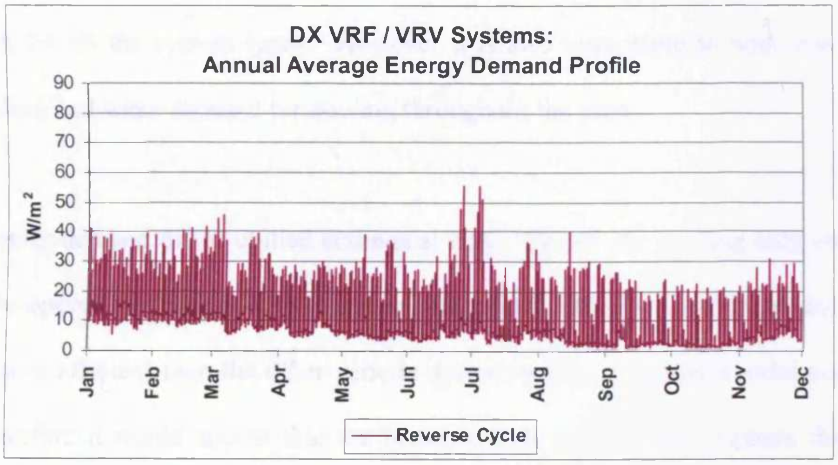


Figure 5.3.5: DX split systems– annual energy demand profile.

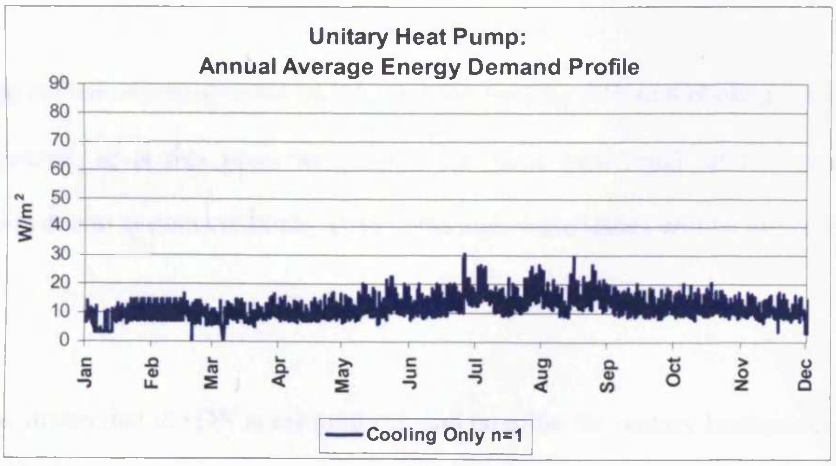


Figure 5.3.6: Unitary Heat Pump – annual energy demand profile. (Note n=1)

Not surprisingly the peak cooling energy demands of all the systems occurred during periods of peak summer weather in the months of July and August. The peak energy demand of the reverse cycle systems on the other hand, occurred at different times of the year depending on the system, with some systems having peak demand in winter and reduced summer demands, while others had a more constant peak daily demand throughout the year to meet both the heating and cooling demands of the buildings.

All the graphs also clearly show lower cooling energy demand during the non-summer months for the cooling only systems, indicating that on average all the cooling systems studied did respond to seasonal climatic variations, with winter energy demand typically reducing to between 25% and 50% of peak for all the system types. However it is also interesting to note that nearly all the systems studied had some demand for cooling throughout the year.

The peak power demand of the chilled ceilings at only 11W/m^2 for cooling only and 46W/m^2 for reverse-cycle operation was on average substantially lower than any other generic system type, and hence more efficient than the other generic system types, assuming similar peak loads were served. Therefore it would appear that the lower overall energy consumption, discussed in the previous Sections, of the chilled ceiling systems was at least in part due to their superior energy efficiency and not just due to differences in load or operational regimes.

However, the chilled ceiling systems may have been serving different cooling loads compared to the other systems, so at this point we cannot determine how much of the apparent superior performance is due to system efficiency alone, although these issues will be discussed in Chapters 6 and 7.

The data also shows that the DX splits systems, and possible the unitary heat-pump systems, with an average peak energy demand of 31W/m^2 and 28W/m^2 respectively may also be more efficient than the centralised all-air and partially centralised fancoil systems for the provision of cooling.

However, with only one example of the unitary heat-pumps systems represented it is hard to be sure of the performance of the entire generic group.

It is clear from the graphs that the cooling energy demand of the majority of the systems responded to the occupancy profiles of the buildings, since the energy demand of most systems was substantially reduced during night time and weekend periods observed in the profiles. This indicates that the systems were generally effectively controlled to match the occupancy patterns of the buildings. But, there were a number of notable exceptions where the energy demand did not reduce outside the occupancy periods of the building, in theory leading to substantial and needless energy consumption of these systems. The most noticeable example being the lone unitary heat-pump system studied shown in Figure 5.3.6.

In addition, there was a substantial amount of out-of-hours energy consumption even in the buildings which did appear to respond to the occupancy of the buildings. This is indicated by the average energy demands of the systems which rarely approached zero energy consumption at any time over the monitoring period for any of the generic system types. Undoubtedly, some of this out-of-hours energy demand was used by control systems to maintain the system in standby and / or to meet constant loads from equipment or telecommunication rooms. However, it is also evident that some systems simply did not have, or had overridden, their time controls so that they could not control the time the systems were operating. This lead to a number of systems operating twenty-four hours a day seven days a week, even at sites where it was known that 24-hour telecom loads were served by separate (not monitored) systems. This issue will be more obvious when we look at daily energy demand profiles and during the analysis of the system run-hours over the monitoring period.

To conclude the annual energy demand profiles indicate that the lower monitored overall energy consumption identified in Chapter 5 for the Chilled ceiling systems, and to a lesser extent cooling only DX split systems, was at least in part due to superior system efficiencies and not just due to differences in loads served and operational regimes. Furthermore the controls systems on the whole responded to seasonal variations in climate and occupancy patterns of the buildings, but a notable number of systems did not have adequate time controls leading to constant operation and substantial out-of-hours energy use even when not required to service the occupied space.

However, when analyzing these annual energy demand profiles we have had to consider the cooling only and reverse-cycle heating and cooling systems separately because we can differentiate between the heating and cooling loads that the reverse-cycle systems are serving, and therefore could not directly assess the efficiency of the reverse-cycle systems compared to the cooling only systems.

5.3.2 Comparison of Cooling Energy Consumption

The previous section discussed the performance of the reverse cycle systems many of which are capable of simultaneous heating and cooling, and the cooling only system separately. Whereas this section compares the energy demand of both system types over a period when we expect only cooling operation to be required and therefore allows direct comparison of their relative cooling energy performance.

Therefore the average weekday power demand profiles during July 2001 and 2002 have been compared for all the systems in 'cooling-only' mode, including the reverse cycle systems. This period of time has been chosen since it is a period during which we would not expect there to be a heating demand in the UK office buildings studied. This assumption is backed up by another monitoring study which showed that there typically was not any heating demand placed from a reverse-cycle air conditioning system in a UK office building during the months of July and August[14].

These cooling energy demand profiles are presented in Figures 5.3.7 to 5.3.12 and show the average weekday energy consumption profiles over the two consecutive summers for each of the generic system types studied and also indicate the range of energy consumption over the same period, in terms of the standard deviation from the average, i.e. average plus and minus the standard deviation.

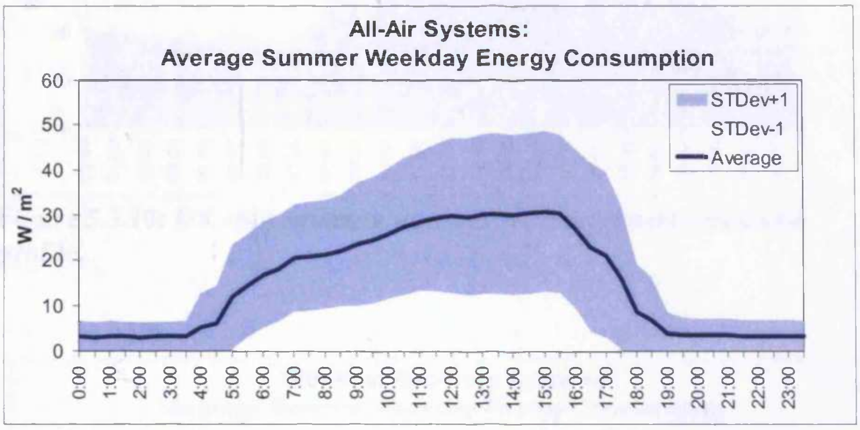


Figure 5.3.7: All-Air systems summer weekday energy demand profile.

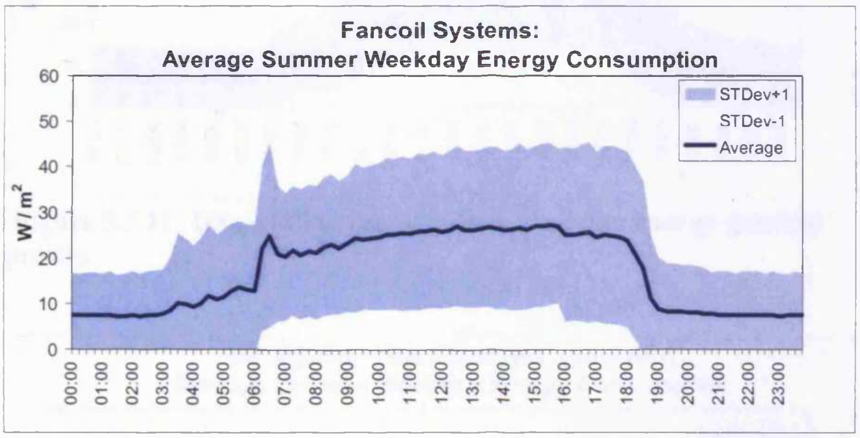


Figure 5.3.8: Fancoil system summer weekday energy demand profile.

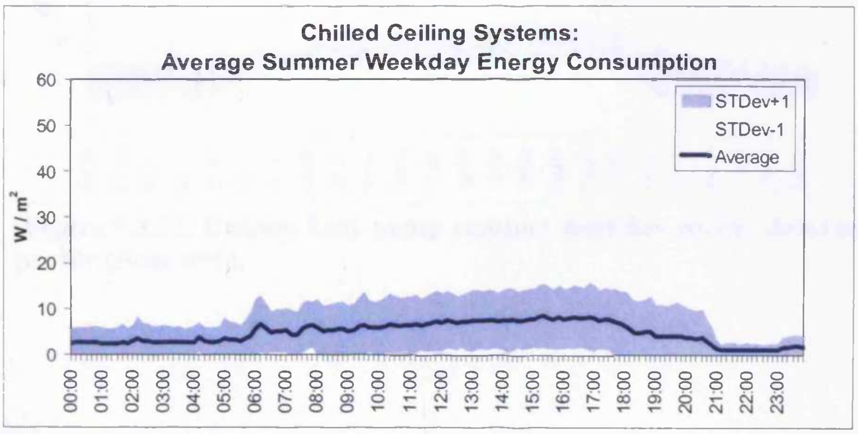


Figure 5.3.9: Chilled ceiling systems summer weekday energy demand profile.

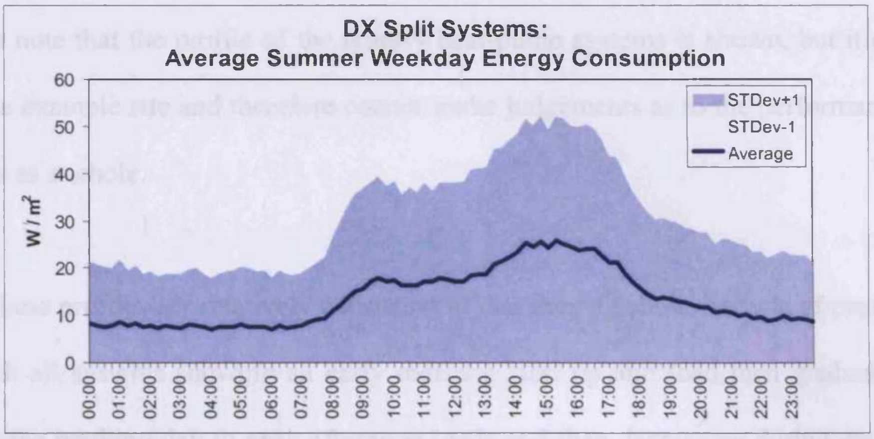


Figure 5.3.10: DX split systems summer weekday energy demand profile.

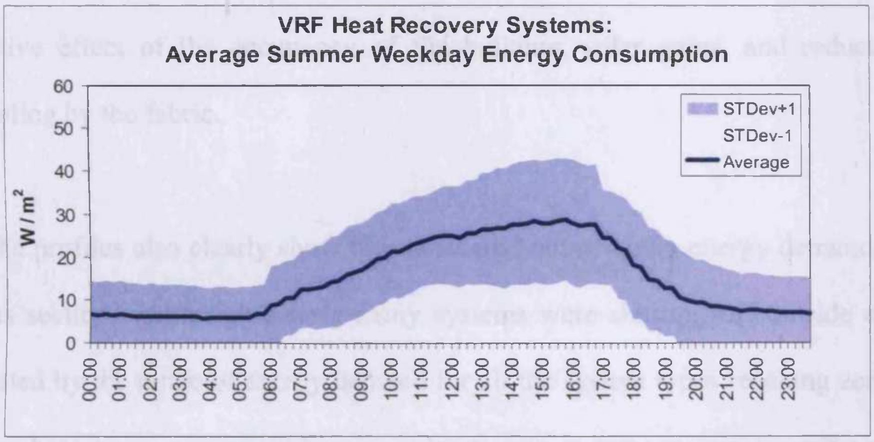


Figure 5.3.11: DX split systems summer weekday energy demand profile.

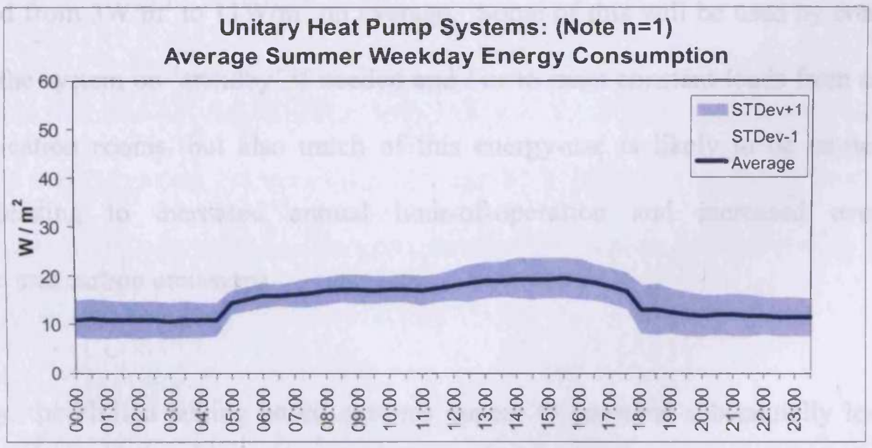


Figure 5.3.12: Unitary heat-pump summer weekday energy demand profile (Note n=1).

Once again note that the profile of the unitary heat-pump systems is shown, but it only includes data for one example site and therefore cannot make judgements as to the performance of unitary heat-pumps as a whole.

All six of these profiles are relatively consistent in that they all show the type of profile we would expect, with all systems showing an early morning start up and load then gradually increasing throughout the working day to peak afternoon loads and then decreasing during early evening as the loads reduce and the systems shut down. This would indicate that in general the controls systems are enabling the air conditioning systems studied to respond to the loads resulting from the cumulative effect of the occupancy of the building, solar gains, and reduction of early morning cooling by the fabric.

However, the profiles also clearly show the substantial out-of-hours energy demand identified in the previous section. Although clearly many systems were shutting off outside of occupancy hours indicated by the range of energy demand for all the system types reaching zero, except the single unitary heat pump systems, indicating at least some systems were consuming no energy out of occupancy hours. However, on average all the system types had overnight energy demands which ranged from 3W/m^2 to 11W/m^2 on average. Some of this will be used by control systems to maintain the system on 'standby' if needed and / or to meet constant loads from equipment or telecommunication rooms, but also much of this energy-use is likely to be un-necessary and inevitably leading to increased annual hour-of-operation and increased overall energy consumption and carbon emissions.

Significantly, the chilled ceiling based systems appear to consume substantially less energy to meet the cooling loads over the period in this comparison since peak power consumption for the individual systems ranged from 50 to 70W/m^2 for the majority of the generic system types including the All-air, fancoil, DX split and VRF/VRV systems, while the peak power demand for chilled ceiling systems were down at 20 W/m^2. This is clearly illustrated in Figures 5.3.7 to

5.3.12 where both the average and range of standard deviation of the chilled ceiling systems are substantially lower than all the other systems types.

Another way to look at this data is shown in Figure 5.3.13 which shows the range of average energy demand of the systems from 9:00am to 17:00pm of the summer weekday periods studied in the previous profiles. The mean energy demand for each generic system types as a whole are also indicated.

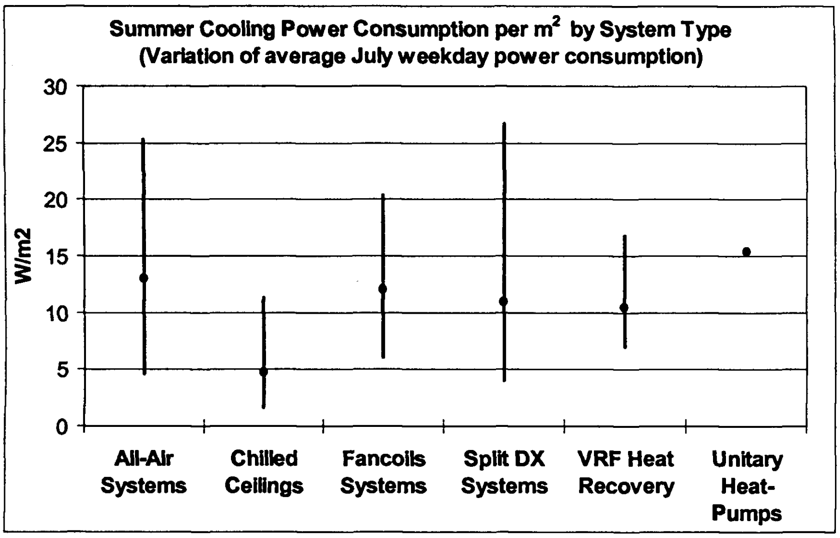


Figure 5.3.13: Range of average cooling power consumption by system type.

This illustrates that the All-Air, fancoil, Split DX and VRF/VRV systems appear to perform similarly with average power consumptions between 10 W/m^2 and 13W/m^2. The chilled ceiling systems studied clearly consumed less energy than the other generic system types with an average summer weekday power demand of around 5W/m^2.

The relative performance of the DX Split systems in this comparison is of note since the annual data suggested that they might be more slightly efficient than the other generic system types except the chilled ceilings. However, the summer weekday profiles do not show substantially reduced energy consumption on average, but also indicate the widest range with both some of the highest and lowest peak loads of any of the system studied. Therefore based on this monitoring it can only be concluded that the relatively high theoretical efficiency of the DX split systems has not carried through in to their actual energy performance in practice on average. The wide range of cooling energy consumption might lead us to speculate that the DX split systems are influenced more by their operation regimes than other system types, since they are more often operated with local controls and perhaps applied in a wider range of circumstances. Further analysis of the system run-hours and loads served are shown in later sections of this thesis and may help to explain why the DX split system did not perform as well as expected.

The performance of the single unitary heat-pump system studied indicates an average July weekday power consumption of around 15W/m^2 which is within the ranges of consumptions of the other systems types except that of the chilled ceiling systems, which may indicate an average energy performance compared to the other system studied here. However since we only have data from one site we can only speculate as to how unitary heat-pump systems perform on the whole compared to other generic types.

The analysis of the energy demand profiles further reinforce the conclusion from the energy consumption data that the chilled ceiling based systems appear to be inherently more efficient than the other generic systems types in the provision of comfort cooling. But differences in the loads served by the systems in the buildings studied have not yet been accounted and therefore based on the analysis in this section it is possible that the chilled ceilings were serving substantially lower cooling loads than the other systems and are therefore not as efficient as they appear compared to the other system types. This issue will be addressed in later chapters by normalising the cooling energy consumption by the estimated loads served.

5.3.3 Conclusions from the Energy Profiles Analysis

Furthermore when assessing the energy required to meet peak comfort cooling demand, the chilled ceiling based systems appear to consume substantially less energy to meet the cooling loads compared to the other system types with average power demand at around 5W/m^2 on average. While the All-Air, fancoil, Split DX and VRF/VRV systems appear to perform similarly with average power consumption ranging between 10 W/m^2 and 13W/m^2. Similarly peak power consumption for the individual systems ranged from 50 W/m^2 to 70W/m^2 for the majority of the generic system types including the All-air, fancoil, DX split and VRF/VRV systems, but the peak power demand for chilled ceiling systems were down at 20W/m^2.

Therefore the chilled ceiling based systems were all notably lower energy consumers in both annual and peak energy consumption, whereas the measured performance of the DX split systems was contradictory, performing well in terms of annual energy consumption but decidedly average in terms of peak demand.

Significantly, the measured energy consumption of the chilled ceiling systems was actually below that predicted by from recent modelling work[15], which itself identified chilled ceilings as the most efficient system type for cooling. This may indicate that the five chilled ceiling systems monitored performed even better 'in practice' than designers would have thought.

Of particular interested to building services designers, the results from computer modelling studies compared favourably to the measured energy consumption from this field monitoring study. The fact that the measured computer design modelling techniques predicted annual energy consumptions similar to the measured 'Good Practice' performance indicates that current design modelling techniques appear appropriate.

However, the predictions were less reliable when required to predict the performance of systems operated in a less than perfect manner, where judgments were required to be made about how systems were actually being operated in practice, without detailed information on each systems operation. The cases where this was attempted reviewed by this work suggested that in practice operational parameters varied far wider than the modelling assumptions, i.e. in many cases the modellers appeared to under estimate how poorly many systems where actual operated.

It is important to note that ALL the generic types of air conditioning studied appear capable of meeting current UK 'good practice' energy consumption standards for comfort cooling on an individual basis, emphasising the importance of appropriate control, maintenance and operational management. While also highlighting that the underlying reasons behind the high energy consumption, and hence carbon emissions, of 'air conditioned' buildings are not inherently due to the use of air conditioning alone.

These last two points emphasize that selecting the a very efficient air conditioning system is not enough to reduce overall energy consumption, and carbon emission, from our buildings as the systems cannot be considered in isolation from the building, its users and other energy uses.

What's more this research has shown that in many cases the energy used for air conditioning is actually a relatively small proportion of the total energy consumption in UK office buildings. This emphasizes the importance of not only selecting efficient systems, but ensuring they are designed and operated to take advantage of their efficiency, putting an increased importance on the role of designers to holistically consider the whole building and its use, but also on facilities management to operate buildings efficiently.

However, this research suggests that the UK market is currently failing to achieve this aim, since two of these issues, air conditioning system control and chiller plant-sizing, have been highlighted by this work as issues where current UK practice appears to be able to improve substantially.

In general the control of the air conditioning systems studied showed reasonable responses to the occupancy patterns of the buildings, as well as seasonal and daily variation in climate, indicating that control systems were capable of effectively controlling the cooling systems studied. But, it is clear that on average most systems are running far longer than we might have expected, indeed it is clear that some systems have no time control, i.e. run 24 hours per day, 7 days a week (8760 hours per annum). The average annual run hours for all systems running in cooling-only mode was 4,919 indicating that in practice they are operating almost twice as much as need be and a 50% saving in energy consumption and carbon emissions may be possible from effective time control of comfort cooling systems alone.

5.4 MEASURED PART-LOAD PROFILES

In the UK climate we know that peak design cooling loads occur relatively infrequently compared to other climates, meaning that the part-load performance of the refrigeration components of an air conditioning system is of particular importance, along with its sizing relative to the load served which determines the amount of part-load operation. It has been suggested that in the UK only 3% of the cooling energy demand occurs at load levels above 75% of the peak[16]. Yet it has also been shown that air conditioning systems, and especially chillers, are commonly sized well in excess of design values[16], although some prudent system over-sizing is clearly necessary as 'safety margins' to provide standby capacity or to meet possible future building usage. It must also be acknowledged that this over-sizing is leading to reduced energy efficiency, higher capital and running costs, and possibly reduced comfort[17].

For these reasons this section of the research considers the part-load profiles of the systems studied to determine how much time the monitored air conditioning systems spent serving the various loads in practice and the relationship between the installed chiller capacity and system loads over the monitoring period.

The chiller part-load of each system has been calculated from the measured power consumption of the each chiller for each interval of recorded data, typically at 15-minute intervals, divided by the chillers rated power consumption at full-load. The calculated percentage part-load of the chiller for each monitored interval of time has then been compiled into frequency histograms as a percentage of time over the entire monitoring period at each site. The result is a histogram that compares the % of time each system operated at each part-load percentage of the systems full-load capacity.

This definition considers only the total chiller power requirements of each system and therefore sidesteps issues such as control, modulation of multiple chillers, balance-of-system energy use, etc. By defining the efficiency this way we can compare the different system types in terms of their part-load operating profiles and make judgments as to the sizing of the whole systems compared to the loads they are actually serving.

Figures 5.4.1 to 5.4.5 show part load profiles in the form of the percentage of time spent at a given percentage of full load capacity for each of the generic system types studied.

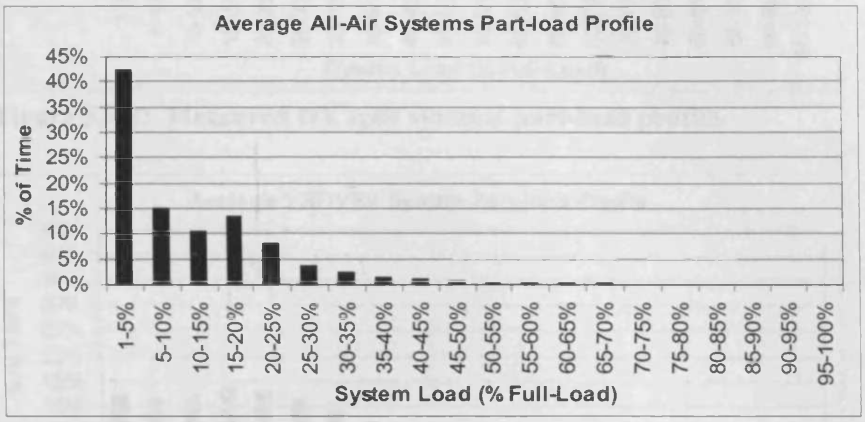


Figure 5.4.1: Measured all-air systems part load profiles.

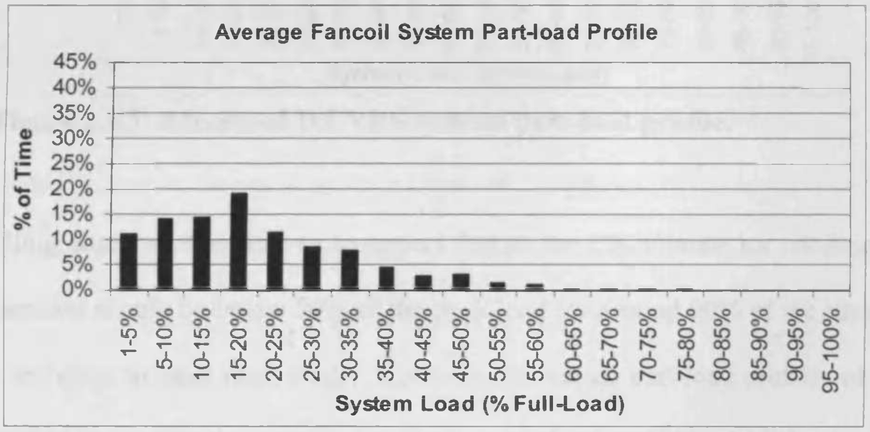


Figure 5.4.2: Measured fancoil systems part-load profile.

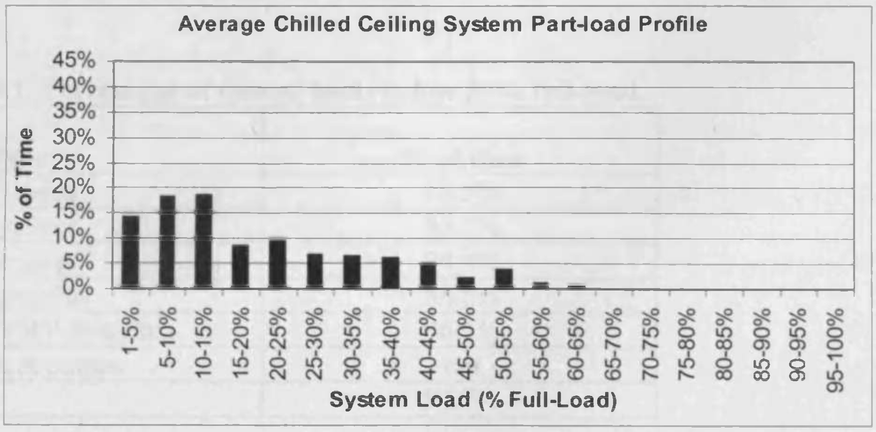


Figure 5.4.3: Measured chilled ceiling systems part-load profile.

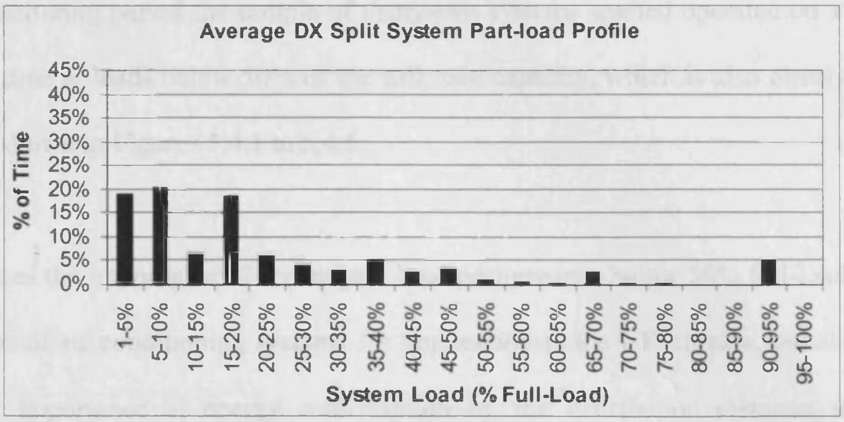


Figure 5.4.4: Measured DX split systems part-load profile.

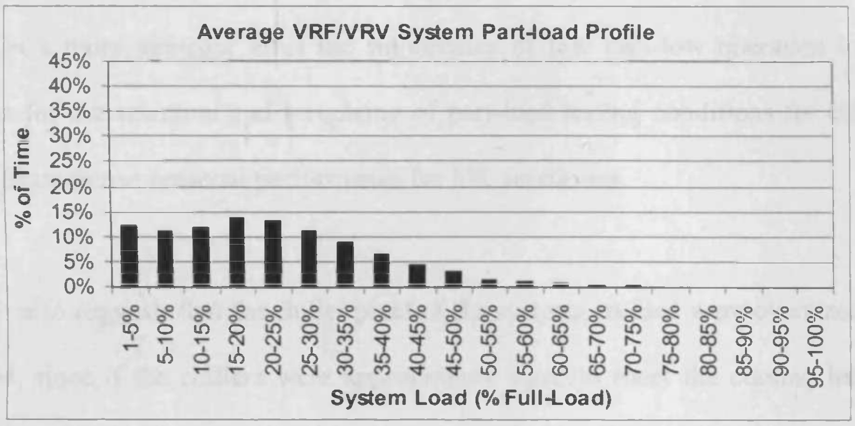


Figure 5.4.5: Measured DX VRF systems part-load profile.

Other modelling based studies lead us to expect that in the UK climate air conditioning chiller part-load operation should be below 50% of the peak load for around 90% of the time[16] assuming the systems are sized to meet peak loads. However, the actual part-load profiles of the systems studied show that in practice the systems actually operated below 50% of full-load capacity more than expected, as shown in Table 5.4.1 below.

Table 5.4.1: Percentage of time at loads below 50% full-load.

System Type	**% of time**
All-Air Systems	98.5%
Fancoil Systems	95.7%
Chilled Ceilings	94.4%
DX Split systems	88.5%
DX VRF/VRV Systems	96.5%
Unitary Heat-pumps	n/a
Average	94.7%

Over the monitoring period the sample of thirty-two systems studied operated on average almost 95% of the time at loads below 50% of the full-load capacity, which is also clearly illustrated in the profiles shown in Figures 5.4.1 to 5.4.5.

This reinforces the importance of chiller part-load performance below 50% full-load in the design and selection of air conditioning systems for application in the UK climate, but also emphasises the relative importance of energy consumption by the distribution elements of the system including fans and pumps etc, since they will be proportionally more important as chiller load reduces. On a more strategic level the importance of low part-low operation in the UK has implications for the selection and weighting of part-load testing conditions for chillers plant to effectively characterise seasonal performance for UK conditions.

However, it also suggests that the chiller plant of the systems studied were oversized for the loads encountered, since if the chillers were appropriately sized to meet the cooling loads we would expect to see peak chiller operation to be in excess of 90% of the installed capacity, assuming a prudent 10% safety margin, even if only for relatively short periods of time. However, of the thirty-two systems studied only four ever operated above 90% of full-load during the monitoring period and even then generally for only 0.2% of the time, with the exception of a single example DX split system which did operate at higher loads for longer periods of time.

Typically the systems studied did not operate for any significant length of time above 40 to 60% of full-load capacity, indicating the majority of the systems are substantially oversized, and a reasonable conclusion might be that the system studied had installed chiller capacities that were generally twice that required for the actual loads served in the buildings studied over the monitoring period. This clearly means that for some reason UK chiller sizing practice is over-estimating the cooling loads in UK office buildings.

5.4.1 Installed Capacity of the Systems Studied

We can get a snap-shot of the current sizing of air conditioning systems in UK offices by looking at the installed capacities of the chillers in the system studied. Table 5.4.2 shows the installed cooling capacity of each site in terms of Watts / m^2 TFA cooling capacity.

Table 5.4.2: Installed chiller cooling capacity in the systems studied.

Site ID Number / System Type	**Installed Cooling Capacity**
Cooling Only Systems	***W/m²***
Site 1 - All-Air	475.7
Site 2 - All-Air	165.1
Site 3 - All-Air	n/a
Site 4 - All-Air	129.7
Site 5 - All-Air	132.6
Site 6 - All-Air	132.6
Site 7 - All-Air	128.0
Site 8 - Chilled Ceiling	76.7
Site 9 - Chilled Ceiling	48.8
Site 10 - Chilled Ceiling	45.6
Site 11 - Chilled Ceiling	86.5
Site 12 - Fancoils	281.4
Site 13 - Fancoils	111.1
Site 14 - Fancoils	45.9
Site 15 - Fancoils	160.0
Site 16 - Fancoils	151.8
Site 17 - DX Split	76.7
Site 18 - DX Split	147.6
Site 19 - DX Split	29.8
Site 20 - DX Split	n/a
Site 21 - DX Split	232.4
Site 22 - DX Split	92.0
Site 32 - Unitary HP	n/a
Reverse Cycle Systems	
Site 23 - Chilled Ceiling	249.1
Site 24 - Fancoils	135.4
Site 25 - DX Split	47.7
Site 26 - DX Split	309.1
Site 27 - DX Split	144.5
Site 28 – VRF HR	117.5
Site 29 – VRF HR	143.9
Site 30 – VRF HR	233.8
Site 31 – VRF HR	117.7
Average	***146.5***
Standard deviation	***95.0***

This comparison shows the wide range of installed capacities found in practice, ranging from less than 30W/m^2 TFA for a Multi-DX split system providing top-up secondary cooling to a staggering 475W/m^2 for a packaged roof-top all-air system, which we can only assume is substantially over-sized for the office accommodation it is serving. However, on average the systems installed cooling capacity was 146.5W/m2 TFA for all the systems, or about 17% higher than the nominally expected installed cooling capacity of 125W/m^2 TFA from current rule-of-thumb guidance[18]. This suggests that compared to current standards the systems studied on average are oversized, but not as dramatically as the double the required capacity the monitored part-load data had suggested, i.e. 17% not 100%. This may indicate that at least in part current design practices are over-estimating the cooling loads actually found in practice, leading to the over-sizing of chiller plant.

5.4.2 Implications of Chiller Sizing & Part-load Operation

This is important since both the theory[17] and other field studies[19] show a direct relationship where the efficiency of the chiller will vary with the load on the chiller and on the condenser and evaporator temperatures, where higher system loads result in higher system efficiencies in most chillers. Conversely low part-load operation caused by over-sizing of chiller plant will reduce the efficiency of the system and therefore increase carbon emissions. Figure 5.4.6 below illustrates this relationship and shows an efficiency curve of an example chiller[20] expressed in chiller kW per ton of refrigeration, where the lowest value equals the "peak" efficiency.

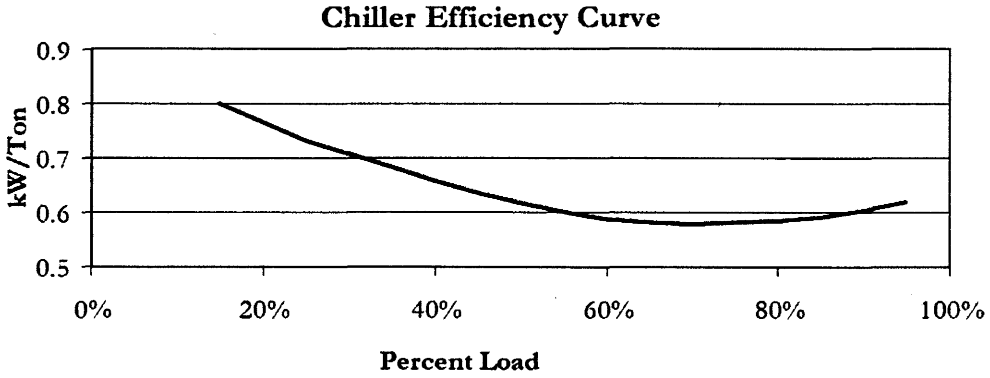


Figure 5.4.6: Efficiency curve of an example chiller[20].

But since chiller part-load performance is very dependant on the actual plant used, and because chiller part-load performance data is currently not readily available, it is not possible to quantify the potential savings that might accrue through more accurate sizing of the systems studied. Although other studies suggest that the savings could be at least 9% of the whole system annual energy consumption[21] and there would appear to be capital and maintenance cost savings to be achieved as well.

It is interesting to note that even the lowest energy consuming Chilled Ceiling systems were not immune from this problem in theory leading to reduced system efficiency as well as increased capital and running costs, implying that there are potentially efficiency improvements to be made even in the most efficient of the system studied.

This has implications to the design of air conditioning systems, since the sample of thirty-two buildings studied by this research would suggest that chiller over-sizing is common practice in the UK building services industry today, which begs the question why this is happening when you consider the potential savings that could be achieved, but also the extra capital cost involved? The data collected during this study suggests that one possible answer is that current design standards and load estimation methods, contribute to the over-sizing of building services plant by over-estimating the design loads used to design air conditioning systems, but this issues needs further investigation.

These findings that the over-sizing of chiller plant in the UK industry, assuming does lead to reduced energy efficiency, has implications to the UK Government's decision to introduce the Carbon Performance Rating (CPR) in Part L of the Building Regulations[22] would appear to be an appropriate legislative control to promote energy efficiency and reduce carbon emissions in the UK market. The CPR by limiting the potential carbon emissions of a proposed design calculated using the installed chiller capacity[22] in effect restricts the installed capacity of chiller plant in order to limit potential energy consumption and carbon emissions and therefore should also limit the over-sizing of chiller plant. However, if the current design and estimation methods are found themselves to be contributing to the over-sizing of chiller plant, the required CPR targets may require being tightened.

The current uncertainty surrounding the issues of chiller part-load operation and plant sizing stems from a distinct lack of the part-load performance data which is vital to assess the actual energy performance of air conditioning systems. Furthermore, with the strong dominance of low part-load operation in the UK the availability of chiller part-load performance data with appropriate weighting of part-load testing for UK conditions is vital to effectively select the most energy efficient air conditioning systems for the UK.

5.4.3 Conclusions from the Chiller Part-Load Analysis

Furthermore, analysis of the part-load profiles of the systems studied showed that typically they did not operate for any significant length of time above 40% to 60% of full-load capacity, indicating the majority of the systems are substantially oversized, and generally had twice the capacity required for the actual loads served in the buildings studied over the monitoring period.

In defence of the system designers, on average the installed cooling capacity of the systems was only about 17% higher than expected based on current rule-of-thumb guidance, suggesting that at least in part current design practices are over-estimating the cooling loads actually found in practice, leading to the over-sizing of chiller plant. However it was also clear that the performance of many of the systems, particularly packaged systems, suffered due to an apparent lack of basic design principles being applied to their installation. Many of these systems were over-sized for the loads severed beyond that attributable to just conservative calculation methods and often without the ability for modulation between multiple chiller units.

Although it is not possible to determine by how much chiller plant over-sizing is increasing the energy consumption and carbon emissions from UK air conditioning systems, it has been shown to reduce air conditioning efficiency and appears to be a very common practice in the UK industry. Therefore this issue requires urgent attention and further investigation, to provide updated and more appropriate design standards, legislative controls and system performance data so that designers and building operators can maximise the potential of air conditioning system to reduce carbon emissions.

5.5 MEASURED HOURS OF OPERATION

The control of the systems studied is of particular interest because it has potentially the greatest influence on how much time the systems actually operate in practice, which will of course have a direct impact on the total amount of energy consumed and carbon emissions from the operation of a given air conditioning system, no matter how efficient, as discussed in Section 2.1. Based on those first principles the amount of time each system is required to operate is clearly a very significant factor in determining the overall energy consumption, and hence carbon emissions of air conditioning systems in practice.

Furthermore analysis of the energy demand profiles in Section 5.3 concluded; "that many of the systems studied are operating far longer than would normally be expected based on the occupancy patterns of the buildings, and indeed some systems did not appear to have any time controls leading to twenty-four hours - seven days a week operation". Potentially this is leading to substantially increased energy consumption and carbon emissions, as well as, increased wear on the systems undoubtedly requiring increased maintenance and its associated costs.

Therefore this section investigates the amount of time each of the monitored systems were actually operating in practice to determine the impact of extended hours of operation on the overall energy consumption of the systems studied. In order to assess the potential savings achievable through better time control of the systems, some operating scenarios for the systems studied have been assumed and compared to the actual run hours found in practice within the buildings monitored.

It is reasonable to expect that if these systems had even basic time control the run-hours of the reverse-cycle heating and cooling systems should not exceed 4,380 hours per year, which assumes the systems are running 12 hours per day for 365 days per annum, i.e. including weekends and the heating season. And the cooling-only systems should operate around 2,500 hours per annum which is the standard used for the Carbon Performance Rating (CPR) of Part L of the Building Regulations[22], but essentially assumes no weekend run hours and 3 months of 'no cooling' in the winter, or 2,340 hours per annum, plus a certain amount of occasional required out-of-hours and weekend operation.

The measured annual run-hours of the air conditioning systems studied by this research are shown in Table 5.5.1 below. These annual run-hour values have been calculated from the measured energy consumption data of the chiller plant over the monitoring period at each site, based on the assumption that the chillers were switched 'off' during each time interval where their power demand was less than 1% of their rated power consumption. This assumption has been used so that the small loads constantly associated with the control systems of the majority of the systems studied would not be counted.

Note the actual annual run-hours of Sites 3, 7, 20, and 32 could not be calculated using this method because the monitoring at these sites was conducted by one of the partner organisations and monitored in a manner that prevented the chiller energy consumption to be separated from other services.

The measured annual run-hours of the systems indicate that on average the cooling only-systems operated 4919 hours per annum, or almost twice (197%) as often as the 2,500 hours expected if effective time controls were in operation on the systems, based on the above assumptions, and with one system operating 8758 hours per year, i.e. it was only switched 'off' for two hours per year, it is clear that it had no time controls at all.

Table 5.5.1: Measured annual chiller operational hours.

Site # / System Type	Annual Run-hours
	hours
Cooling Only Systems	
Site 1 – All-Air	2085
Site 2 - All-Air	4674
Site 3 - All-Air	n/a
Site 4 - All-Air	3926
Site 5 - All-Air	5519
Site 6 - All-Air	8314
Site 7 - All-Air	n/a
Site 8 - Chilled Ceiling	4613
Site 9 - Chilled Ceiling	2374
Site 10 - Chilled Ceiling	1722
Site 11 - Chilled Ceiling	4012
Site 12 – Fancoils	2230
Site 13 – Fancoils	4870
Site 14 – Fancoils	2668
Site 15 – Fancoils	5977
Site 16 – Fancoils	7683
Site 17 - DX Split	8559
Site 18 - DX Split	8757
Site 19 - DX Split	8758
Site 20 - DX Split	n/a
Site 21 - DX Split	2023
Site 22 - DX Split	4700
Site 32 - Unitary HP	n/a
Average	***4919***
Standard Deviation	***2481***
Site 23 - Chilled Ceiling	5308
Site 24 – Fancoils	7073
Site 25 - DX Split	4674
Site 26 - DX Split	1160
Site 27 - DX Split	6573
Site 28 – VRF HR	8755
Site 29 – VRF HR	5198
Site 30 – VRF HR	5136
Site 31 – VRF HR	8753
Average	***5848***
Standard Deviation	***2332***

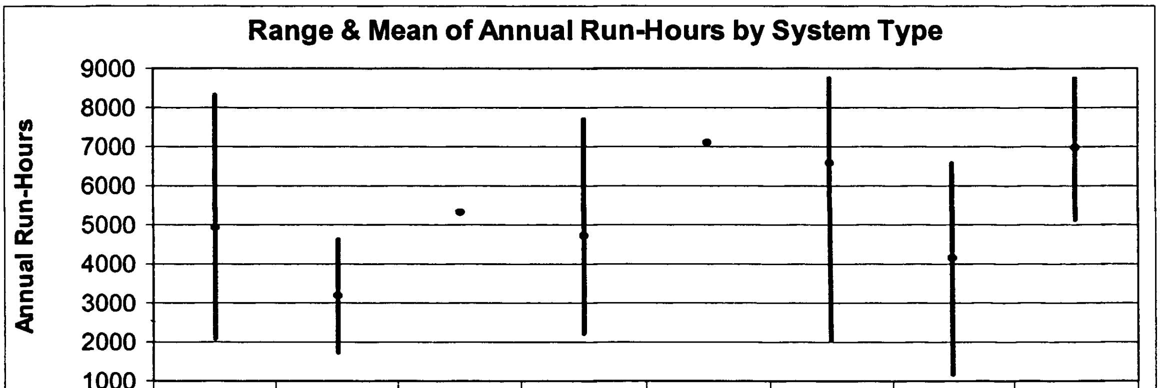
At first glance the reverse-cycle systems providing both heating and cooling appear to fare better since on average they operated 5848 hours per year, or only about one-third more often than expected (134%), but if we exclude the data from Site 26, which exceptionally operated far less of the time than any of the other sites, it indicates that the average reverse-cycle system was in fact operated 6434 hours per year, or about one and a half times as often (147%) as expected.

It is clear from the systems monitored that in practice on average most of the systems are running far longer than we might have reasonably expected. Indeed some systems appear to have no time control, i.e. running 24 hours per day, 7 days a week or 8760 hours per annum. The average annual run hours for all systems running in cooling-only mode was 4,919 indicating that in practice they are operating almost twice as much as needed and a 50% saving in energy consumption, and hence carbon emissions, may be possible from effective time control of comfort cooling systems alone and further 33% saving for the heating and cooling of building using reverse-cycle air conditioning systems.

5.5.1 Variation of Operational Hours by Generic System Type

Clearly the extended hours of operation of many of the systems studied is not the whole story, since the significant differences in energy performance observed between the different air conditioning systems studied and the apparent superior performance of the chilled ceilings might be in part due to better control of those systems compared to the other and not necessarily just due to differences in system efficiency. Therefore we also need to compare the operational hours of the system by generic system type, to determine whether time controls are influencing the differences in performance observed between the different generic system types.

Figure 5.5.1 shows the range and average annual hours of actual operation from Table 5.5.1 for each generic type of system studied in both cooling-only and reverse-cycle configurations over the monitoring period.



	All-Air - Cooling Only n= 1	Chilled Ceiling - Cooling	Chilled Ceiling - Reverse	Fancoil - Cooling Only	Fancoil - Reverse Cycle	DX Splits - Cooling Only	DX Splits - Reverse Cycle	VRF/VRV - Reverse Cycle
Min	2086	1722	5308	2230	7073	2023	1160	5136
Max	8314	4613	5308	7683	7073	8758	6573	8755
• Average	4904	3180	5308	4686	7073	6560	4136	6960

Figure 5.5.1: Annual Hours of Operation by generic system type and mode of operation.

This comparison indicates that the chilled ceiling systems generally had better time control than the other generic systems types, leading to lower annual run-hours of 3,180 hours per annum for the cooling-only systems, which evidently contributed towards the lower annual energy consumption and carbon emissions discussed in Section 5.2.

However, the lower summer cooling energy demand of the chilled ceiling systems discussed in Section 5.3, which are not influenced by time control, indicated that there were inherent differences in the efficiency of the system studied in practice, so it is unlikely that time control alone accounted for all the differences observed in the energy consumption of the between the ceiling and other system types. Instead time control was just one of the contributing factors that lead to the chilled ceiling systems superior annual energy consumption and carbon emissions compared to the other system studied. The following section attempts to determine by how much time controls were influencing the annual energy consumption of the systems studied.

5.5.2 Energy Consumption Normalised by Standard Hours of Operation

To determine the relative importance of effective time controls on the annual energy consumption of the systems studied, the monitored annual energy consumption of each system has been normalised by the annual run-hours, i.e. Annual energy consumption (kWh/m2) divided by total annual run hours, as shown in Table 5.5.2 below.

Table 5.5.2: Normalised annual energy consumption.

System Type	Cooling-only		Reverse-Cycle	
	Average (kW/m^2)	**Range** (kW/m^2)	**Average** (kW/m^2)	**Range** (kW/m^2)
All-air	48.1	20 to 105	n/a	n/a
Fancoils	54.5	28 to 114	58.2	n/a
Chilled Ceilings	13.7	10 to 18	64.8	n/a
DX splits	24.8	7 to 55	117.9	86 to 150
DX VRF/VRV	n/a	n/a	67.9	46 to 88

When normalized by annual hours of operation, the measured energy consumption of the systems studied still clearly indicates the chilled ceiling systems consumed less energy than the other generic types for the delivery of cooling services consuming on average $13.7kW/m^2$.

This analysis also indicates that the cooling-only DX split systems performed second best overall at $24.8kW/m^2$ annually, perhaps indicating that the performance of the DX split systems, which in theory we had expected to be relatively efficient (Chapter 2), in practice their overall performance are more sensitive to controls regimes than the other system types studied. There is some logic to this argument since DX split systems were more likely to be operated with local controls, which certainly explains the wider range of operation hours and energy consumption of any system type. This emphasizes the importance of informed occupants / users with air conditioning systems on local control, since studies have shown that informed users and effective local leads to reduced run-hour and energy consumption[8], but this data also shows that inappropriate use of local controls can also have the opposite effect.

From this we might conclude that cooling-only DX splits are relatively efficient compared to the other system types studied, except the chilled ceilings, as the annual energy consumption, modelling and theoretical review concluded in Chapter 2, but in the sample of buildings monitored these systems did not achieve their potential performance due to poor control leading to longer than required hours of operation. The assessment of system efficiency presented in Chapter 7 may clarify this issue further.

However, the picture is not as clear for the reverse-cycle systems because of the smaller sample of systems to studied, making it difficult to draw conclusive comparisons between the relative performances the different systems. But the data available indicates that the reverse-cycle fancoil, chilled ceiling and DX VRF/VRV systems performed similarly in terms of overall energy consumption when normalised for run-hours, with the reverse-cycle DX split systems consuming more on average than the others in terms of annual energy consumption, when normalised by hours run. This further supports the conclusion that the DX split systems, which were more often operated with local control, performance in practice was severely reduced by poor control. Since, if poor local control was a significant factor as the cooling-only data has suggested, the reverse-cycle systems would potentially suffer worse as system conflicts between units providing heating and cooling could develop leading to substantial extra energy use and run-hours and energy consumption.

5.5.3 Conclusions from the Hours of Operation Analysis

The analysis of the run-hour data of the systems studied as shown in the above sections, indicates that in practice most of the systems are running far longer than we might have reasonably expected and that some systems appear have no time control at all, i.e. running 24 hours per day, 7 days a week or 8760 hours per annum. On average over the monitoring period of the systems running cooling-only operation was 4,919 and 5848 hours per annum for the reverse cycle systems , or hours per annum indicating that 50% and 33% savings respectively in energy consumption, and hence carbon emissions, may be possible from effective time control alone.

Furthermore, it is clear that more effective controls contributed to, but did not account of all, the superior overall energy performance of the chilled ceiling systems, which also generally had better time control than the other generic systems types.

This analysis has also suggested that poor control might be the underlying reason why the cooling-only DX splits systems, which were expected to be relatively efficient compared to the other system types studied (except the chilled ceilings), did not achieve their potential in practice.

5.6 OVERVIEW OF THE ENERGY MONITORING FINDINGS

This section aims to briefly summarise the results from the monitoring presented and discussed in the previous sections of this chapter. The building energy monitoring undertaken by this research has therefore shown the following:

- The measured annual building energy consumption and carbon emissions correlate to the range of current UK energy consumption benchmarks for air conditioned office buildings and therefore the current benchmarks appear to be set at a suitable level.
- Chilled Ceiling based systems, and to a lesser extent the cooling-only Direct Expansion systems, typically consumed less energy to deliver comfort cooling than the other generic system types studied.
- The reverse-cycle air conditioning systems studied were as efficient as any other type of heating system in terms of carbon emissions and more efficient in terms of delivered energy.
- ALL the generic types of air conditioning studied appear capable of meeting current UK 'good practice' energy consumption standards for comfort cooling on an individual basis, emphasising the importance of appropriate control, maintenance and operational management.

- The control of the systems studied showed a response to internal loads, seasonal and daily variation in climate, but time control was typically poor. On average operating almost twice as much as expected indicating that a 50% saving in energy consumption and carbon emissions may be possible from more effective time control alone.
- Analysis of the part-load profiles of the systems studied showed that the majority of the systems generally had twice the capacity required for the actual loads served over the monitoring period and this oversizing maybe in part due to current design practices which appear to over-estimate the cooling loads actually found in practice.
- A strong correlation was observed between recent computer design modelling of 'good practice' energy consumption and the monitored results suggesting that current modelling techniques appear accurate for comparative design assessment, but are less accurate at predicting actual energy performance of a given site without detailed operational parameters.

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Chapter 6: Assessment of Air Conditioning System Efficiency

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6.0 ASSESSMENT OF AIR CONDITIONING SYSTEM EFFICIENCY

This section discusses the results of the energy consumption monitoring, normalised for the internal heat gains in each treated space served by each system, in terms of the air conditioning efficiency for each of the air conditioning systems studied as described in Section 3.4. This assessment therefore allows a first indication to be gained of the relative efficiencies of the generic system types. This will enable us to determine more clearly whether the apparent differences observed in the energy consumption and energy demand profiles were to do with the loads served or the system efficiency.

6.1 ASSESSMENT OF COOLING LOADS SERVED

This section covers the assessment of loads served by the systems studied over the monitoring period, which have been calculated using the detailed information collected about each building during a building characteristics survey. These calculated loads are used to assess the overall system energy efficiency for each of the systems studied, but are also in their own provide an important insight into the actual occupancy patterns and heat-gains found in UK office buildings, and thereby the appropriateness of current design standards and air conditioning sizing practices.

A full description of the building characteristics survey and calculation methods used is provided in Section 3.3. In summary, the survey was based on the parameters required to complete the CIBSE energy assessment and reporting methodology for offices[1] and conducted using a survey format developed for the UK Non-Domestic Building Stock Energy Database[2] and aimed to establish detailed knowledge of the following issues at each sample building: Building identity and categorization, Building structure and layout, Building occupancy levels and patterns, Type and details of HVAC systems, Building and plant history.

A summary of the information gathered for each building in the monitoring sample during the surveys is provided in Appendix A.

Ideally, thermal modelling of each building should have been undertaken to determine the fabric, solar and ventilation loads placed on the systems over the monitoring period, but this was not possible with the resources available to this project. So the fabric and solar component of the loads could not be reliably estimated. Therefore, only the internal heat-gain components of the total system cooling load will be fully assessed and the total cooling loads including the fabric, solar and ventilation can only be discussed based on rule-of-thumb values.

6.2 ASSESSMENT OF INTERNAL HEAT-GAINS

A full description of the methods used to determine the cooling loads is provided in Section 3.3, but to summarise, the internal heat gains 'as found' in the office buildings studied during the monitoring period have been calculated using the CIBSE nameplate-ratio method[3] assuming worst-case power demand and full occupancy in order for the calculated gains to represent likely maximum gains, and therefore be comparable to loads calculated in the sizing of building services plant. The calculations were based on observations obtained by the building characteristic surveys carried out at each site which observed the levels of occupancy, lighting and small power during a walk-through survey of a representative office space within each building.

The preliminary findings for this work have already been presented in a peer reviewed conference paper[4] and academic journal[5], as well as, a project web-page[6]. It is also understood by the author that part of the results from this aspect of the research is being considered for inclusion in the next revision of the *'Building Regulations, Part L2, The Conservation of Fuel and Power in Buildings Other than Dwellings.'*

6.2.1 Building Occupancy Survey Observations

The findings from the surveys are summarised in Table 6.2.1, which shows the type of office layout; the area of the representative space surveyed; number of people; type, quantity and assumed ratings of lighting; type and quantity of office equipment found in the sample space for each of the buildings surveyed.

Note that some equipment quantities are expressed as fractions which refer to shared equipment that also serves office areas outside the area surveyed, and has been apportioned by treated floor area.

Table 6.2.1: Summary of Survey Observations.

General		Occupancy	Lighting				Small Power					
Site Number	Sample Floor Area *(m^2)*	Number of People	Lighting Fixtures	Lamps per Fixture	Lamp Rating *(Watts)*	Other Lighting *(Total Watts)*	Desktop Computers	Laptop Computers	Printers	Photo Copiers	Fax Machines	Desk Fans
28	738	60	192	4	18	0	48	26	8	3	3	3
24	126	20	32	4	18	0	15	5	3	1	1	1
29	56	6	13	1	100	0	6	1	2	1	1	1
17	487	66	132	3	27	0	90	0	6	1	0	5
12	140	8	40	2	20	0	4	4	2	1	0	1
13	354	57	56	1	70	652	57	1	10	2	4	7
30	427	76	34	3	40	0	76	5	4	2	2	5
1	104	6	16	3	20	0	6	2	3	1	1	3
14	31	4	8	4	36	0	4	2	1	0	0	0
8	1195	178	112	2	36	738	178	50	3	3	3	1
10	56	4	12	4	18	0	4	0	1	0.25	0.25	1
23	765	42	120	2	36	2100	42	5	2	4	2	2
11	600	51	78	1	65	0	51	10	8	1	1	0
19	124	26	24	3	18	0	26	0	2	0.25	0	2
21	68	4	16	1	65	0	5	1	2	0	1	1
22	33	3	6	3	18	0	3	0	1	1	1	1
25	450	55	72	3	36	0	53	3	3	1	1	4
31	75	7	12	3	36	0	7	2	1	0.2	0.2	1
26	13	3	3	2	58	0	3	0	1	0	0	1
27	17	5	4	2	58	0	5	0	1	0	0	1
16	944	88	188	3	18	0	88	20	10	2	1	5
18	508	83	88	4	18	0	86	10	5	2	2	0
15	84	8	12	2	36	54	6	2	1	0.1	0.25	3
20	54	12	18	2	58	200	12	0	2	0.25	0.25	1
7	56	8	8	1	65	0	8	2	1	0.2	1	3
4	52	12	16	2	18	0	12	4	1	0.1	0.1	3
5	52	12	16	2	18	0	12	4	1	0.1	0.1	3
6	52	12	16	2	18	0	12	4	1	0.1	0.1	3
32	56	10	8	3	18	0	10	6	0.5	0.25	0.125	2
3	84	9	6	3	72	0	9	2	2	0.25	0.2	0

*Note: Sites 26, 27, & 28 are standard fit-out with different buildings with a single complex under the same ownership.

6.2.2 Calculated Internal Heat-gains

The calculated heat-gains for each site surveyed are summarised in Table 6.2.2, in terms of both heat-gains per unit floor area and heat-gains per person for the total and component internal loads. Maximum and minimum values are high-lighted, as well as average and standard deviation values shown for each of the calculated values.

The calculated total internal gains as shown in Table 6.2.2 averaged 44.9W/m^2 and ranged from 20.8W/m^2 to 86.1W/m^2 of treated floor area. Figure 6.2.1 shows the calculated total and component heat gains per unit floor area for each site, which are sorted from highest to lowest total internal gains per unit floor area.

Table 6.2.2: Calculated heat-gains for each site surveyed.

General		**Occupancy**		**Lighting**		**Small Power**		**Totals**	
Site	**Treated Floor Area** *(m^2 TFA)*	**Thermal Load** *(W / m^2 TFA)*	**People Density** *(m^2 TFA / person)*	**Lighting Load** *(W / m^2 TFA)*	**Lighting Load** *(W / person)*	**Total Small Power** *(W / m^2 TFA)*	**Total Small Power** *(W / person)*	**Space Gains** *(W / m^2 TFA)*	**Space Gains** *(W / Person)*
1	130	6.0	21.7	7.4	160	10.0	217	23.4	507
3	105	11.1	11.7	12.3	144	13.0	152	36.5	426
4	65	24.1	5.4	8.9	48	29.4	159	62.4	337
5	65	24.1	5.4	8.9	48	29.4	159	62.4	337
6	65	24.1	5.4	8.9	48	29.4	159	62.4	337
7	69	15.0	8.7	7.5	65	19.2	167	41.7	362
8	1494	15.5	8.4	8.7	73	17.4	146	41.6	350
10	70	7.5	17.4	12.4	216	9.3	163	29.2	509
11	750	8.8	14.7	6.8	99	10.0	148	25.6	377
12	175	6.0	21.8	9.2	200	**5.7**	**124**	**20.8**	454
13	443	16.7	7.8	10.3	80	19.3	150	46.4	360
14	39	13.5	9.6	29.9	**288**	16.4	158	59.8	576
15	105	9.9	13.1	8.7	115	9.9	130	28.6	375
16	1180	9.7	13.4	8.6	115	11.2	150	29.5	396
17	609	14.1	9.2	17.6	162	20.3	188	52.0	480
18	635	17.0	7.7	10.0	76	19.3	147	46.2	354
19	155	21.8	6.0	8.4	50	23.2	138	53.4	**318**
20	68	23.1	5.6	**33.9**	191	25.6	144	82.6	465
21	85	6.1	21.3	12.2	260	9.5	201	27.8	**591**
22	41	9.6	13.6	8.0	108	16.9	**229**	34.4	467
23	956	**5.7**	**22.8**	11.2	256	7.0	160	24.0	545
24	158	16.5	7.9	14.6	115	15.9	126	47.1	371
25	563	12.7	10.2	13.8	141	13.4	137	39.9	408
26	17	23.6	5.5	21.1	116	28.2	155	72.9	401
27	21	**30.4**	**4.3**	21.7	93	**34.0**	145	**86.1**	368
28	923	8.5	15.4	15.0	230	9.0	139	32.5	499
29	70	11.1	11.7	18.5	217	16.4	191	46.0	538
30	534	18.5	7.0	7.6	54	20.4	144	46.6	327
31	94	9.7	13.5	13.8	185	11.8	159	35.2	474
32	70	18.7	7.0	**6.2**	**43**	24.4	169	49.3	343
Average	***325***	***14.6***	***11.1***	***12.7***	***133***	***17.5***	***158***	***44.9***	***422***
Standard Deviation	***395***	***6.7***	***5.5***	***6.7***	***73***	***7.7***	***25***	***17.2***	***81***

**Note: Sites 26, 27, & 28 are standard fit-out with different buildings with a single complex under the same ownership.*

▨ MAX
MIN

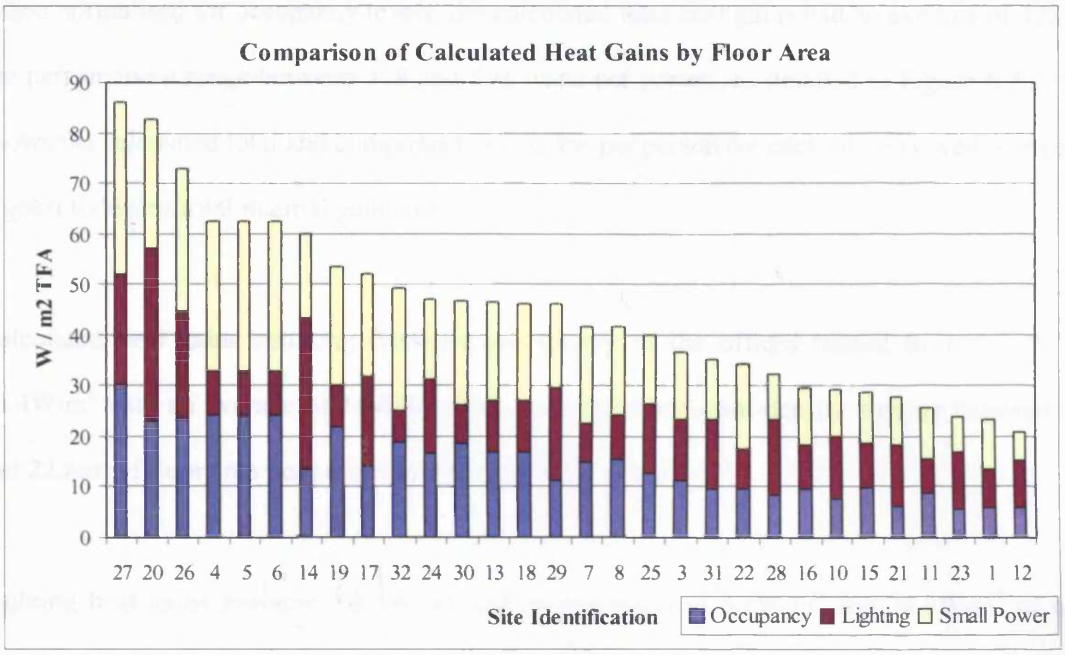

Figure 6.2.1: Comparison of calculated heat gains by floor area.

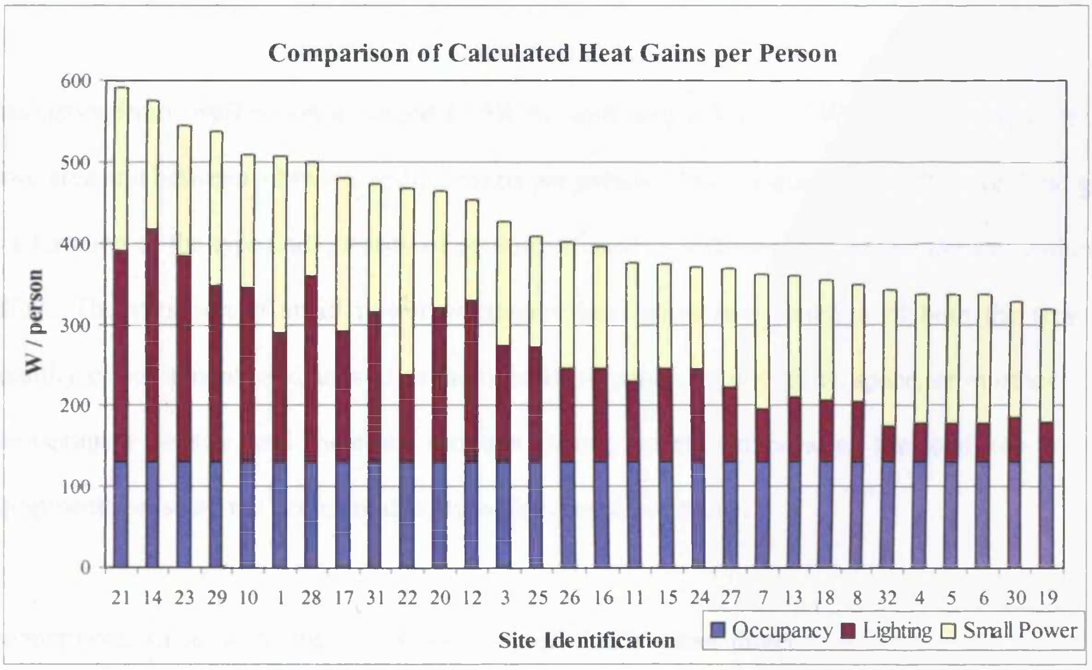

Figure 6.2.2: Comparison of calculated heat gains by occupancy.

When normalised for occupancy levels, the calculated total heat gains had an average of 422 watts per person and a range between 318 and 591 watts per person, as detailed in Figure 6.2.2, which shows the calculated total and component heat gains per person for each site surveyed, sorted from highest to lowest total internal gains per person.

Calculated heat gains resulting from the occupancy in the offices ranged from 5.7 W/m^2 to $30.4W/m^2$ with an average of 14.6 W/m^2 as a result of occupant density varying between $4.3m^2$ and $22.8m^2$ of floor area per person in the offices surveyed.

Lighting heat gains averaged $12.7W/m^2$ and ranged between $6.2W/m^2$ and $33.9W/m^2$ of treated floor area primarily based upon the type and quantity of light fittings utilised. Lighting heat gains per person averaged 133watts and ranged from 43 watts to 288watts per person, as a function of the type and quantity of lighting fittings used.

Heat gains from small power averaged $17.5W/m^2$, and ranged from 5.7 W/m^2 to $34W/m^2$ of treated floor area and between 124watts and 229watts per person. The variation of small power heat gains is a function of the type and quantity of equipment used as well as the occupant density within the office. The variation of small power equipment heat gains is a function of both the type and quantity of equipment used as well as the number of people in any given space, or in other words the occupant density, and therefore shows a strong correlation[i] between the total small power equipment loads and the occupant density within the office space.

Furthermore, since all of the component internal loads either directly, as with small power and occupancy, or indirectly, such as lighting which is a function of floor area, varies as a function of occupant density within the offices, the total internal gains should also vary as a function of occupant density, which has been graphed in Figure 6.2.3.

Figure 6.2.3 compares the variation of calculated total gains to the occupant density in terms of floor area per person and shows a correlation[ii] in which the total internal gains vary as a function of the occupant density. This relationship has been determined from the empirical data and is characterised by the equation; $Q_{Int}=224.97D^{-0.7334}$, where Q_{Int} is the total internal heat gains in *W/m² TFA* and D is the occupancy density in *m² TFA per person*. This relationship clearly indicates that the higher the density of occupants (i.e. the less the floor area per person), the higher the total internal gains within the office space. Clearly a number of similar lines could be drawn through the data, and more data would help to improve the accuracy of the equation produced. However, the data does show clearly that there is a strong correlation between the occupant density and internal heat gains.

When considering any of these values it is important to remember that, as with any 'design' calculation, these are based on 'worst-case' assumptions and therefore represent peak heat gains, implying that actual loads should be lower for the majority of the time.

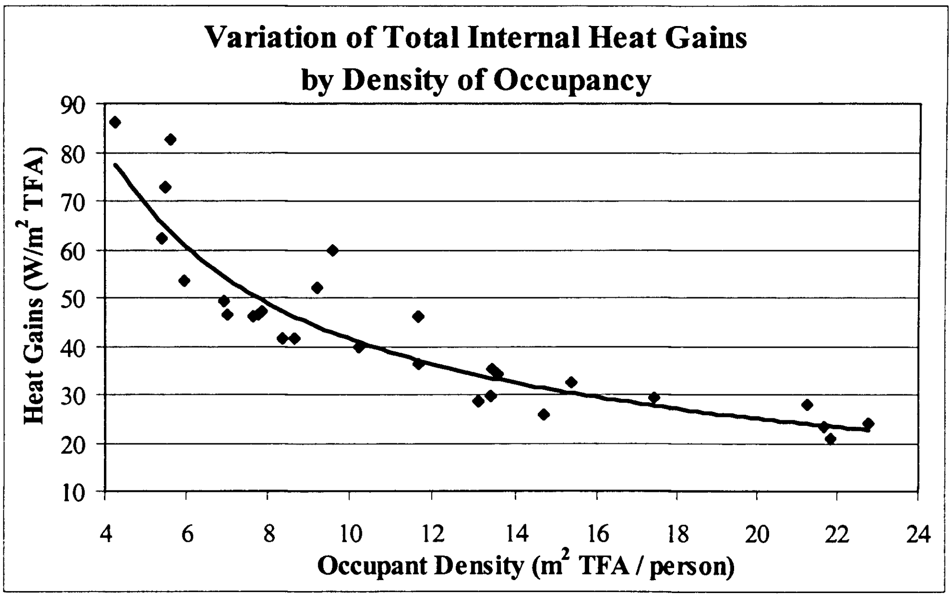

Figure 6.2.3: Variation of total internal gains with occupant density.

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[i] R^2=0.91
[ii] R^2=0.88

6.2.3 Variation of Internal Load by Generic System Type Studied

This section looks at the calculated total internal heat gains of the systems studied to determine if the different systems are serving substantially different cooling loads, since this could be one source contributing to the apparent differences in energy performance observed between the different generic types studied. Figure 6.2.4 show the range and mean calculated 'peak design' total internal heat-gains by generic air conditioning system type studied.

As Figure 6.2.4 shows there does indeed appear to be some differences in the internal heat-gains served by the different generic system types, and undoubtedly these differences in the cooling load served are at least in part leading to the differences in the observed energy consumption.

Overall the chilled ceiling systems and DX VRF/VRV system studied were serving a narrower range of loads, where as the DX split systems were serving the widest, but on average the chilled ceiling systems were serving the lowest loads at just over 30W/m^2 compared to the other generic system types which all had average internal load between 40 and 50W/m^2.

The single example unitary heat-pump in the sample of buildings studied had calculated internal heat-gains of 49W/m^2. Chapter 7 will take into account the different cooling loads served by using them to make an assessment of the efficiency of the systems studied.

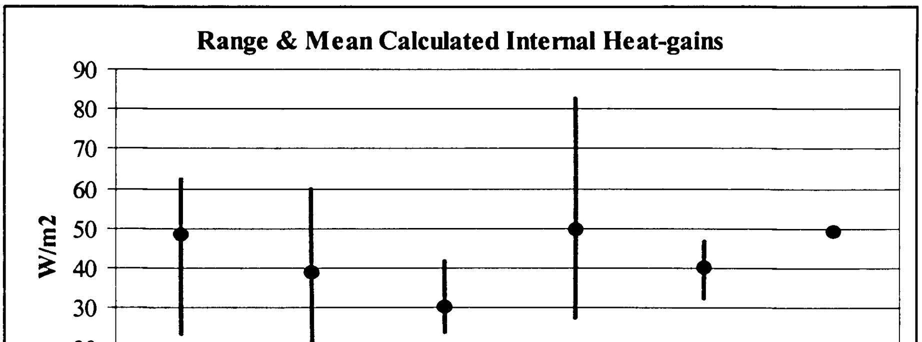

Figure 6.2.4: Variation of total internal gains by system type

6.2.4 Comparison to Current Design Standards

The analysis of the chiller part-load operation from the monitored data presented in Chapter 7 concluded that "the chiller plant of the system studied were over-sized for the load encountered over the monitoring period" which at least in theory is leading to reduced air conditioning energy efficiency, increased carbon emissions, and higher capital and running costs[3].

This appears to confirm what many building services professionals believe to be common practice in the UK building services industry. Undoubtedly some system over-sizing occurs when designers factor in 'safety margins', to provide standby capacity or to meet possible future building usage. However, it is also reasonable to assume that inappropriate design standards and load estimation methods could also be contributing to the over-sizing of building services plant by over-estimating the loads used to size air conditioning systems.

If this is the case we would expect current UK design guidance for heat gains within UK office buildings to be higher than the calculated peak design loads in the actual office buildings studied by this research. Therefore the current available design guidance reviewed in Section 2.3.4 have been summarised and compared to the calculated internal gains from the surveys undertaken in this study.

This comparison is shown in Table 6.2.3 and Figure 6.2.5, which shows the calculated internal heat gains from Table 6.2.2 and the composite range of design guidance values for each component heat gain. But note that no single source of design guidance could provide the comprehensive data for this comparison, the design guidance values shown in Table 6.2.3 are composite ranges of values derived from a number of sources including; the CIBSE Guides[3], Government Good Practice Guides[7], BSRIA Rules-of-Thumb[8] and a report from an energy monitoring study[9].

Table 6.2.3: Comparison of calculated internal gains to composite guidance values.

Load type	**Range of Calculated Values (W/m^2 TFA)**	**Range of Composite Guidance Values (W/m^2 TFA)**
	(Min. & Max.)	*(Min. & Max.)*
Occupancy	6 to 30	20
Lighting	6 to 34	8 to 32
Small Power	6 to 34	7 to 45
Total Internal Gains	**21 to 86**	**37 to 90**

The guidance values compare favourably to the calculated values in terms of the maximum calculated heat gains, which are comparable with the upper end of the guidance range of values. However, even considering the wide ranges of expected values from the guidance, all the sites surveyed in this study had calculated heat-gains below the maximum predicted by the guidance. Indicating that the use of the upper limit design guidance from the current standards, which would appear inevitable considering the wide range of guidance values without means to narrow the range, would lead to the over-estimation of heat gains in ALL the offices studied,

Similarly, the available guidance and rules-of-thumb regarding occupancy levels compare well with the information from the 30 buildings surveyed in this study. According to the guidance, office occupancy levels are expected to be between $8m^2$ and $16m^2$ of floor space per person[7] in typical offices and down to around $4.5m^2$ per person in 'clerical' offices[8]. The actual surveyed occupancy levels ranged between $4.3m^2$ and $22.8m^2$ per person. Furthermore, standard benchmark values for typical and good practice lighting and small power loads from Econ19 for Type3 standard air-conditioned offices[10] all fall within the min and max range of the loads calculated for the buildings studied.

However, as shown in Figure 6.3.1, the current guidance does not correlate as well when considering the minimum expected peak internal gains. The calculated gains for 12 of the 30 sites, or 40% of the sites surveyed in this study fell below the minimum guidance range.

Therefore, although current guidance and rules-of-thumb available to the industry broadly matches the overall range of calculated occupancy, lighting and small power heat gains based on the surveys undertaken in this study, 40% of the sites had calculated heat-gains below the minimum guidance values indicating that the current guidance would lead to the significant over estimation of heat-gains at least 40% of the time. Therefore, the 'worst-case' calculations mean that current guidance is overestimating the actual internal heat-gains between 5% and more than 320%. But this is further exacerbated by the fact that the calculated internal heat-gains assumed worst case-power demand and no factors for the diversity of loads normally encountered in modern offices, meaning that most of the time the actual loads within the offices studied would be even lower than the 'peak design' loads indicated in the calculations.

It is only at the higher densities, i.e. less than 5m^2/person, that the current guidance appears to be accurate and then it appears that the minimum figure is too low. Therefore, a more selective method of benchmarking internal heats-gains would be beneficial, a method that more accurately accounts for the minimum peak gains and provides a narrower range of possible values for a given site.

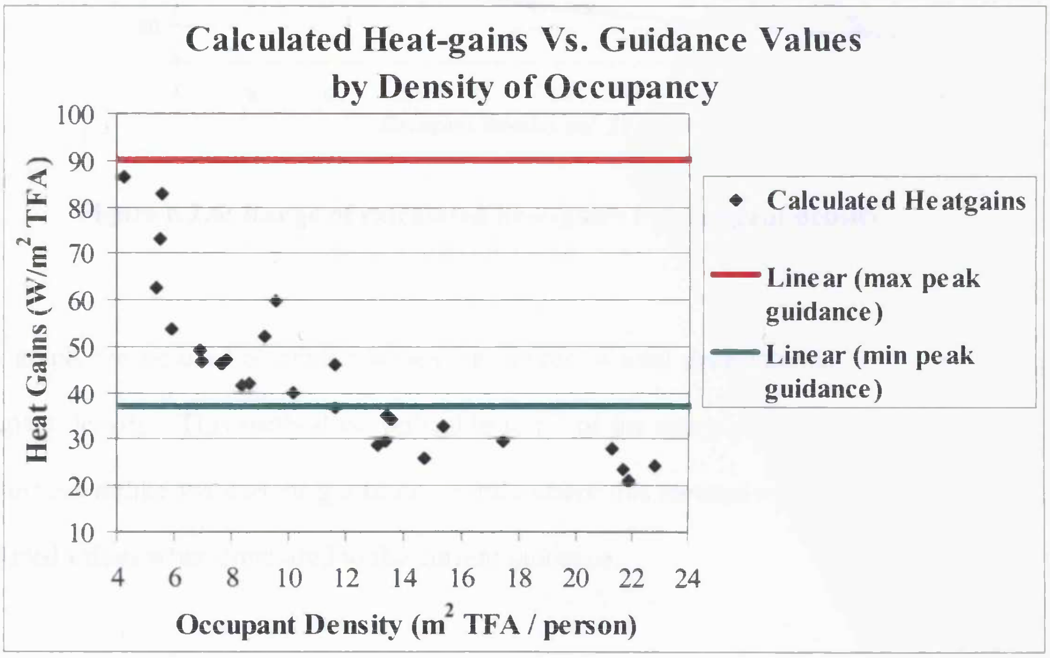

Figure 6.2.5: Comparison of calculated internal gains to composite guidance values.

6.2.5 An Improved Internal Heat-gain Estimation Method

Based upon the results of this study, such a method of benchmarking internal heat-gains could be based on the relationship to occupant density, instead of the traditional benchmarks based on floor area. A similar strategy has been suggested in the good practice guidance[7] relating to small power loads. If the relationship between occupant density and heat gains in the buildings surveyed in this study holds true for the building stock as a whole, it could be the basis for a more sensible method of benchmarking internal heat gains in UK office buildings.

Figure 6.2.6, shows the calculated heat gain values in each of the 30 sites surveyed in this study, as well as indicative maximum and minimum values shown in relation to occupant density.

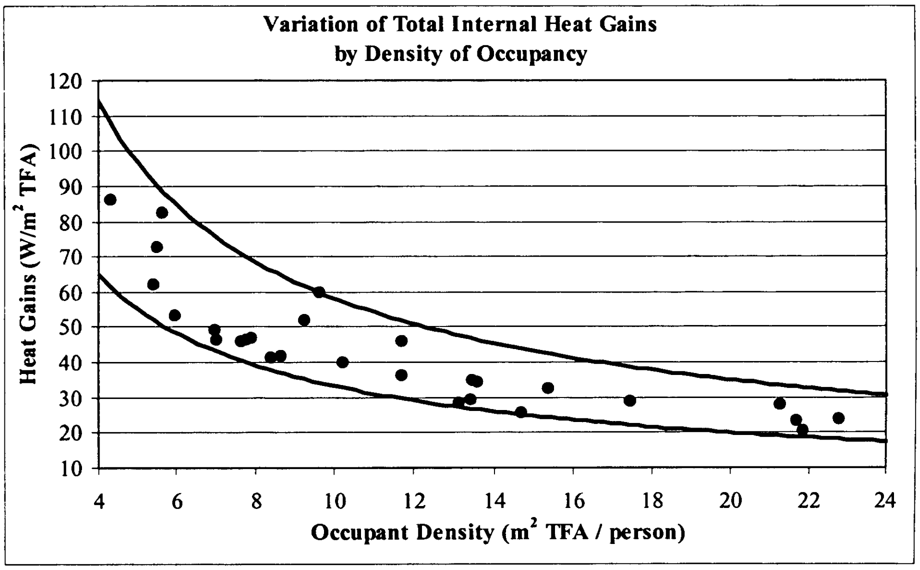

Figure 6.2.6: Range of calculated heat-gains by occupant density.

This graph can be used to predict indicative ranges of total peak internal heat gains based upon occupant density. This method is applicable to all of the occupant densities encountered during the surveys unlike the current guidance. Furthermore this method results in a narrower range of predicted values when compared to the current guidance.

For example, assuming an occupant density of 10m^2 per person, this method predicts expected total peak internal heat gains of 33W/m^2 to 56W/m^2. At an occupant density of 20m^2 per person this method predicts expected total peak internal heat gains of 20W/m^2 to 35W/m^2. At these occupant densities, existing upper and lower internal heat gain guidance limits of 37W/m^2 and 90W/m^2 would over-estimate the gains by 61% and 157% respectively.

It is important to note that the use of this suggested method of estimating internal heat-gains is intended to improve the estimation of rules-of-thumb assessment only and should not be used as a substitute for 'full' design calculations or modelling techiques utilising the diversity factors in the sizing of building services plant.

6.3 IMPLICATIONS OF THE ASSESSMENT OF LOADS SERVED

Although it is clear that rules-of-thumb should not be used as a substitute for 'full' design calculations in the sizing of building services plant, we acknowledge that rules-of-thumb are often used in the industry, even if only to check that calculated or modelled values are reasonable. The results from this study suggest that the current guidance available to the industry is leading to significant over-estimation of internal heat gains actually encountered.

But the biggest problem with the current guidance values is their wide overall range with no way of narrowing this range without detailed knowledge of the particular installation, information which may not be available to building services designers, particularly on speculative developments. This inevitably means the upper worst case values are assumed, in which case the current guidance values would lead to the over-estimation of small power equipment loads by at least 24% and, in the worst case 650 % based on the surveys conducted.

The overestimation of small power equipment loads in the design of building services affects air conditioning systems by requiring them to operate at very low loads for much of the year. This leads to increased running costs and reduced thermal comfort, as well as increased capital costs resulting from the over-sizing of plant components[3].

A more appropriate benchmarking method such as suggested in Section 6.3.1 would be beneficial to help avoid the over sizing of building services that is evidently common practice based on the results from the field monitoring undertaken by this research, shown in Chapter 5, and should aid the design of lower energy consuming buildings.

The impact of the loads served by the systems studied here has yet to be assessed, but there are differences in the internal heat-gains served by the different generic system types, and undoubtedly these differences in the cooling load are leading to some of the differences in the observed energy consumption presented in Chapter 5. But to fully take into account the differences in cooling load served, these loads are used to make an assessment of the efficiency of the systems studied in Chapter 7.

6.3.1 Consideration of Fabric, Solar and Ventilation Loads

This research has not been able to assess the other components of the total cooling loads including the fabric, solar loads, and ventilation loads but it is expected that these loads to be of a similar order of magnitude to the internals gains and therefore as important to determining the energy performance and efficiency of the air conditioning systems studied.

However, we can speculate on what these other component loads might be using standard guidance. Section 2.3.4 concluded that the peak fabric, solar and ventilation gains will amount to between 50W/m^2 and 88W/m^2 taken over the whole treated floor area of an office building. In which case based on the range of calculated values discussed in this chapter and the derived guidance values for the fabric, solar and ventilation components the total cooling loads on the system studied would be between 71W/m^{2}TFA and 174W/m^{2}TFA.

6.4 ASSESSMENT OF COOLING EFFICIENCY

This section discusses the results of the energy consumption monitoring, normalised for the internal heat gains in each treated space served by each system, in terms of the air conditioning efficiency for each of the air conditioning systems studied as described in Section 3.4. This assessment therefore allows a first indication to be gained of the relative efficiencies of the generic system types. This will enable us to determine more clearly whether the apparent differences observed in the energy consumption and energy demand profiles were to do with the loads served or the system efficiency.

The method used by this research to establish the relative energy efficiency of each of the air conditioning systems studied is based on the normal expression of efficiency used for building services, the co-efficient of performance (COP), but calculated using the measured energy consumption obtained from the monitoring work presented in Chapter 5 and the calculated cooling loads served presented in Chapter 6.

However, since the fabric, solar and ventilation loads placed on the systems over the monitoring period were not accurately determined, because resources were not available to the project to undertake the thermal modelling of these loads, these loads cannot be included in this efficiency assessment. Therefore, the efficiency calculation used to normalise the measured energy consumption obtained from the monitoring for the different loads served has been modified to only consider the internal components of system load. To fully apply these results with full confidence it is important that these results are further developed to include the fabric and solar loads served and a method to do this has been suggested in the future research section presented in Chapter 9.

In order to avoid confusion with other expressions of efficiency, the modified expression of efficiency used in this thesis will be referred to as the 'Internal Load Performance Ratio' (ILPR) and is defined in Section 3.4.1 and below by the following equation for any given period of time:

$$\text{ILPR} = \frac{\text{calculated internal load (W/m}^2\text{)}}{\text{power input to the AC system (W/m}^2\text{)}}$$

Furthermore, the calculated internal heat-gains assessed in Chapter 6 are 'peak' values and therefore only applicable to periods of peak cooling demand and not the whole monitoring period. Therefore energy consumption data from the peak summer weekday periods has been used from Section 5.4.2 to calculate the ILPR for each system studied, since this data covers a period of time when we know the systems were serving peak cooling loads.

The preliminary findings from this ILPR assessment of air conditioning cooling efficiency have already been presented at a number of peer reviewed conferences'[11,12] and further publicised though trade journals'[13,14] and the project web-page[15].

6.4.1 Calculated Air Condition System Efficiency

This section presents the results of the ILPR analysis for the systems studied. These results use the measured peak summer energy demand profiles and calculated peak internal loads for each building studied to assess their relative efficiency. The analysis has been carried out based on data obtained for July weekdays from 9am to 5pm averaged over both 2001 and 2002 for each site where data was available for both years for each 15 minute interval of data recorded.

The ILPR analysis for each generic system type studied are shown Figures 6.4.1 to 6.4.6, showing the average system ILPR and range of ILPR values indicated by the average plus and minus the standard deviation.

Note that the particularly high ILPR of some systems during the early morning or late afternoon seen in a number of the above figures is simply the result of some of the sample systems turning off early or on-late during the working day.

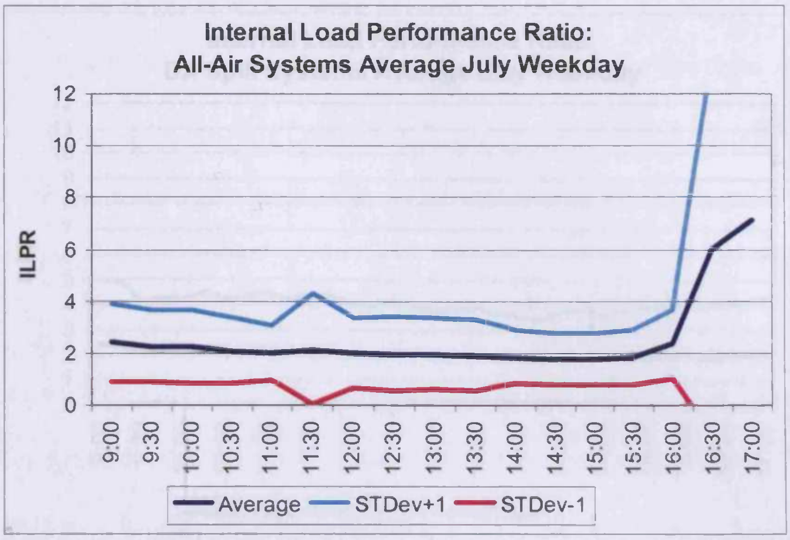

Figure 6.4.1: All-Air systems - Average and range of calculated ILPR efficiency ratings.

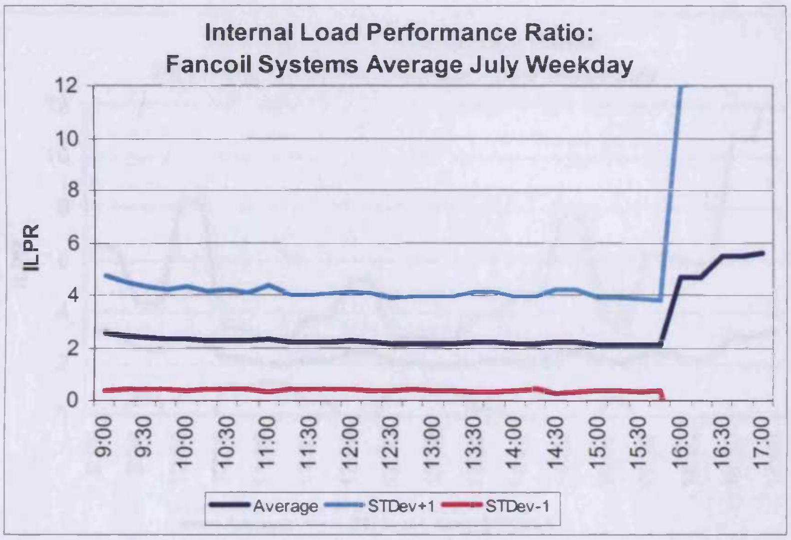

Figure 6.4.2: Fancoil System - Average and range of calculated ILPR efficiency ratings.

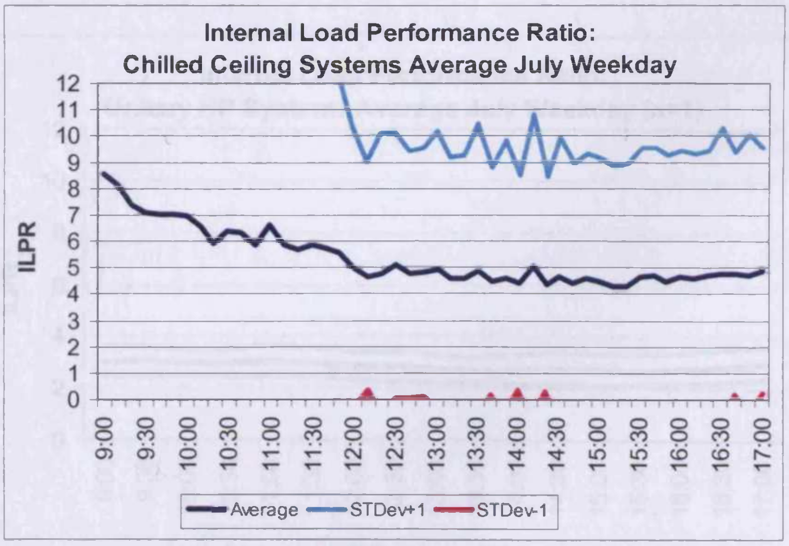

Figure 6.4.3: Chilled ceiling systems - Average and range of calculated ILPR efficiency ratings.

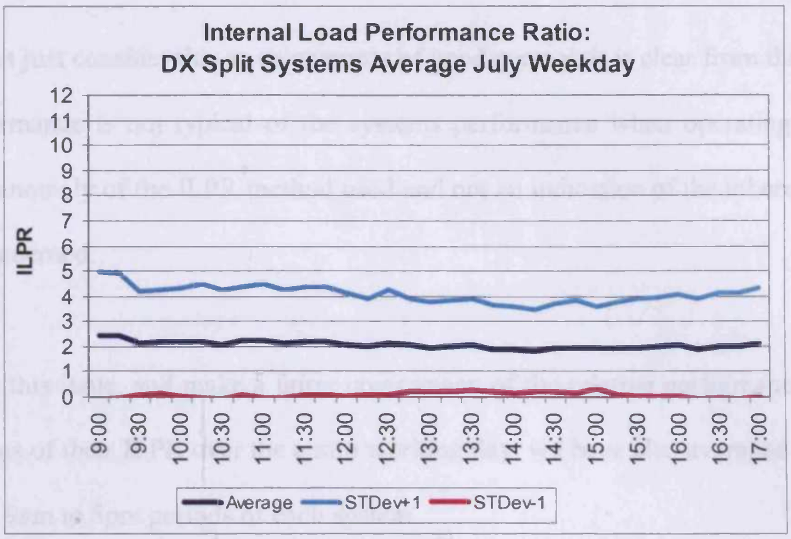

Figure 6.4.4: DX split systems - Average and range of calculated ILPR efficiency ratings.

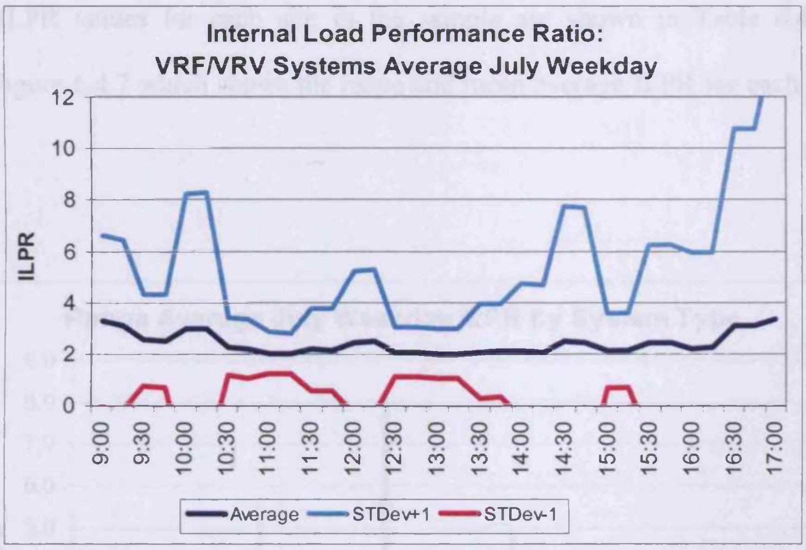

Figure 6.4.5: DX VRF / VRV systems - Average and range of calculated ILPR efficiency ratings.

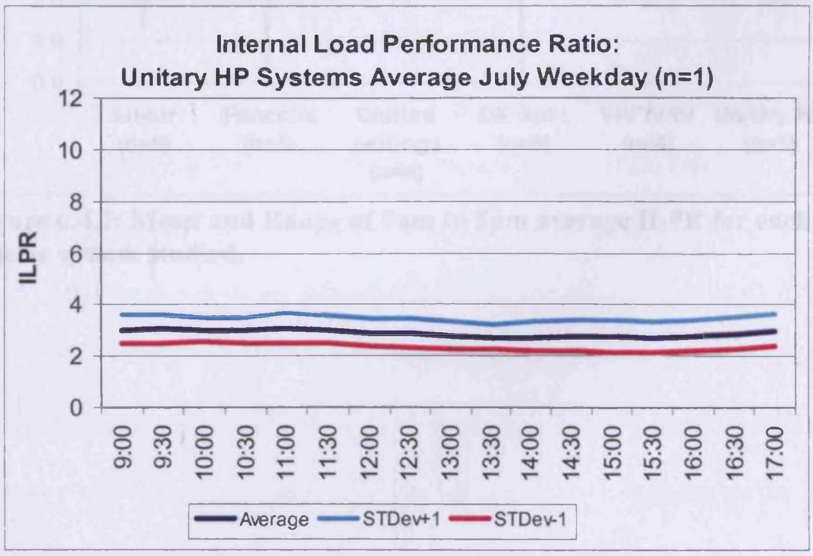

Figure 6.4.6: Unitary Heat Pump - Average and range of calculated ILPR efficiency ratings (Note n=1).

While we might just consider this as an example of good control, it is clear from the rest of the day that this performance is not typical of the systems performance when operating and should be considered an anomaly of the ILPR method used and not an indication of the inherent efficiency of the systems concerned.

To circumvent this issue, and make a fairer comparison of the relative performance of the studied systems in terms of their ILPR over the entire working day, we have also averaged the ILPR rating over the entire 9am to 5pm periods of each system.

The average ILPR values for each site in the sample are shown in Table 6.4.1 and further illustrated in Figure 6.4.7 which shows the range and mean average ILPR for each generic system type studied.

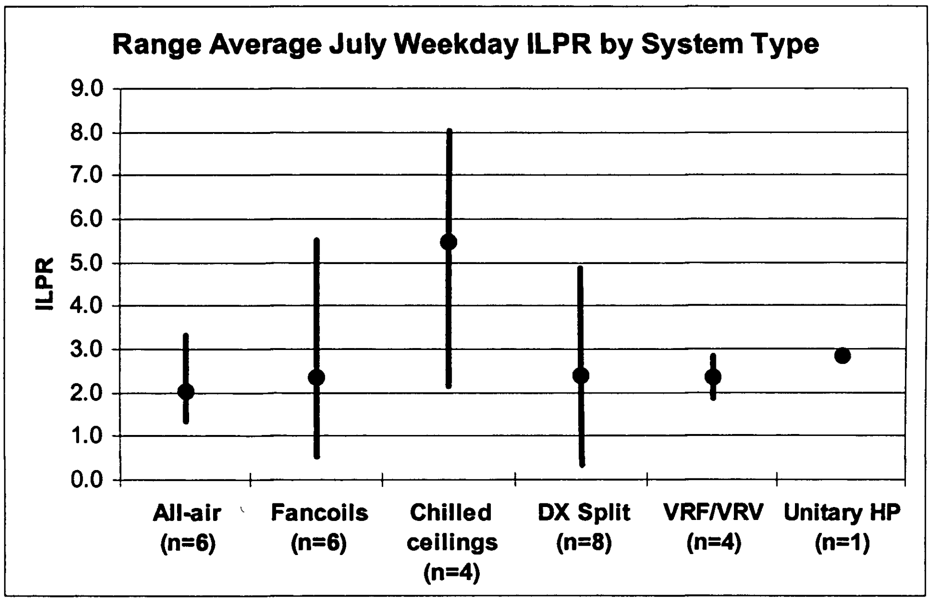

Figure 6.4.7: Mean and Range of 9am to 5pm average ILPR for each generic system studied.

Table 6.4.1: Average July weekday ILPR value by site studied.

Site Number - System Type	**Average Summer Weekday ILPR** *(9am to 5pm, July 2001 & 2002)*
Site 1 - All-Air	1.3
Site 3 - All-Air	3.3
Site 4 - All-Air	1.5
Site 5 - All-Air	2.6
Site 6 - All-Air	1.9
Site 7 - All-Air	1.4
Site 8 - Chilled Ceiling	8.0
Site 10 - Chilled Ceiling	6.4
Site 11 - Chilled Ceiling	5.4
Site 12 - Fancoils	0.5
Site 13 - Fancoils	2.1
Site 14 - Fancoils	5.5
Site 15 - Fancoils	3.3
Site 16 - Fancoils	0.6
Site 17 – DX Split	3.2
Site 18 – DX Split	4.7
Site 20 – DX Split	4.9
Site 21 – DX Split	1.1
Site 22 – DX Split	1.3
Site 32 - Unitary HP	2.8
Site 23 - Chilled Ceiling	2.1
Site 24 - Fancoils	2.0
Site 25 – DX Split	1.4
Site 26 – DX Split	0.3
Site 27 – DX Split	2.3
Site 28 – VRF HR	1.8
Site 29 – VRF HR	2.8
Site 30 – VRF HR	2.8
Site 31 – VRF HR	1.9

The ILPR system cooling efficiency profiles shown in Figures 6.4.1 to 6.4.6 appear to indicate that the Chilled ceilings are the most energy efficient systems, with the average ILPR typically ranging between 4 and 8 over the 9am to 5 pm weekday period. On average the chilled ceiling ILPR over this period was 5.5, compared to all the other generic system types studied which on average typically had ILPR's of between 2.0 and 2.4. Therefore the All-air systems, Fan coil systems, DX split systems appear to perform similarly in meeting the calculated loads and all provide relatively low cooling energy efficiency compared to the chilled ceiling system based on the ILPR analysis.

This in one respect contradicts the initial findings of this analysis previously published in 2002[11], that was based on only the first years data and a slightly reduced sample size, and concluded that the DX VRF/VRV were clearly the second best performer based on the ILPR definition of performance with an average ILPR of just over 3. However once all the data from the entire sample of 32 buildings and both the 2001 and 2002 summers were included this was no longer the case, as the DX VRF/VRV had an overall ILPR efficiency of 2.4 on average.

However, the average system performance does not tell the whole story as shown by the differences in the range of system efficiencies in Figure 6.4.7, which indicate that although, overall, the chilled ceiling systems studied appear more efficient than the other generic types, since the ranges of ILPR overlap, it is clear that individual systems of the other generic types are capable of being very efficient. In particular the performance of the most efficient Fancoil and DX split systems was at efficiencies approaching the average chilled ceiling system efficiency. Conversely the performance of the least efficient chilled ceiling system, Site 24, was only as efficient as the average non-chilled ceiling system, although part of this is because it is an active chilled ceiling system providing additional ventilation services and potentially able to meet higher cooling loads[16].

Note that according to the ILPR analysis the single example of unitary heat-pump studied had a indicative cooling system efficiency ILPR of 2.9 on average, which lies within the ILPR range of all of the system types studied as illustrated in Figure 6.4.7, and therefore it is not possible to determine the relative performance of unitary heat-pumps as a whole, other than to say that the one example system studied performed slightly better than the average of all the systems (ILPR 2.7 on average).

6.4.2 Impact of Plant Sizing on Calculated System Efficiency

The discussion of the measured part-load profiles and sizing of the air conditioning systems studied in Chapter 5 concluded that the systems studied were oversized for the loads actually encountered by the systems over the monitoring period, but also that the balance of evidence would suggest that the over-sizing of chiller plant leads to reduced energy efficiency and hence increased running costs and carbon emissions as well as capital and maintenance costs. This is corroborated by further detailed field monitoring work[17] and the TAS modelling study discussed in Chapter 2[18].

However due to the complexity of the issues, and lack of firm performance data on the actual systems studied, it is not possible to estimate the potential savings from more appropriate plant sizing. But, if the systems studied were substantially oversized and this does in fact lead to substantially reduced energy efficiency, as is believed, it is reasonable to expect that the effect of sizing would be evident in the ILPR efficiency calculated in the above section, where systems with higher installed capacities per m^2 might be expected to have lower calculated ILPR efficiency ratios. Figure 6.4.8 shows this comparison, and graphs the calculated ILPR for each site studied, from Table 6.4.1, plotted against the total installed chiller capacity/m^2 of treated floor area for each air conditioning system from Table 5.4.2.

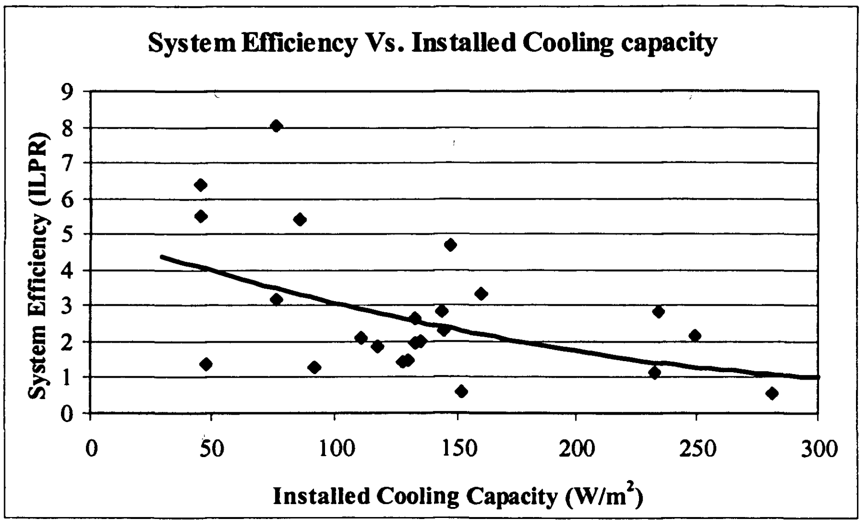

Figure 6.4.8: Variation of system efficiency (ILPR) vs. total installed chiller capacity.

The figure data includes all the systems studied, including the chilled ceilings which we know to be inherently more efficient in terms of ILPR. Some of the systems were also operating multiple chillers in sequence so the lack of a close overall correlation between ILPR efficiency and the installed chiller capacity shown in Figure 6.4.8 is not un-expected, as we know a certain amount of variation will be due to other variables and a number of different relationships could be imposed on the data shown.

However the graph does indicate that in general the systems with higher total installed chiller capacities had lower calculated ILPR cooling efficiency, especially the systems with installed chiller capacities above 125W/m^2 which would normally be considered potentially over-sized for UK office accommodation based on current rule-of-thumb guidance[8].

Significantly, this implies that over-sizing of chiller plant does in practice result in reduced air conditioning energy efficiency, and hence increased running costs and carbon emissions. It is difficult to assess the actual extent of efficiency reduction from a certain amount of chiller over-sizing using the ILPR method because the sizing issue cannot be isolated from all other variables and the fabric and solar loads have not been accounted for yet (see Chapter 9).

With all these provisos we can still obtain a rough estimate from Figure 6.4.8 of the effect of chiller over-sizing on efficiency. Assuming 125W/m^2 as an appropriate chiller capacity for UK offices[8] the typical system studied would have an ILPR of about 2.5, but if the chillers had twice the capacity required, i.e. 250W/m^2 (as concluded in Chapter 5), based on the above graph the ILPR would drop to about 1.3, which is about a 50% drop in the ILPR system cooling efficiency.

This is a potentially highly significant result, and further endeavours should be made to explore this area further (see Chapter 9).

6.5 IMPLICATIONS OF THE CALCULATED SYSTEM EFFICIENCIES

The internal load performance ratio (ILPR) analysis presented in this chapter compared the peak cooling efficiency of the systems studied normalised for the internal loads served in the buildings, and has shown that the chilled ceilings systems appear to be more efficient in delivery comfort cooling in UK offices than the other generic system types studied.

This implies the exceptionally low recorded overall energy consumptions of the chilled ceiling ceilings systems studied, which included sites that appeared to benefit from better control leading to reduced annual run-hours and possibly lower cooling loads than many of the other systems, were indeed inherently more energy and carbon efficient than the other systems studied. This confirms the expected superior performance of chilled ceiling systems from the review of existing information discussed in Chapter 2.

In addition the combination of efficiency, design and operational issues may explain why the annual energy consumption of the monitored chilled ceiling systems was even better in practice than had been predicted, since not only does the evidence suggest that the chilled ceilings are more efficient, but the individual chilled ceiling sites studied also appear to have been more efficiently operated as well.

Overall these results do not clearly show the relative efficiency ranking of the other non-chilled ceiling system types, as on average they performed similarly to one another. In theory the Direct Expansion (DX) based systems, i.e. Splits and VRF, were expected to be the second most efficient system types, but this is not borne out in the monitored results. However, individual non-chilled ceiling systems, including examples of fancoil and DX split systems, did have ILPR efficiencies approaching the performance of the chilled ceiling systems.

The ILPR analysis also reinforces the importance of appropriate chiller sizing to achieve maximum air conditioning energy efficiency. Although difficult to estimate with certainty, the evidence suggests that over-sizing of chiller plant by 100%, as appears to be common practice compared to the actual load encountered, reduced the cooling efficiency of the air conditioning systems studied by as much as 50%. Therefore it is of particular importance that further research is undertaken to determine the extent of potential energy and carbon savings possible through more appropriate chiller sizing, as well as the need to set part-load design and testing criteria appropriate to UK climatic conditions.

As previously mentioned this research has not considered the effect of the Fabric, Solar and Ventilation components of the total cooling load on the energy performance of the system studied. Therefore further research to determine the actual cooling loads including all the component loads, from fabric and solar etc, would be very beneficial to the application of the results of this research.

It is also important to note that the ILPR values are relatively high compared to the seasonal efficiency values discussed in Chapter 2, and these values will only increase once the fabric and solar loads are added. However, this is because the ILPR method is looking at peak cooling loads not seasonal, and is also exacerbated by the 'design' calculation methods used, which may over-estimate actual internal loads encountered in practice as suggested in Chapter 6. This highlights a further benefit of the proposed further development of this research using the method proposed in Section 9.3, since it will be able to assess loads served throughout the year and therefore will provide seasonal efficiency data, and not peak cooling efficiency as considered here.

Overall these results imply that the provision of cooling in UK Office buildings can be undertaken far more efficiently than generally occurs at present, by combining the selection of highly efficient air conditioning systems such as chilled ceilings with also designing and operating in an energy efficient manner. The potential for reduction in current air conditioning energy consumption, and hence carbon emissions and operating costs in the majority of UK Offices would appear to be comfortably over 50% compared to current practice. Significantly this means that the air conditioning portion of the Government's goal to reduce carbon emissions by 60% overall can be achieved using existing air conditioning technology.

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Chapter 7: Projected Future AC Carbon Emissions

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7.0 FUTURE CARBON EMISSIONS

The underlying theme and motivating factor behind this research was to explore the potential of existing air conditioning technology to resolve the dilemma of our increasing expectations for thermal comfort in buildings and the need to reduce carbon emissions at the same time to help mitigate the effects of climate change.

The findings of the field monitoring and efficiency analysis (Chapters 5 & 6) have shown that, based on the performance of the thirty-two buildings studied, there appears to be substantial scope to reduce current air conditioning energy consumption, and hence carbon emissions in the majority of UK offices buildings. This reduction could comfortably be over 50% compared to current practice by combining highly efficient systems with improved building design and operation focused on low carbon cooling solutions. This might be accomplished using existing air conditioning technology.

However, this result although extremely promising does not necessarily mean that the improved used of air conditioning systems alone can reduce carbon emissions resulting from UK building services by the estimated[1] 50% required for the UK Government's target of a 60% reduction in overall emissions of greenhouse gases by 2050[2] to be achieved. Since, the emissions from air conditioning are also effected by the electricity generation and transmission emission from the national grid, and because the UK air conditioning market is projected to grow substantially with more buildings becoming air conditioned[3], such changes could easily more than offset the potential emissions saved from improved air conditioning use.

In general solutions to reduce carbon emissions in buildings will probably have to address both energy supply and demand side issues. The energy supply side is likely to involve cleaner energy generation and delivery, as well as the increased use of renewable energy systems. However it is likely that the UK National Grid would only support a certain proportion of renewable energy[1] and potentially much of the reduction in carbon emissions achieved through increased use of renewable energy resources could be offset by a reduced use of nuclear energy[1]. A substantial proportion of the required carbon emissions reduction will therefore have to be met through demand side management. This requires greatly reducing the carbon emissions from our buildings.

Therefore this chapter addresses the specific issue of carbon emissions resulting from the use of air conditioning, and explores a 'business as usual' scenario, as well a number of alternative scenarios, for carbon emissions associated with air conditioning use taking into account the predicted market growth[4], the current market share of the different air conditioning system types[7] and National Grid emissions rates[4] to determine the potential for reducing carbon emissions using existing air conditioning technology.

7.0.1 The UK Air Conditioning Market

The energy consumption and associated carbon emissions resulting from air conditioning system use in the UK currently represents around 5% of the total carbon emissions from non-domestic buildings[5]. However, only 10% of commercial floor space is currently air conditioned so the potential for growth is considerable[3].

Market trends, including greater expectations of thermal comfort in the workplace, improved air quality and worker productivity demands, as well as increased competition resulting in reduced unit prices, are all driving growth of the UK air conditioning sector[6] and therefore increases in associated energy use and carbon emissions.

Market forecasts[6, 7] suggest that this growth could increase the annual carbon emissions resulting from UK air conditioning to 1.33 MtC per annum by the year 2020, up from 0.72 MtC in 2000, based on business as usual projections of current market conditions.

The underlying reason for this growth is the increased use of air conditioning as more buildings become air conditioned including retro-fit applications as illustrated in Figure 7.1.1, which shows the projected growth in UK building floor area which is air conditioned.

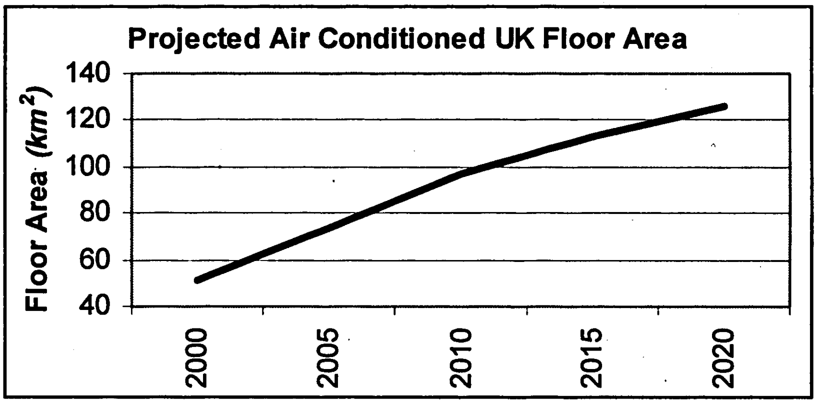

Figure 7.1.1: Projected growth of air conditioning use in the UK.

Significantly the expected reduction of emissions per unit of electricity from the increased use of cleaner energy generation, renewable energy sources and more efficient distribution is likely to be more than offset by the substantial projected growth in air conditioning use, resulting in the net increase of energy use and emissions noted above.

7.0.2 Carbon Emissions from UK Air Conditioning

The total carbon emissions by generic air conditioning system type in the UK have been estimated from:

- Annual cooling energy system consumption by generic A/C system type as installed and operated in UK Offices drawn from the monitored field monitored performance of the cooling-only systems from Chapter 5.
- Current proportion that each of the generic A/C system types occupies as a percentage of the total UK market[7].
- Total air conditioned floor area in the UK[5].
- Carbon emissions per unit of electricity[4].

The data used for the market proportion by generic system type[7] does not have any specific data for chilled ceilings and unitary heat pumps, so it is assumed that these systems made up 1% and 0.5% of the overall market respectively in 2000.

Furthermore, the annual cooling energy consumption of the DXVRF/VRV systems was based on the performance of the 2-pipe VRF DX multi-split systems (Sites 17, 19, & 20) and not of the 3-pipe heating and cooling systems since the energy used for only cooling could not be separated from that used for heating.

Based on these assumptions the total UK carbon emissions resulting from air conditioning energy consumption was estimated to be 0.53 MtC in 2000.

Using forecasts of the growth of air conditioning use up to 2020[5] and the projected carbon emissions per unit of electricity in the UK over the same period[5] then, assuming the breakdown of the market by system type remains the same and a 'business as usual' market (Scenario 1), this method predicts that by 2020 UK air conditioning systems will emit 0.91 MtC annually (Figure 7.2.1). This is an increase in carbon emissions of 72% from the year 2000.

To see how this growth in emissions might be reduced we will consider two alternative scenarios. Scenario 2: Assume that all new air conditioning systems installed from 2005 onwards are of equivalent efficiency to the most efficient system type currently available.

Figure 8.2.1 shows that this scenario would reduce emissions growth such that the total emissions in 2020 would now be 0.62 MtC. This is equivalent to a 29% annual saving over the business as usual Scenario 1, but still results in a 22% growth in emissions compared to 2000 levels.

Scenario 3: Assumes that in addition to all new systems being of equal efficiency to the most efficient systems currently available (Scenario 2) we also progressively replace all existing air conditioning installations, such that they have all been replaced by 2020. Under this scenario the annual carbon emissions for UK air conditioning is reduced by 58% below 2000 levels to 0.22 MtC annually. This is a 76% saving on emissions compared to Scenario 1.

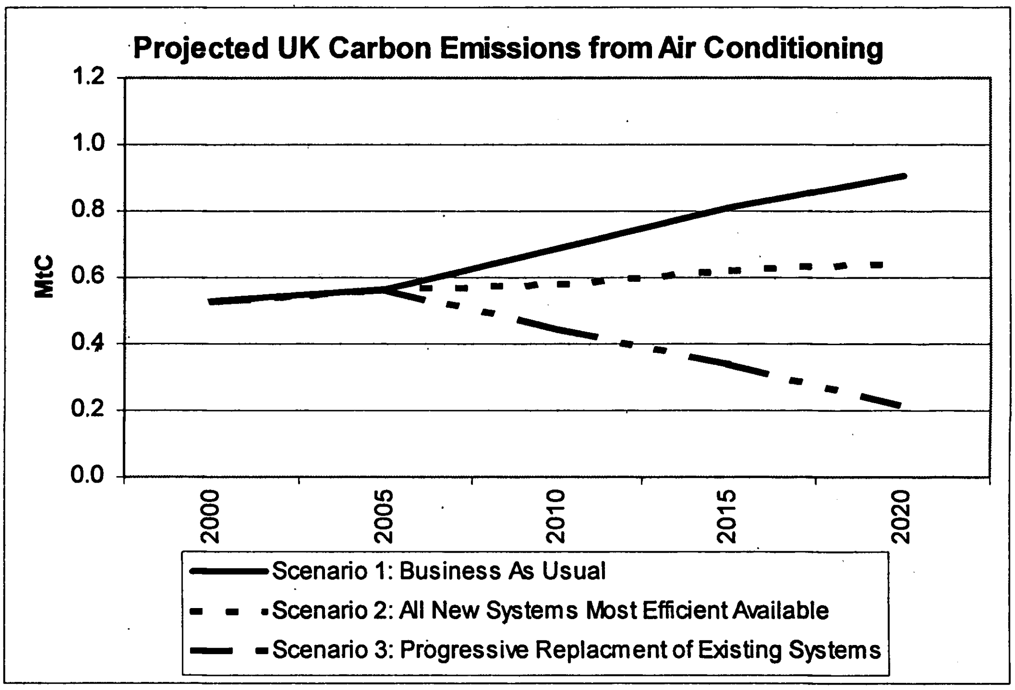

Figure 7.2.1: Predicted UK air conditioning carbon emissions 2000 to 2020.

These three simplified scenarios clearly demonstrate the importance of addressing the energy efficiency of existing systems as well as future A/C system installations if we are to reduce the greenhouse gas emissions from air conditioning our buildings.

What is important to note is that if the rate of air-conditioning installation continues to grow beyond 2020 then, even assuming Scenario 3 is achieved; at some point overall carbon emissions from air conditioning systems will start to rise again. This may prevent air conditioning systems playing their role in achieving the UK's target of a stated 60% reduction in carbon emissions[8]. This implies that the carbon intensity of the energy supply mix and the amount of air conditioning systems installed in buildings are still likely to be important factors.

7.1 FUTURE AIR CONDITIONING EMISSIONS IMPLICATIONS

The findings from this section have significant implications for legislation that addresses carbon emissions and building services. The following are the main points that have been concluded from this analysis:

- Business as usual market projections indicate that UK A/C related carbon emissions will increase by 72% by 2020 from year 2000 levels.
- Increasing the efficiency levels of all current and future A/C systems to those of the most efficient, by year 2000 standards, would potentially reduce UK A/C carbon emissions by 58% from year 2000 levels by 2020. This is a reduction of 76% from the 'business as usual' forecast for 2020.

Significantly this means that in principle existing air conditioning technology has the potential to significantly reduce the carbon emissions associated with its use, and therefore enable the increasing demands for thermal comfort in our buildings by business and occupant alike, to be met by mechanical means using existing technology.

But assuming air conditioning systems have a proportionate part to play in reducing building carbon emissions and that there are no major changes in the forecast electricity generation mix, it would appear based on the above analysis for the UK to meet its 2050 target carbon emissions targets for air conditioning systems, ALL air conditioning systems must perform at least as well as the current best systems, currently chilled ceiling systems, as well as ensuring that all systems are properly sized and controlled to maximise the potential savings from the operational side.

However, if the current growth of the UK air conditioning market continues beyond year 2020, the UK will almost certainly also have to address the issues of market growth and the carbon intensity of the electricity supply to reach the stated emissions reduction targets for the year 2050.

For manufacturers and designers of air conditioning systems, these results imply that legislation will in future require air conditioning systems to meet given energy performance specifications, eventually leading to the phasing out of the less efficient system types. It will also place an increased emphasis on the operations and maintenance aspects of building operation to ensure carbon emission reductions are actually achieved in practice – and the EU Energy Performance of Buildings Directive specifically addresses AC systems[9]. This is likely to require operators to publicly account for the energy used and the carbon emissions of organisations, along with potentially revised emission based taxation systems and certainly an effort to increase the awareness and skills of building professionals across all trades to work towards reduced emissions.

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Chapter 8: Research Conclusions

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8.0 RESEARCH CONCLUSIONS

This chapter presents the overall conclusions from this research, drawing together the findings from each aspect of the work presented in the previous chapters. It discusses the actual performance of the air conditioning systems studied over the monitoring period and the implications of their performance to the wider UK building services industry and future regulatory controls regarding the provision of comfort cooling, energy-use and carbon emissions in the UK context. To conclude, the thesis addresses issues that require further investigation.

8.1 RESEARCH OBJECTIVES

The underlying motivation to carry out this research was to explore the potential of existing air conditioning technology to meet the conflicting demands of our society's increasing expectations for thermal comfort in buildings, and hence increasing demand for air conditioning, without compromising Government commitments to reduce greenhouse gas emissions in order to tackle the potential threat of climate change.

The European Energy Performance of Buildings Directive (EPBD), the promise of Emissions Trading Schemes (ETS) and fears about the security of energy supply are all strong drivers that mean industry and Government are already tackling the need to reduce green-house gas emissions, and hence the way we use energy in our buildings. These drivers all have a common theme in a building context; they all place a much greater emphasis on designing low carbon emission buildings and services, in order to help mitigate the effects of climate change.

Air conditioning has been marked out for particular scrutiny by current and forthcoming legislation due to its perceived high energy consumption, and hence carbon emissions associated with its use. Emissions which are rising as more buildings become air conditioned[1]. Increased demand for air conditioning is apparently being driven by greater expectations of thermal comfort, perceived productivity benefits to business and air quality issues[2], but this demand combined with the relatively low current market penetration levels mean that the potential growth in carbon emissions from air conditioning could threaten Government targets and commitments to international treaties to reduce green-house gas emissions[3].

However at the outset of this research there was very little information on how much energy air conditioning systems actually consume when used in the real world, or which factors have the most significant influence on the energy performance in practice, once the influence of real world building operation is brought to the design, operation and maintenance of air conditioning systems.

This research undertook an independent field study that monitored the energy consumption of thirty-two air conditioning systems in real office buildings throughout the UK, monitoring their energy performance, and hence carbon emissions required to provide comfort cooling.

This monitoring was typically undertaken at 15-minute intervals over a three-year period and studied a number of examples of all-air, fancoil, chilled ceiling, DX split, and DX variable refrigerant flow systems. In addition the performance of unitary heat-pump type systems were considered, but the sample only consisted of a single example system.

The monitoring aimed to answer the following major questions regarding the energy performance of air conditioning systems in UK office buildings:

- How Carbon efficient are current air conditioning systems in providing comfort cooling in real buildings?
- Are some air conditioning systems inherently more carbon efficient than others when used in real buildings?
- By how much is it possible to improve the average carbon performance of AC systems in UK Offices using currently available air conditioning technology?

8.2 OVERVIEW OF THE RESEARCH FINDINGS

The average weekday daily energy consumption profiles taken over the consecutive summers of 2001 and 2002 for each of the generic system types studied, proved to be relatively consistent between the systems studied, with all systems showing an early morning start up load and a peak afternoon load. But the Chilled Ceiling based systems, and to a lesser extent the cooling-only DX split systems, typically consumed substantially less energy to deliver comfort cooling than the other generic system types studied. As illustrated in Figure 8.1.1.

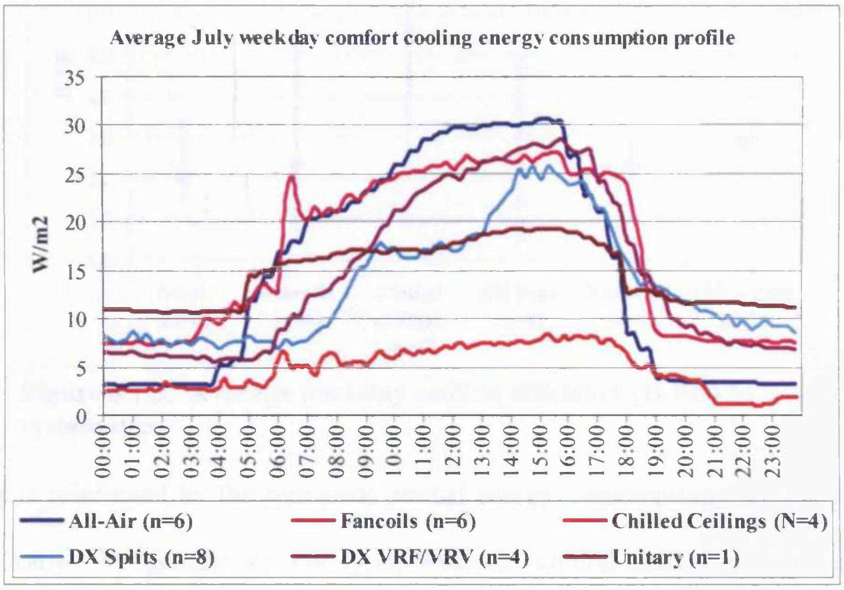

Figure 8.1.1. Average weekday cooling energy consumption profiles by system type.

It is important to note that ALL of the generic types of air conditioning studied appear capable of meeting current UK 'good practice' energy consumption standards for cooling on an individual basis and that the study also showed that the underlying reasons behind the relatively high energy consumption of 'air conditioned' buildings are not inherently due to the use of air conditioning systems alone.

Work was undertaken to normalise this consumption for the internal heat gains encountered per unit of floor area in the offices monitored. The result is a dimensionless term of energy efficiency referred to as the Internal Load Performance Ratio (ILPR) in order to avoid confusion with other expressions of efficiency. The ILPR analysis clearly showed that the Chilled Ceiling based systems still consumed less than half the energy per unit floor area of the other generic system types studied once any differences in internal was accounted. As illustrated in Figure 8.1.2.

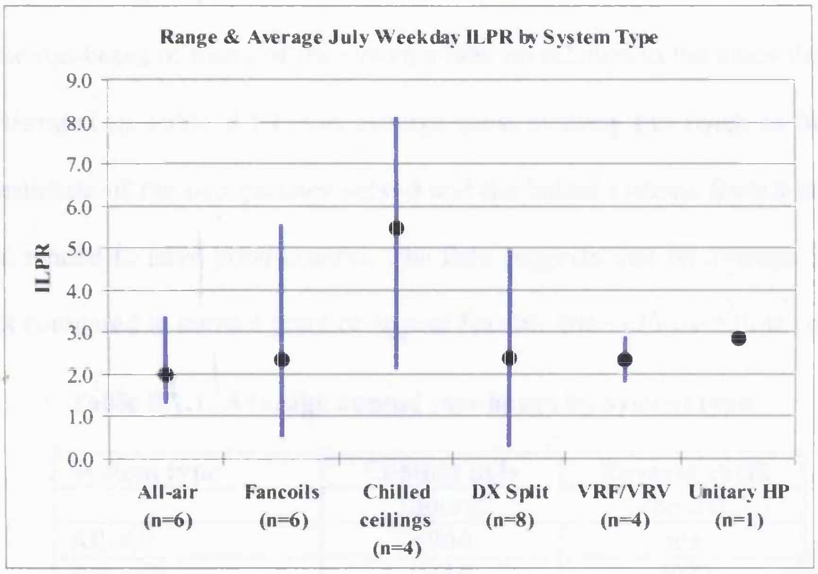

Figure 8.1.2. Average weekday cooling efficiency (ILPR) by system type.

This finding is reinforced by the measured annual energy consumptions for the systems tested which also varied by generic system type, with the chilled ceiling systems also typically consuming less energy overall than the other system types.

But there is still one area that is unaccounted by the analysis undertaken thus far and this is the effect of fabric and solar gains on the load imposed on each system. The information needed to assess these loads was collected during this research but the time and resources required was not available to complete the analysis, but the methods required to complete this aspect have been developed and are discussed in Chapter 9.

However, it is the author's belief that even accounting for the fabric and solar loads, the Chilled Ceiling systems will still hold a clear efficiency advantage over the other systems studied. This belief is supported by modelling results of air conditioning seasonal energy performance by other researchers[4] and the theoretical performance of the systems in principle from the review carried out in Chapter 2.

One of the other important findings from the study is that control of the systems in practice was patchy; typically showing response to internal loads, as well as seasonal and daily variation in climate. But the run-hours of many of the systems bore no relation to the times they were actually needed, as illustrated in Table 8.1.1. On average most systems ran twice as long as the most conservative estimate of the occupancies served and the better systems from a carbon emissions viewpoint also tended to have good control. The data suggests that on average 50% energy and carbon savings compared to current practice appear feasible from effective time control alone.

Table 8.1.1. Average annual run-hours by system type.

System type	Cooling only (hours)	Reverse cycle (hours)
All-Air	4904	n/a
Fancoils	4686	7073
Chilled ceilings	3180	5308
DX Split	6560	4136
DX VRF	n/a	6960
All	4919	5848

Analysis of the part-load chiller energy consumption profiles also revealed that virtually all the systems were oversized for the loads they actually encountered in practice. An example part-load frequency chart is shown in Figure 8.1.3.

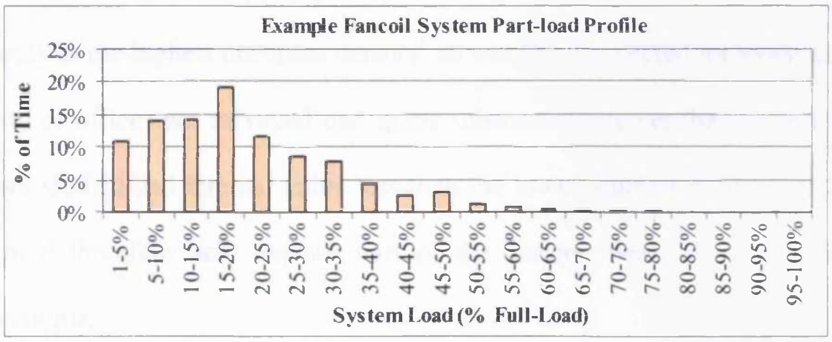

Figure 8.1.3. Example measured part-load frequency profile.

Typically the systems had at least twice the peak capacity required during the study, since few of the systems ran for any length of time at more than half their rated maximum output, indicating that not only were these systems over-sized but over-sizing would appear to be common practice. Even the lowest energy consuming Chilled Ceiling systems were not immune from this problem which leads to reduced system efficiency as well as increased capital and running costs[5].

Significantly the efficiency of the systems studied in practice appeared to be influenced by the sizing of the chiller plant, where systems with large installed chiller capacity compared to the cooling load tended to be less efficient. However, further work is required to establish by how much this over-sizing affects the efficiency and costs of the air conditioning systems. One possible conclusion for the reasons behind the common over-sizing might be that current load estimation and plant sizing methods are over-estimating the actual cooling loads found in practice within UK Offices. However, comparison of the installed chiller capacities to rule-of-thumb guidance revealed that the guidance values did not indicate the substantial over-sizing that the monitoring had shown.

This finding is widely accepted as being correct within the industry, and the reasons for it are not difficult to find. One of the more important reasons in the offices studied appears to be the use of inappropriate design standards for internal heat gains. Comparison of the internal heat gains encountered in the offices studied to good practice guidance indicated that current guidance figures only apply at the highest occupant density[6] as would be expected for worst-case situations, but the majority of offices we surveyed had gains substantially lower than these figures. Indeed 40% of the sites studied had internal gains less than the lowest current guidance estimates. This observation could therefore help explain part of the current over-sizing occurring in the air conditioning systems.

However it was also clear that the performance of many of the systems, particularly the packaged systems, suffered due to an apparent lack of basic design, as many of the systems were over-sized beyond that attributable to just conservative calculation methods and often also without the ability for modulation between multiple chiller units.

Based on the results of the load analysis carried out during this research to normalise the measured energy consumption, a more accurate method to estimate internal heat gains has been suggested that uses occupant density rather than floor area. Although the suggested improved method should not be used in lieu of full design methods it can be used instead of rule-of-thumb data to narrow the estimated possible range of internal heat-gains with only minimal extra information. The relationship on which this method is based is illustrated in Figure 8.1.4 and the author has been advised that this method is currently being considered by the Building Regulations Advisory Committee (BRAC) for inclusion in future revisions to *'Part L, Conservation of Fuel and Power,'* of the Building Regulations for England and Wales.

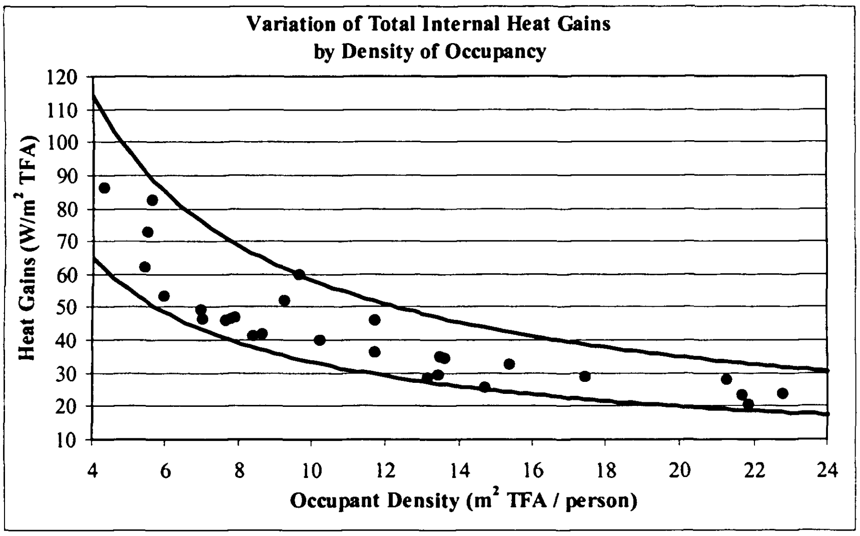

Figure 8.1.4: Range of calculated heat-gains by occupant density.

Overall the results imply that the provision of cooling in UK Office buildings can be undertaken far more efficiently than generally occurs at present, by combining the selection of highly efficient air conditioning systems such as chilled ceilings while also ensuring building design and operation is undertaken in an energy efficient manner.

Specifically the findings of the field monitoring study show:

- Chilled ceiling and beam systems appear to be the most efficient way of providing cooling in UK Offices where appropriate.
- Most systems appear to be poorly controlled, and that 50% savings appear feasible from effective time control alone.
- Most systems appear to be sized to be twice as large as required by the loads actually encountered, which lead to reduced energy efficiency in the systems studied, so further savings are therefore possible from improved system sizing.
- Current design guidance appears to be over-estimating the loads actually encountered in UK offices and therefore contributing to the over-sizing of air conditioning systems in the UK. An improved method of internal heat gains estimation based on occupancy has been presented as a result of this study.

Therefore the potential for reduction in current air conditioning energy consumption, and hence carbon emissions in the typical UK Offices would appear to be comfortably over 50% compared to current practice and these savings can be achieved through the better application of existing air conditioning technology and design methods.

8.3 OVERVIEW OF THE IMPLICATIONS TO CARBON EMISSIONS

The implications from the study findings for future Carbon emissions from UK air conditioning is shown in Figure 8.1.5 which shows the predicted UK carbon emission from air conditioning up to the year 2020 using expected UK market growth[7] and electricity carbon intensity estimates[8]. Three possible scenarios are presented:

- Scenario 1: Business as usual, which assumes no major change to the way we currently use air conditioning.

- Scenario 2: Assumes all new air conditioning systems from 2005 onwards are as efficient as the most efficient systems currently available based on their measured performance obtained by this research.
- Scenario 3: Assumes all air conditioning systems, both new and existing, are progressively replaced with the most efficient currently available by the year 2020.

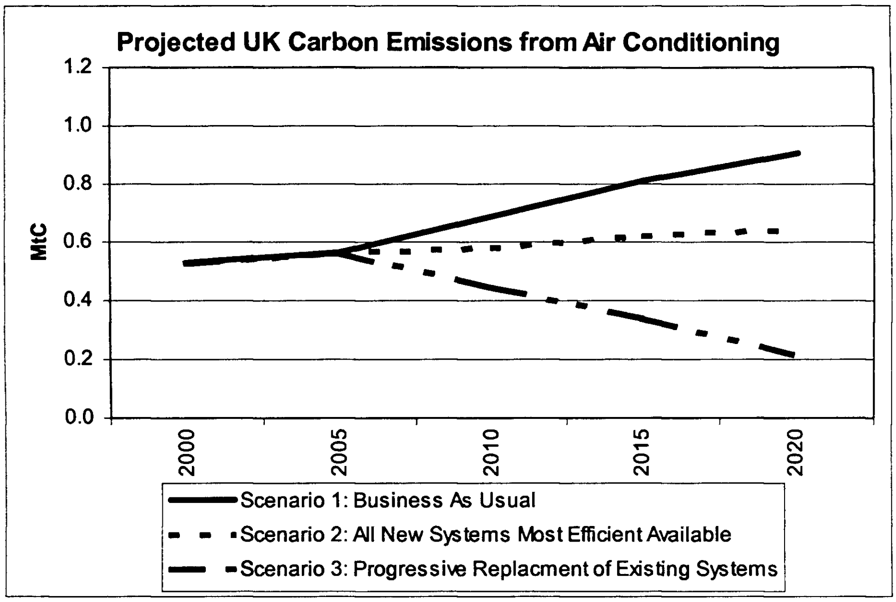

Figure 8.1.5: Predicted UK air conditioning carbon emissions 2000 to 2020.

From Scenario 3 it is clear that, if all air conditioning systems were able to perform to the level of the current best performers, i.e. chilled ceiling type systems, then the carbon emissions resulting from the use of air conditioning in the UK could be reduced by 58% from 2000 levels, despite the projected increased use of air conditioning systems, by the year 2020. However, if the air conditioning market growth continues beyond 2020 then further improvements in air conditioning technology, legislative restrictions on the use of air conditioning, or improving the carbon efficiency of electricity generation may be required to maintain the carbon emissions at this level.

Overall this research shows that air conditioning systems used in UK Offices show the possibility for substantial improvements in system carbon emissions performance, and that these improvements can feasibly lead to the future UK Government carbon emission targets, of a 60%

reduction by 2050, being met using existing air conditioning technology available on the UK market today. But if current emissions reduction targets are to be achieved the carbon efficiency of the existing building stock must be urgently improved, since improving only new installations will not result in the savings required.

8.4 FINAL THOUGHTS

The findings of this research regarding the energy performance and current practices surrounding the use of air conditioning in UK offices may not be particularly surprising to many building services professionals since the results confirm what many people working in this field already suspect, with the possible exception of the exceptional performance of the chilled ceiling systems which performed better than expected.

However, the author believes the significance of this research lies in the empirical approach used to collect the data, i.e. that the results reflect actual practice 'as found' in UK market. The author hopes that, by providing insight into the actual performance of air conditioning in the UK, this research will increase the confidence of those required to make decisions to improve the energy performance of buildings, by enabling them to base their decisions on the performance of real buildings and not just relying on speculation and theoretical models.

Importantly this research has shown that the conflicting demands for increased thermal comfort by building occupants and the need to substantially reduce carbon emissions from our buildings can be achieved using existing air conditioning technology, even when considering the predicted large growth in the UK air conditioning market, so long as all future air conditioning systems are as efficient as the most efficient air conditioning systems currently available.

However, the often substantial difference between the 'design' and 'actual' energy performance of buildings highlights the importance of not considering buildings and their services in isolation during their design and operation. The onus is therefore on the designers to provide systems which are potentially the most efficient for a given application through performance focused design practices that integrate the design of the systems and buildings. But also places an increased emphasis on facilities management to operate buildings so that they achieve their 'design potential' and actually lead to reduce energy consumption and carbon emissions from our buildings. This is particularly important in regards to the existing building stock, which make up the majority of buildings at any given time, for which the potential possible carbon emissions savings are inevitably limited by the existing building fabric, even when retrofitted with new efficient systems.

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Chapter 9: Further Research

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9.0 FURTHER RESEARCH

This work has already highlighted the superior energy performance of chilled ceiling systems, the relevance of current government energy and carbon benchmarks, as well as, the prevalence of plant over-sizing in the UK building services industry. It has also suggested an improved heat gain estimation method all of which have contributed to the body of knowledge in this field and started to answer some of the difficult questions required to develop and promote low carbon buildings on the UK.

However, the opportunity exists to further develop this research in order to definitively answer the question of which AC system types are the most efficient in practice and determine the relative impact of individual aspects of building and AC system design on the overall energy and carbon performance. The overall aim being to enable real improvements to the energy and carbon performance of buildings by providing the evidence required to fully capitalise on the carbon savings possible in integrated building and system design, maintenance and operation. Such information could also be used to more effectively target and apply various regulatory initiatives aiming to promote energy efficiency including statutory inspections, energy audits and certification.

9.1 FURTHER RESEARCH ALREADY UNDERWAY

Some of this further development and application of the results from this research have already been undertaken by the author in conjunction with other researchers including:

- A detailed air conditioning energy performance monitoring study which studied in detail the energy efficiency of four AC systems[1], an overview is provided in Section 9.1.1.
- Exploration and validation of theories regarding the application of cooling degree-day analysis techniques in the UK, the results of which were published in 2003[2], which has help under-pin an upcoming CIBSE technical memorandum on Cooling Degree Days.

- Representative annual consumption figures for heating, cooling and auxiliary energy use from this research were used to underpin the proposed CEN standards and national calculation method for estimating AC energy consumption[3] as part of the implementation of the Energy Performance in Buildings Directive.
- Further work is also underway to holistically assess the energy performance of the buildings studied by this research by taking into account analysis of heating and cooling loads within the buildings studied, an overview is provided in Section 9.3.2 below. This development is also supporting a European funded collaborative project[4] aiming to promote good practice in air conditioning energy audits and inspection.

9.1.1 A Detailed AC Energy Performance Monitoring Study

This section presents an overview of the detailed field monitoring study, which determined the energy efficiency of three fancoil and a single packaged direct expansion (DX) air conditioning (A/C) systems 'in-use' within actual UK office buildings. The method employed and findings of this research have been peer reviewed and presented to a European conference on energy efficiency[5] and published in an international periodical[1].

The method employed determined the in-use efficiency of each system through the measurement of both their electrical energy consumption and their thermal cooling output. The work considered the efficiency of the whole system including all equipment loads associated with the delivery of cooling to the occupied space and not just the chiller and refrigeration aspects. This enabled direct comparison of the energy efficiency of the different DX and fancoil systems studied. In addition it provided detailed profiles of system energy consumption, cooling output and the frequency that various cooling loads were encountered, as well as the breakdown of energy consumption by sub-system component for the non-packaged systems.

The field monitoring measured the in-use efficiency of three liquid chillers with fancoil systems and a packaged split direct expansion system between May 2002 and July 2003. These results are compared with estimates derived from comprehensive building and system simulations. Although not commonplace, such simulations are easier to carry out than field measurements but, of course, represent simplified situations. The simulations cover a wider range of systems than have been monitored and so help to place the results in a wider context.

The monitored energy efficiency of the fancoil and DX split systems showed that refrigeration energy efficiency varies with outdoor temperature and the load placed on the system. Logically the outdoor temperature and the system load are inter-related (but not perfectly correlated) and therefore must be considered together when assessing the actual operational efficiency of refrigeration plant and air-conditioning systems.

This relationship between system load and ambient temperature that affects the refrigeration efficiency resulted in the optimum energy efficiency in the systems studied occurring at ambient temperatures of between 20 to 25°C. At outdoor temperatures higher than optimum, the efficiency drops even though system loads are generally higher, presumably due to the increased temperature lift required of the refrigeration cycle. Similarly, at lower outdoor temperatures the system efficiency also drops, as system loads are generally much lower resulting in reduced system efficiency, as the constant energy demands of the system such as fans, pumps and controls become proportionally higher compared to the total energy consumption of the whole system.

The measured energy efficiency of the refrigeration cycles in all four systems studied was broadly in line with their rated efficiencies. The water cooled chiller in System 2 had the most efficient refrigeration cycle as expected, but the effect of this higher efficiency on the overall system efficiency was lost due to very high ancillary energy consumption per capacity.

Comparison of the measured energy efficiency of each system shows that the DX system was generally more efficient over the monitoring period than the three fancoil systems', once energy used by the entire system including fancoils, pumps and reheat was considered. Based on typical operating efficiencies weighted by average system load, the DX split system was around 40% more efficient than the fancoil systems.

The energy performance of the DX system was further improved by effective local controls including time clocks and easy occupant interfaces, contributing to not only higher efficiency while running but also in significantly lower annual energy consumption through reduced operational time.

This monitoring has also reinforced the importance of appropriate plant sizing and its effect on energy efficiency, since a clear relationship between system load and energy efficiency was observed in all of the systems studied and two of the four systems had at least twice the cooling capacity they required, i.e. never operating above 40-50% of their full load.

It is not possible to assess the improvement in energy efficiency that could occur were the chillers sized more appropriately, as we are unable to say what effect control issues were having on the energy performance without further investigation.

Since the measured energy performance of the systems studied here were in-line with the seasonal efficiencies predicted through building simulation, greater confidence can be assigned to such simulation results in the future and assuming these simulation results actually represent the performance of other the system types, it also suggests that the generic chilled ceiling and direct expansion (DX) system types offer significant energy efficiency advantages over other system types.

It is suggested that further investigation is undertaken to determine the actual in-use efficiency of the other system types including all-air, chilled ceiling and VRF/VRV systems, as well as the energy performance implications of control issues including the use of electric reheat batteries and plant system sizing. Once this information has been obtained, informed decisions can be made about choice of system type, controls and sizing for given situations. From the data shown here and the larger energy consumption study, the potential energy savings are very significant.

9.1.2 Assessing the Influence of Fabric and Solar Loads

To refine the conclusions from the analysis already undertaken in this thesis, the next stage of the study is to thermally model the monitored buildings to establish the solar and building fabric loads experienced by the AC systems.

By combining the empirical field energy consumption data, thermal building modelling, and actual weather data this research will be able to assess the integrated energy performance and AC efficiency of each building and system, taking into account the heating and cooling loads served, occupancy and management regimes, as well as the efficiency of each AC system in practice.

The primary output of this research will be an "in-practice system cooling efficiency ratio" (SERIn-pract) calculated from the measured cooling system energy consumption and modelling of the loads served within the occupied buildings over the monitoring period. This method for calculating the AC system efficiency in practice is illustrated in Figure 9.2.1.

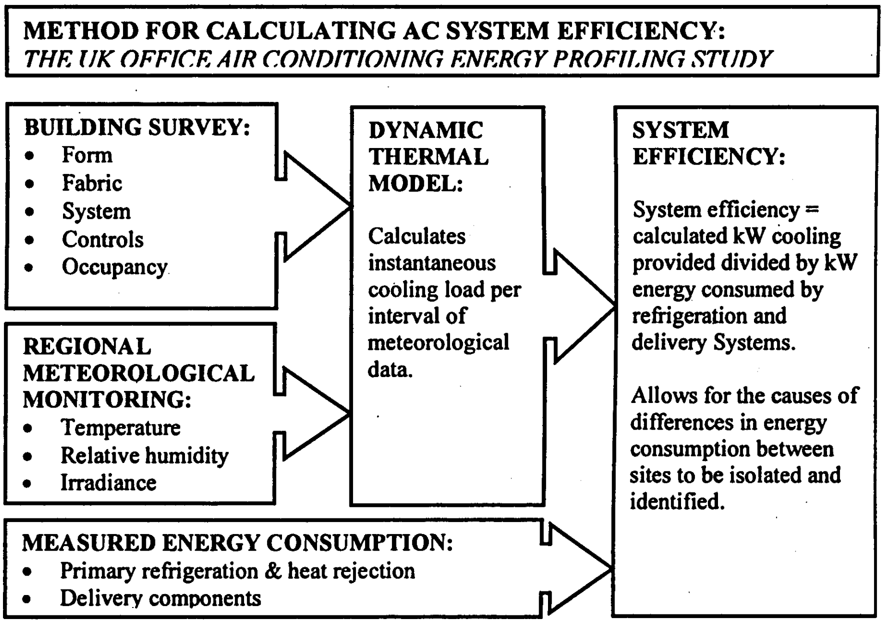

Figure 9.1.1. Method for calculating AC system efficiency.

Where:

- The System Energy Consumption is the measured energy consumption of the entire system including all the sub-systems involved with servicing the system load obtained from the field monitoring already undertaken.
- The System Load is the total load served by the system including the internal heat-gains calculated from occupancy surveys, and the fabric and solar loads within the serviced space as modelled using a dynamic thermal model and weather data for the same period.

This method will enable:

- definitively answer the question of which AC system types were the most efficient in practice in the Case Study systems monitored,
- provide detailed profiles of the actual cooling loads encountered in UK offices,
- Enable individual aspects of each building or system to be isolated to assess their relative impact on overall energy performance.

Therefore this research will provide the opportunity to answer a number of important questions relating to building and services energy performance including; the relevance of current design guidance to actual buildings and the relative importance of each parameter on overall building energy and carbon performance. Empirical modelling criteria based on data from actual buildings to provide reliable and realistic input values, thereby improving design and research modelling applications. Design advance, able to provide accurate data on which systems perform best in practice and when in terms of energy consumption and carbon emissions as well as, underpin life-cycle building and system carbon and cost analysis and assess the potential for integrated renewable and cogeneration systems.

The results of this research are contributing to the 'Field benchmarking and Market development for Audit Methods in Air Conditioning' project (AUDITAC), a two-year project funded by the

European Commission's Intelligent Energy Europe programme. The project aims to increase the take-up of system and building energy efficiency upgrades by developing, and encouraging the use of energy auditing procedures for AC systems and case studies that demonstrate the achievable benefits.

9.2 OTHER AIR CONDITIONING RESEARCH OPPORTUNITIES

In addition to research already underway above all else this work has highlighted the need and benefits of research that aim to provide similar data based on real world scenarios. Establishing typical 'in practice' energy consumption profiles of other generic system types, and sub-systems e.g. heat-pumps of mechanical ventilation systems, as well as applications in other building types and market sectors, i.e. retail or hotels outside the scope of this thesis will likely provide similar useful data.

More detailed monitoring that aim to answer specific issues raised by this monitoring study, which are likely to include:

- To determine how much plant over-sizing influences energy efficiency in practice.
- To determine the actual influence of reheat on energy performance.
- To determine the actual 'in practice' efficiency of DX VRF heat recovery systems when providing heating and cooling in order to establish why these theoretically very efficient systems did not perform above average in this monitoring study.
- Look for the other reasons behind current over-sizing, this research has already looked at internal heat gains and a more effective method has already been proposed, but what are the influences of fabric and solar loads as well as occupancy.
- Data needs to be collected to assess the appropriateness of current load estimation methods for electrical systems.

This research has highlighted the often substantial difference between 'design' and 'actual' performance and as such the assessment of the relative performance 'in practice' of novel and / or low energy building cooling solutions compared to the more traditional air conditioning systems would be of benefit to determine the 'real' benefits many non-traditional systems. Such novel systems may include evaporative chillers and ground source cooling systems.

9.3 IMPORTANCE OF CONTINUED RESEARCH

The data obtained by the research is of crucial importance at this moment in time as ways are sought to reliably reduce the energy use of our building services by a significant amount. The author believes this can be done with existing technology and effective holistic design, a route that the recent proposed amendments to Part L of the building regulations is advocating as well. It is probably clear to anyone involved in the design of building services since April 2002 that the requirement for sub-metering in buildings from the *'Building Regulations Part L 2002'* means that the actual energy consumption of their building services systems will soon be indisputable and therefore possible grounds for legal action or other measures perhaps by the Inland Revenue.

Therefore building services designers are in the forefront of reducing carbon emissions from buildings, but do not necessarily have the latest design guidance. Clear guidance is needed that is fact based, enabling the correct design decisions to be made for actual buildings and occupancy levels. The development of the data resource obtained by this research has the opportunity to answer a wide variety of questions relating to building and energy issues. However from a building services viewpoint, there are probably three main areas of particular interest:

- The assessment of current and future design parameters for building services in UK offices.
- The development of improved input data for design and modelling applications.
- Fact based energy efficiency advice.

The further developments of this work aim to definitively answer the question of which AC system types are the most efficient in practice and determine the relative impact of individual aspects of building and AC system design on the overall energy and carbon performance, as well as, contribute to the European AUDITAC project. This should result in real improvements to the energy and carbon performance of buildings throughout Europe by providing the evidence required to fully capitalise on energy audits and inspections.

9.4 CHAPTER REFERENCES

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SITE INFORMATION SHEET

Building identification: SITE 1

General Building Data:

Year of construction:	1960's	N/A
	N/A	N/A
Refurbishment HVAC	1999	New Air Conditioning system
Refurbishment Lighting	1999	New in this area of the building
Refurbishment Other	N/A	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Engineering / Manufacturing	N/A
Type of tenancy	Owned	Office space within larger industrial building
Tenancy Since	This area new use 1999	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Constant Volume All-Air system.	Heating coil served from site MPHW circuit.
Ventilation System	Constant Volume All-Air system.	This area only
Cooling System	Constant Volume All-Air system.	This area only
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	HD Top-lit Hall	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	Entire site
Cooling	Elec.	This area only
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	2276 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Large steel framed light industrial building top lit from skylights	N/A
Layout	This area is a mezzanine office area over a production line, and cellular in layout.	N/A
Exterior elevations	No external façades in this area	Within larger structure, roof only external surface
Number of floors	mezzanine	N/A
Floor area (Gross)	203 sq m	From Building mgr.
Floor area (Treated MVAC)	185 sq m	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	185 sq m	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	148 sq m	Est. * Energy Consumption Guide 19

Windows

Type	Single glazed fixed	To other internal areas only.
Total Area		N/A
Total Area operable	none	N/A
Type of glazing	Two layer partition type	N/A
Area glazing by facade	None External	N/a
Percentage of glazing by facade	N/a	Part of larger structure
	N/a	Part of larger structure
	N/a	Part of larger structure
Glazing (u-value)		N/a
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	N/a	N/A
External shading devices (Size & Loc)	N/a	N/A
Internal shading devices (Type)	Vertical blinds	N/a
Internal shading devices (Location)	Between pains of partition glazing	N/A

Other

Wall Structure	Modular internal partitions to other internal areas only.	N/A
Wall Insulation	100mm rock wool	N/A

Wall area by façade	N/a	Part of larger structure
	N/a	Part of larger structure
	N/a	Part of larger structure
	N/a	Part of larger structure
Roof Structure	Metal panels on steel frame	N/A
Roof Insulation	200mm rock wool above ceiling	N/A
Roof Area	212 sq m	Ceiling area 185sq m + extra from 30 pitch
Ceiling Type	Suspended	N/A
Ceiling Height	2.5 m	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	8	In mezz area only
Average	6	On visits
Typical Visitors	Conference room upto 12 persons	Conference room infrequent use.
Normal Hours	9 am to 5:30pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	N/A	n/A
Typical Cellular Office	2/3 people	9m x 3m aprox.

Small Power Loads:

Typical Cellular Office	27 sq m	N/A
	3 x Personal Computers	N/A
	1 x fax	N/A
	1 x laser Printer	N/A
	1 x Desk Fan	N/A

Lighting Loads:

Typical Cellular Office	27 sq m	Normal occupancy
	2 x (2 x 2ft) Fluorescent (Elec HF Ballast)	Ceiling recessed mounted w/ diffuser
Lighting controls:	Local by cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Roof Mounted packaged constant volume comfort cooling system. Integral refrigeration system for cooling see details below, and heating coil serviced from sites MPHW circuit.
	Ventilation Equipment	As above, providing conditioned re-circulated air with a percentage freshair mixed
Heating & Cooling system	Packaged CV system	Packaged constant volume comfort cooling system with integral refrigeration system for cooling of 88kW capacity see details below, and heating coil serviced from sites MPHW circuit. Ducted flow and return to conditioned space via ceiling diffusers.
	Compressors	2 @ 14.8 kW max rated input
	Fans	2 @ 0.6 kW max rated input
	Motors / control module	1@ 5.47 kW max rated input
DHW	Localised elec. Point of use	This system is not monitored as part of the study.
Refrigerant Type:	R-22	N/A
HVAC Plant Control:	Carrier integrated controls on room stats.	Site wide BEMS controls start / stop times and ensures not heating / cooling conflicts.
Set Points	Heating 18 deg C	N/A
	Cooling 24 deg C	N/A
Run times of HVAC plant	As per normal occupancy	N/a
Identify HVAC zoning of building	Operated as single zone	N/a

Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	N/a	N/a

Monitoring Notes:

General:

Building Owner is generally very energy conscious with an active M&T policy.
Some controls changes may have from the monitoring and feedback discussions.

Specific:

CV Energy Consump	Possible control changes from 2pm 12/2/01, reduction in supply air volume to match occupancy load?
Interior Temp	High confidence in the quality of this data thought out the monitoring period
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment
Supply Air Temp	Data not available until 2/4/01

Monitoring Points:

Energy supply to CV	kWh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals
Supply Air Temp	Deg C @ 15 min intervals

Summary Info.

System Category	All-Air System
System Basic Description	Packaged constant volume system
Installed Capacity (Heating)	88kW
Rated Power Consumption	35kW
Total Cooling Capacity	88kW
Cooling Capacity By area	475.68W/m2

Downloading dates:

Install	14-Sep-00
Download 1	30-Nov-00
Download 2	20-Feb-01
Download 3	14-Sep-00
Download 4	11-Jul-01
Download 5	11-Dec-01
Download 6	01-Mar-02
Download 7	May-02
End	06-Nov-02

Building Description General:

Building identification: **SITE 2**

General Building Data:

Year of construction:	1990	N/A
Refurbishment HVAC	N/A	N/A
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices, canteen, retail street level	N/A
Occupiers Business Type	Government	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	since 1990	N/A
Caretaker / Porter	Contract	N/A
Heating System	Variable Air Volume All-Air system.	Plus perimenter rediators
Ventilation System	Variable Air Volume All-Air system.	N/A
Cooling System	Variable Air Volume All-Air system.	N/A
Econ 19 Category	Type 4 (Air Conditioned Prestige)	* Energy Consumption Guide 19
Building Category BRE	OD Artificially Lit Open Plan Multi-storey	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	Entire site
Cooling	Elec.	This area only
DHW	Elec.	Localised by core
Annual fuel bills:	Yes	Available at request
Energy Manager	Yes	On-site
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Large concrete framed office building in an L shaped configuration	N/A
Layout	Mixed open and cellular offices	N/A
Building floor plan showing north	See plans	North is to the bottom of the plan
Exterior elevations	See example photo's	N/A
Number of floors	8 storeys (basement +7)	7 occupied including lower ground basement
Floor area (Gross)	8265 sq m	Est. * Energy Consumption Guide 19
Floor area (Treated MVAC)	7025 sq m	Est. from plans (A Block Only)
Floor area (Treated MV)	7025 sq m	Est. from plans (A Block Only)
Floor area (Nett Usable Office)	5620 sq m	Est. * Energy Consumption Guide 19
Windows		
Type	Sealed, metal framed	N/A
Total Area	2226 sq m	N/A
Total Area operable	None	Smoke extract only
Type of glazing	Tinted double	N/A
Area glazing by facade	North - Internal Only	N/a
	South - None	N/a
	East - 1252 sq m	N/a
	West - 974 sq m	N/a
Percentage of glazing by facade	North - Internal Only	N/a
	South - None	N/a
	East - 48%	N/a
	West - 48%	N/a
Glazing (u-value)	1.3 w/m2K	Est. from PartL of the Building Regulations
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	<50mm Typical	N/A
External shading devices (Size & Loc)	None	N/A
Internal shading devices (Type)	Vertical blinds	N/a
Internal shading devices (Location)	Behind Glazing	N/A
Other		
Wall Structure	Masonry Cavity walls	N/A
Wall Insulation	to 0.45 W/m2K	Per 1990 spec.
Wall area by façade	North - Internal Only	N/a
	South - 580 sq m	N/a

	East - 2610 sq m	N/a
	West - 2030 sq m	N/a
Roof Structure	Metal	Flat membrane plant area only
Roof Insulation	to 0.45 W/m2K	N/A
Roof Area	1033 sq m	Est. from plans (A Block Only)
Ceiling Type	Suspended	N/A
Ceiling Height	3m Approx	Typical office area

Building Occupancy and Operation:

Occupancy

Staff Total	Varies 700-900	N/A
Average	N/A	N/A
Typical Visitors	Varies	Conference room infrequent use.
Normal Hours	9 am to 5:30pm M-F	Some 24hrs / 7 Day operations
Cleaning Hours	within normal hours	N/A
Other Usage	N/A	N/A

Small Power Loads:

Typical Office Area	Design 30 W/m2	N/A

Lighting Loads:

Typical Office Area	Design 10 W/m2	Ceiling recessed mounted w/ diffuser
Lighting controls:	Local by cellular space or structural bay in open plan areas	N/a
Special energy uses:	None	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Centralised all-air variable air volume system
Heating & Cooling system	Centralised Variable Air Volume system	1 Supply and return AHU per core, 2 cores in A Block, VAV boxes in ceiling of office spaces. Return air via air handling luminaries.
	Chillers	2x York International Model LCHHD 200 water cooled chillers of 580kW Capacity each. Each with 2x 2-stage reciprocating compressors.
	Dry Coolers	2x York International each with 10 Propeller fan rated at 0.25kW each.
	Air Handling Units	2x each consisting of supply and return fans rated 34kW each, heating, cooling batteries and filter pack. Note % fresh air controlled by CO2 sensors.
	Primary Chilled water pumps	Stamorm rated @ 11 kW each
	Secondary chilled water pumps	Stamorm rated @ 18.5 kW each
	Boilers	2x gas fired draught steel boilers each rated 360kW,
	Primary Heating pumps	Stamorm rated @ 1.5 kW each
	Secondary Heating pumps	Stamorm rated @ 0.55 kW each
	VAV boxes	By trox brothers fan assisted dampered with water reheat, ceiling mounted on local stat controllers.
DHW	Localised elec. By core	This system is not monitored as part of the study.
Refrigerant Type:	R-22	N/A
HVAC Plant Control:	Landis & Staefa BEMS	Freshair mix controlled by Co2 sensors (Sensors known to drift)
Set Points	Heating 21 deg C	N/A
	Cooling 23 deg C	N/A
Run times of HVAC plant	As per normal occupancy	N/a
Identify HVAC zoning of building	By service core and floor	VAV boxes by local stat

Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	Airdale close control AC system on comms / IT areas	Stand-a-lone system.

Monitoring Notes:

General:

Building Owner is generally very energy conscious with an active M&T policy.

This building has historically been un-typically low-energy for its type

Specific:

Chiller Energy Consump	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Interior Temp	High confidence in interior temperature data throughout the monitoring period
Exterior Temp	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.
MCCA1 (Fans, pumps, dry coolers etc)	Some concern that heat rejection equipment loads may not monitored (un-confirmed)

Monitoring Points:

Energy supply to Chiller A1	kWh @ 30 min intervals
Energy supply to Chiller A2	kWh @ 30 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals

Summary Info.

System Category	All-Air System
System Basic Description	VAV
Installed Capacity (Heating)	2x 580kW
Rated Power Consumption	2x 189kW
Total Cooling Capacity	1160kW
Cooling Capacity By area	165.1 W/m2

Downloading dates:

N/A

Building Description General:

Building identification: **SITE 3**

General Building Data:

Year of construction:	1990	N/A
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	N/A	N/A
Refurbishment Lighting	N/A	N/A
Refurbishment Other	various	Addition of some cellular offices
Space Activity	Office, Warehouse	N/A
Occupiers Business Type	High Tech - Sales, Distribution & Service	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1992	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	VAV & Some split Heat Pumps	Office Block VAV Only
Ventilation System	VAV & Passive	Office Block VAV Only
Cooling System	VAV & Some Splits	Office Block VAV Only
Econ 19 Category	Cat 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip, upto 4 stories	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	VAV w/ Centralised chiller, Pumps & AHU's
DHW	Gas	Centralised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Two adjoining steel frame two story blocks, one of office accommodation centrally serviced and organised round a covered courtyard, and a warehouse with mezzanine offices serviced locally.	N/A
Layout	Mainly open plan with some cellular spaces.	N/A
Building floor plan showing north	See Plans	Note: The front door to the office wing faces directly north. (Left on plan as shown here)
Exterior elevations	See Photos	N/A
Number of floors	Ground + 1	N/A
Floor area (Gross)	3547.2 sq. m.	All Areas
Floor area (Treated MVAC)	1429.5 sq. m.	VAV Office Area (Office Block) only
Floor area (Treated AC + Passive Vent.)	767.9 sq. m.	Mezzanine Services & Technical Offices
Floor area (Nett Office)	1143.6 sq. m.	VAV Office Area (Office Block) only

Windows

Type	Opening	by manager
Total Area	474.64 sq. m	Office Block VAV Only
Total Area operable	51 sq. m	Office Block VAV Only
Type of glazing	Tinted Double w/ aprox 6mm air void	N/A
Area glazing by facade	110.14 sq. m North	Office Block VAV Only
	55.02 sq. m South	Office Block VAV Only
	110.04 sq. m East	Office Block VAV Only
	110.04 sq. m West	Office Block VAV Only
	89.5 sq. m Roof	Office Block VAV Only
Percentage of glazing by facade	57 % North	Office Block VAV Only
	57 % South	Office Block VAV Only
	57 % East	Office Block VAV Only
	57 % West	Office Block VAV Only
Glazing (u-value)	3.1 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	VAV Office Area Only
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm	Office Block VAV Only
External shading devices (Size & Loc.)	None	Office Block VAV Only

Internal shading devices (Type)	Vertical Blinds	Office Block VAV Only
Internal shading devices (Location)	Immediately behind glazing	Office Block VAV Only

Other

Wall Structure	Glass Curtain Wall	Office Block VAV Only
Wall Insulation	Cavity filled with fibrous insulation	Per 1990 specs
Wall area by façade	192.57 sq. m North	Office Block VAV Only
	96.29 sq. m South	Office Block VAV Only
	192.57 sq. m East	Office Block VAV Only
	192.57 sq. m West	Office Block VAV Only
Roof Structure	Flat	N/A
Roof Insulation	Fibrous Quilt	Per 1990 min. spec
Roof Area	762.31 sq. m	Office Block VAV Only
Ceiling Type	Suspended	N/A
Ceiling Height	3 m aprox	N/A

HVAC Spaces Data:

Ground Floor	Floor Area	672.8 sq. m
	Glazing Area	192.57 sq. m
	Ceiling Height	3 m
First Floor	Floor Area	672.8 sq. m
	Glazing Area	192.57 sq. m
	Ceiling Height	3 m
Display Area (Ground)	Floor Area	84.1 sq. m
	Glazing Area	89.5 sq. m
	Ceiling Height	7 m

Building Occupancy and Operation:

Occupancy

Staff Total	180	N/A
Average	162	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	8:30 to 6:30 M-F	N/A
Cleaning Hours	5:15 to 7:15 M-F	N/A
Other Usage	20% Staff half day SAT	N/A
Typical Open Office Area:	9 persons	84 sq. m
Typical Cellular Office:	1 person	Size Various See plan
Display Area	1-5 Occasional Visitors	84 sq. m

Small Power Loads:

Typical Open Office Area:	84 sq. m	Structural Bay
	9 x Personal Computers	N/A
	1/4 x Scanner	Based on whole building average
	2 x laser Printer	N/A
	1/4 x Large Photocopier	Based on whole building average
Typical Cellular Office:	Size Various See plan	N/A
	1 x Personal Computer	N/A

Lighting Loads:

Typical Open Office Area:	84 sq. m	Structural Bay
	6 x (3 x 6ft) Fluorescent H.F. Elec. Ballast	Ceiling mounted w/ diffuser Vent Extract
Typical Cellular Office:	Size Various See plan	N/A
	2 x (3 x 6ft) Fluorescent H.F. Elec. Ballast	Ceiling mounted w/ diffuser Vent Extract
Lighting controls:	Switched By Bank	Cleaners switch off at night
Special energy uses:	Display Area	See plan for location
	9 x Large Photocopiers	Occasional Usage

Building HVAC plant:

List of HVAC plant by location:

System Description:	Single duct Variable Air Volume with ducted return from ceiling void and zoned one area per floor.	Additional reverse cycle splits in other non-monitored areas of the building.
Centralised Plant Room:	Supply AHU	W/ Electric De-frost, Heating coil served by hot water circuit, DX cooling coil, single centrifugal fan, filters and dampers.
	Return AHU	Single centrifugal fan, recirculation with aprox 10-20% freshair and plate type heat recovery.

	Boilers 1, 2 & 3	3 modular boilers made by Regency Ltd. and each having an output of 67KW and 84KW input.
	Primary Heating Pumps	1 x Pair of 3 stage pumps rated @ 0.665kw stage one, 1385kw stage 2 and 2.02kw stage 3.
	Chiller	York 2 stage chiller with 2 compressors of 1.6kw each, and remote DX coils within supply AHU and remote condensers, dated 1990.
	Condenser	4 x York remote unitary condensers with ducted o/s air supply and integral circulation fans rated at 20.4kw each.
Distributed Equipment:	VAV boxes	Damper only type with no reheat or fan assist, mounted within ceiling.
	Duct Layout	Each floor has one pair of supply and return loops. Supply via linear ceiling diffusers along the perimeter and returned through the light fittings.
Refrigerant Type:	R22	10.4kg
HVAC Plant Control:	BEMS	Optimised
Set Points	20 heating and 22 cooling	Aims to maintain 23 deg C internal temp
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	By floor	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

Monitoring by EA, survey by WSA

Specific:

VAV Energy Consumption	Data collected by EA therefore WSA do know if all "loads" are accounted in this data.
VAV Power Factor	Data missing from 31/1/01 to 9/3/01
Interior Temp	Temperature loggers appear to have been installed in stairwells NOT office areas
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply AC Panel	kWh & kVarh @ 30 min intervals
Internal Temperature x2	Deg C @ 30 min intervals
External Temperature	Deg C @ 30 min intervals
External Relative Humidity	%RH @ 30 min intervals

Building Description General:

Building Identification: **SITE 4**

General Building Data:

Year of construction:	1985	N/A
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	Jan-01	VSD Drives fitted on all AHU Fans
Refurbishment Lighting	1999	Replaced w/ 2x 18W ceiling mounted tubes (H.F. Elec. Ballast)
Refurbishment Other	N/A	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Finance & Insurance	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1985	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	VAV	N/A
Ventilation System	VAV	N/A
Cooling System	VAV	N/A
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD5 - Day lit Open Plan Strip 5 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elect	Centralised chiller & pumps, AHU's by conditioned space
DHW	Gas	N/A
Annual fuel bills:	No	Available at request
Energy Manager	Yes	Head-Office
HDD	2194 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	story office building part of a complex of 3 separate buildings, steel framed with curtain wall enclosure.	N/A
Layout	L-shaped building almost entirely open-plan with a few cellular spaces.	N/A
Building floor plan showing north	See Plans	Note north is left side of the plan
Exterior elevations	See Photo	Note all facades have identical glazing modules
Number of floors	Ground + 4	N/A
Floor area (Gross)	12,718 sq. m.	N/A
Floor area (Treated MVAC)	11,446 sq. m.	* Energy Consumption Guide 19
Floor area (Nett Usable Office)	9,157 sq. m.	* Energy Consumption Guide 19

Windows

Type	Sealed	N/A
Total Area	3863 sq. m	Est.
Type of glazing	Tinted Double w/ aprox 12mm air void	N/A
Area glazing by facade	934 sq. m North	Est.
	997.5 sq. m South	Est.
	997.5 sq. m East	Est.
	934 sq. m West	Est.
Percentage of glazing by facade	65 % North	Est.
	65 % South	Est.
	65 % East	Est.
	65 % West	Est.
Glazing (u-value)	2.8 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Modular Curtain Wall	N/A
Wall Insulation	40mm Foam integral to panel	N/A
Wall area by façade	1429 sq. m North	N/A
	1526 sq. m South	N/A
	1526 sq. m East	N/A
	1429 sq. m West	N/A
Roof Structure	Flat	N/A
Roof Insulation	As per min spec 1985	N/A
Roof Area	2600 sq. m	Est.
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 3 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	1335	N/A
Average	1201	Est. *CIBSE Guide
Typical Visitors	minimal	N/A
Normal Hours	7am to 8 PM M To F	N/A
Cleaning Hours	Within Normal hours	N/A
Other Usage	7am to 1 PM SAT	N/A
Typical Open Office Area:	12 People	51.8 sq. m
Typical Cellular Office:	1	Size Various See plan

Small Power Loads:

Typical Open Office Area:	51.8 sq. m	Per Structural Bay
	12 x Personal Computers	N/A
	4 x Laptops	N/A
	1 x laser Printer	N/A
	3 x Desk Fan	N/A
	1/10th Large Photocopier	Based on whole building average
	1/10th Fax	Based on whole building average
Typical Cellular Office:	Size Various See plan	N/A
	1 x Personal Computer	Either Desktop or Laptop
	1/4th Desk Fan	Based on whole building average
	1/2 x Laser Printer	N/A

Lighting Loads:

Typical Open Office Area:	51.8 sq. m	N/A
	16 x (2 x 4ft) 18W ea. Fluorescent	Ceiling mounted w/ diffuser and H.F. Ballast
Typical Cellular Office:	Size Various See plan	N/A
	6 x (2 x 5ft) Fluorescent	Ceiling mounted w/ diffuser and H.F. Ballast
Lighting controls:	Centralised lighting control with on / off timer as per standard occupancy,	Manual override using phones.
Special energy uses:	None Specific	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Centralised VAV with economizer cycle and reheat on perimeter zones only. VAV boxes are independently controlled but are of damper only without secondary circulation fans.
Rooftop Equipment	Chiller #1	York packaged air cooled 245kw operating on R407c with 5 compressors and integral primary chilled water pumps.
	Chiller #2	York packaged air cooled 245kw operating on R22 and integral primary chilled pumps. (due to be replaced 2002)
	Chiller #3	York packaged air cooled 245kw operating on R22 and integral primary chilled pumps. (due to be replaced 2002)
Central Plant Room	AHU #1, #3 & #4	Supply and return air handling unit with prevision for heating, cooling and humidification. Each unit having 2 centrifugal supply fans of 30kw each on inverter drives at constant speed and 2 return fans of the same type and control but of 18.5kw each. Th

	AHU #2	Identical configuration as AHU 1,3 & 4 except the supply fans are 45kw each and return fans are 25kw each, as this AHU serves the circulation cores in addition to the floor zones.
	Heating Circulation Pumps	3 @ 15 kW each
	Secondary Cooling Pumps	3 @ 22 kW each
	Secondary Heating pumps	1 Pair @ 1.1 kW each
	Primary Boilers	2 large Strebel modular boilers rated at 580w (input) each.
	Secondary Boiler (Summer)	1 Stebel boiler rated at 98.9kw (input)
Refrigerant Type:	R22 & R407c	all R407c by end of 2002
HVAC Plant Control:	BEMS	Optimised with economizer cycle (free cooling).
Set Points	22 +/- 1 deg C	Pneumatic controls with temperature stats by each damper box.
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	Building is zoned into 4 areas with 2 zones in each wing (Perimeter & Interior). Additionally the service and circulation core is zoned as part of one interior zone handlers.	N/A
Details of planned maintenance	Contract maintenance by Honeywell as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Computer Suite:

Located in separate building

Monitoring Notes:

General:

Monitoring by EA, survey by WSA

Specific:

VAV Energy Consumption	Data collected by EA therefore WSA do know if all "loads" are accounted in this data.
VAV Power Factor	Data missing from 31/1/01 to 9/3/01
Interior Temp	Temperature loggers appear to have been installed in stairwells NOT office areas
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Building Description General:

Building identification: SITE 5

General Building Data:

Year of construction:	1989	N/A
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	Jan-01	VSD Drives fitted on all AHU Fans
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Finance & Insurance	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1990	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	VAV	N/A
Ventilation System	VAV	N/A
Cooling System	VAV	N/A
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OA - Artificially lit open plan multi-storey	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elect	Centralised chiller & pumps, AHU's by conditioned space
DHW	Gas	N/A
Annual fuel bills:	No	Available at request
Energy Manager	Yes	Head-Office
HDD	2194 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	story office building part of a complex of 3 separate buildings, steel framed with curtain wall enclosure.	N/A
Layout	building almost entirely open-plan with a few cellular spaces.	N/A
Building floor plan showing north	See Plans	Note north is to the bottom of the plan
Exterior elevations	See Photo	Note all facades have identical glazing modules
Number of floors	Ground + 7	N/A
Floor area (Gross)	8294.4 sq. m.	N/A
Floor area (Treated MVAC)	7464.9 sq. m.	* Energy Consumption Guide 19
Floor area (Nett Usable Office)	5971.9 sq. m.	* Energy Consumption Guide 19
Windows		
Type	Sealed	N/A
Total Area	3506 sq. m	Est.
Type of glazing	Tinted Double w/ aprox 12mm air void	N/A
Area glazing by facade	1274.9 sq. m North	Est.
	1274.9 sq. m South	Est.
	478.1 sq. m East	Est.
	478.1 sq. m West	Est.
Percentage of glazing by facade	69 % North	Est.
	69 % South	Est.
	69 % East	Est.
	69 % West	Est.
Glazing (u-value)	2.8 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A
Other		
Wall Structure	Modular Curtain Wall	N/A
Wall Insulation	40mm Foam integral to panel	N/A
Wall area by façade	1843.2 sq. m North	N/A

	1843.2 sq. m South	N/A
	691.2 sq. m East	N/A
	691.2 sq. m West	N/A
Roof Structure	Flat	N/A
Roof Insulation	As per min spec 1985	N/A
Roof Area	1100 sq. m	Est.
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 3 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	912	N/A
Average	820.8	Est. *CIBSE Guide
Typical Visitors	minimal	N/A
Normal Hours	7am to 8 PM M To F	N/A
Cleaning Hours	Within Normal hours	N/A
Other Usage	7am to 1 PM SAT	N/A
Typical Open Office Area:	12 People	51.8 sq. m
Typical Cellular Office:	1	Size Various See plan
Small Power Loads:		
Typical Open Office Area:	51.8 sq. m	Per Structural Bay
	12 x Personal Computers	N/A
	4 x Laptops	N/A
	1 x laser Printer	N/A
	3 x Desk Fan	N/A
	1/10th Large Photocopier	Based on whole building average
	1/10th Fax	Based on whole building average
Typical Cellular Office:	Size Various See plan	N/A
	1 x Personal Computer	Either Desktop or Laptop
	1/4th Desk Fan	Based on whole building average
	1/2 x Laser Printer	N/A
Lighting Loads:		
Typical Open Office Area:	51.8 sq. m	N/A
	16 x (4 x 4ft) 18W ea. Fluorescent	Ceiling mounted w/ diffuser and H.F. Ballast
Typical Cellular Office:	Size Various See plan	N/A
	6 x (4 x 5ft) Fluorescent	Ceiling mounted w/ diffuser and H.F. Ballast
Lighting controls:	Centralised lighting control with on / off timer as per standard occupancy,	Manual override using phones.
Special energy uses:	None Specific	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Centralised VAV with economizer cycle and reheat on all zones. VAV boxes are independently controlled but are of damper only without secondary circulation fans.
Rooftop Equipment	Chiller #1	McQuay International Packaged air cooled chiller with 2 multi-stage compressors rated at 495Kw on R22.
	Chiller #2	McQuay International Packaged air cooled chiller with 2 multi-stage compressors rated at 495Kw on R22.
Central Plant Room	AHU #1	Air handling unit with prevision for heating, cooling and humidification with 1 pair of centrifugal supply fans rated at 75kw each on inverter drives at constant speed and i pair of return fans of the same type and control but of 45kw each. The AHU's ar
	AHU #2	Air handling unit with prevision for heating, cooling and humidification with 1 pair of centrifugal supply fans rated at 75kw each on inverter drives at constant speed and i pair of return fans of the same type and control but of 45kw each. the AHU's ar
	Primary Chilled Water Pumps	1 Pair @ 30 kW each
	Primary Heating pumps	1 Pair @ 30 kW each
	Compensated Heating Pumps	1 Pair @ 2.2 kW each

	Primary Boilers	12 modular boilers each rated at 125 kW input and 100kw output.
Refrigerant Type:	R22	N/A
HVAC Plant Control:	BEMS	Optimised with economizer cycle (free cooling).
Set Points	22 +/- 1 deg C	Honeywell electronic controls with temperature stats by each
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	The building is divided into 2 zones along its north south axis where both zones operate reheat.	N/A
Details of planned maintenance	Contract maintenance by Honeywell as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Computer Suite:

Located in separate building

Monitoring Notes:

General:

Monitoring by EA, survey by WSA

Specific:

VAV Energy Consumption	Data collected by EA therefore WSA do know if all "loads" are accounted in this data.
VAV Power Factor	Data missing from 31/1/01 to 9/3/01
Interior Temp	Temperature loggers appear to have been installed in stairwells NOT office areas
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Temp. Internal 1	
Temp. Internal 2	
Temp. External	
Humid. External	
AirCon Load 1 (kW)	CHILLER TC05
AirCon Load 1 (kVar)	CHILLER TC05
AirCon Load 3 (kW)	CHILLER MSP TC06
AirCon Load 3 (kVar)	CHILLER MSP TC06
AirCon Load 4 (kW)	DIS BOARD GNE1 CONTROL PANELS
AirCon Load 4 (kVar)	DIS BOARD GNE1 CONTROL PANELS
AirCon Load 5 (kW)	CHILLER TC07
AirCon Load 5 (kVar)	CHILLER TC07
AirCon Load 6 (kW)	MOTOR CONTROL CENTRE MCC TC01
AirCon Load 6 (kVar)	MOTOR CONTROL CENTREMCC TC01

Building Description General:

Building Identification: **SITE 6**

General Building Data:

Year of construction:	1988	N/A
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	Jan-01	VSD Drives fitted on all AHU Fans
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Finance & Insurance	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1989	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	VAV	N/A
Ventilation System	VAV	N/A
Cooling System	VAV	N/A
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OA - Artificially lit open plan multi-storey	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	Centralised chiller & pumps, AHU's by conditioned space
DHW	Gas	N/A
Annual fuel bills:	No	Available at request
Energy Manager	Yes	Head-Office
HDD	2194 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	story office building part of a complex of 3 separate buildings, steel framed with curtain wall enclosure.	N/A
Layout	building almost entirely open-plan with a few cellular spaces.	N/A
Building floor plan showing north	See Plans	Note north is Right side of the plan
Exterior elevations	See Photo	Note all facades have identical glazing modules
Number of floors	Ground + 7	N/A
Floor area (Gross)	8294.4 sq. m.	N/A
Floor area (Treated MVAC)	7464.9 sq. m.	* Energy Consumption Guide 19
Floor area (Nett Usable Office)	5971.9 sq. m.	* Energy Consumption Guide 19
Windows		
Type	Sealed	N/A
Total Area	3506 sq. m	Est.
Type of glazing	Tinted Double w/ aprox 12mm air void	N/A
Area glazing by facade	478.1 sq. m North	Est.
	478.1 sq. m South	Est.
	1274.9 sq. m East	Est.
	1274.9 sq. m West	Est.
Percentage of glazing by facade	69 % North	Est.
	69 % South	Est.
	69 % East	Est.
	69 % West	Est.
Glazing (u-value)	2.8 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A
Other		
Wall Structure	Modular Curtain Wall	N/A
Wall Insulation	40mm Foam integral to panel	N/A
Wall area by façade	691.2 sq. m North	N/A

	691.2 sq. m South	N/A
	1843.2 sq. m East	N/A
	1843.2 sq. m West	N/A
Roof Structure	Flat	N/A
Roof Insulation	As per min spec 1985	N/A
Roof Area	1100 sq. m	Est.
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 3 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	690	N/A
Average	621	Est. *CIBSE Guide
Typical Visitors	minimal	N/A
Normal Hours	7am to 8 PM M To F	N/A
Cleaning Hours	Within Normal hours	N/A
Other Usage	7am to 1 PM SAT	N/A
Typical Open Office Area:	12 People	51.8 sq. m
Typical Cellular Office:	1	Size Various See plan
Small Power Loads:		
Typical Open Office Area:	51.8 sq. m	Per Structural Bay
	12 x Personal Computers	N/A
	4 x Laptops	N/A
	1 x laser Printer	N/A
	3 x Desk Fan	N/A
	1/10th Large Photocopier	Based on whole building average
	1/10th Fax	Based on whole building average
Typical Cellular Office:	Size Various See plan	N/A
	1 x Personal Computer	Either Desktop or Laptop
	1/4th Desk Fan	Based on whole building average
	1/2 x Laser Printer	N/A
Lighting Loads:		
Typical Open Office Area:	51.8 sq. m	N/A
	16 x (4 x 4ft) 18W ea. Fluorescent	Ceiling mounted w/ diffuser and H.F. Ballast
Typical Cellular Office:	Size Various See plan	N/A
	6 x (4 x 5ft) Fluorescent	Ceiling mounted w/ diffuser and H.F. Ballast
Lighting controls:	Centralised lighting control with on / off timer as per standard occupancy,	Manual override using phones.
Special energy uses:	None Specific	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Centralised VAV with economizer cycle and reheat on all zones. VAV boxes are independently controlled but are of damper only without secondary circulation fans.
Rooftop Equipment	Chiller #1	McQuay International Packaged air cooled chiller with 2 multi-stage compressors rated at 495Kw on R22.
	Chiller #2	McQuay International Packaged air cooled chiller with 2 multi-stage compressors rated at 495Kw on R22.
	Chiller #3	McQuay International 24 hour operation Packaged air cooled chiller serving the computer suite and server room for all three tricentre buildings, rated at 128Kw on R22
Central Plant Room	AHU #1	Air handling unit with prevision for heating, cooling and humidification with 1 pair of centrifugal supply fans rated at 75kw each on inverter drives at constant speed and i pair of return fans of the same type and control but of 45kw each. The AHU's ar
	AHU #2	Air handling unit with prevision for heating, cooling and humidification with 1 pair of centrifugal supply fans rated at 75kw each on inverter drives at constant speed and i pair of return fans of the same type and control but of 45kw each. the AHU's ar
	Primary Chilled Water Pumps	1 Pair @ 30 kW each

	24HRS Chilled Water Pumps	1 Pair @ 7.5 kW each
	Primary Heating pumps	1 Pair @ 30 kW each
	Compensated Heating Pumps	1 Pair @ 2.2 kW each
	Primary Boilers	12 modular boilers each rated at 125 kW input and 100kw output.
Refrigerant Type:	R22	N/A
HVAC Plant Control:	BEMS	Optimised with economizer cycle (free cooling).
Set Points	22 +/- 1 deg C	Honeywell electronic controls with temperature stats by each damper box.
Run times of HVAC plant	As per occupancy	Except comms suite plant which is 24hrs
Identify HVAC zoning of building	The building is divided into 2 zones along its east west axis where both zones operate reheat.	N/A
Details of planned maintenance	Contract maintenance by Honeywell as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Computer Suite:

Located in this building which serves all three tricenter buildings and has separate 24hrs essential services including air conditioning from dedicated svstems

Monitoring Notes:

General:

Monitoring by EA, survey by WSA

Specific:

VAV Energy Consumption	Data collected by EA therefore WSA do know if all "loads" are accounted in this data.
Interior Temp	Temperature loggers appear to have been installed in stairwells NOT office areas
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

- Temp. Internal 1
- Temp. Internal 2
- Temp. External
- Humid. External

CHILLER TC03
CHILLER TC03
DIST BOARD GS1
DIST BOARD GS1
CHILLER TC01
CHILLER TC01
MOTOR CONTROL CENTRE TC01
MOTOR CONTROL CENTRE TC01
CHILLER TC02
CHILLER TC02

Building Description General:

Building identification: **SITE # 7**

General Building Data:

Year of construction:	1987	N/A
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	N/A	N/A
Refurbishment Lighting	N/A	N/A
Refurbishment Other	1997	Controls: Installed sachwell BEMS
Space Activity	Offices, canteen, print facility	N/A
Occupiers Business Type	Government Dept/body	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	1987	N/A
Caretaker / Porter	Occupiers Own	Contract
Heating System	VAV & perimeter heating	N/A
Ventilation System	VAV	N/A
Cooling System	VAV	N/A
Econ 19 Category	Type 4 - Air Conditioned Prestige	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	See VAV System
Cooling	Elect	See VAV System
DHW	Elect	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	2230 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	A 4 storey (Ground + 3) purpose built prestige office building	N/A
Layout	2 rectangular 4 story open plan office blocks connected by an atrium.	N/A
Building floor plan showing north	See Sketch Plan	N/A
Exterior elevations	See Photo	Note all facades have identical glazing modules
Number of floors	Ground + 3	N/A
Floor area (Gross)	11709 sq. m.	N/A
Floor area (Treated MVAC)	9952.7	* Energy Consumption Guide 19
Floor area (Nett Usable Office)	7962.1	* Energy Consumption Guide 19

Windows

Type	Double	12 mm air cavity w/ grey / blue tint
Total Area	3863 sq. m	Est.
Type of glazing	Tinted Double w/ aprox 12mm air void	N/A
Area glazing by facade	670.9 sq. m North	Est. from scaled plans
	670.9 sq. m South	Est. from scaled plans
	524.5 sq. m East	Est. from scaled plans
	524.5 sq. m West	Est. from scaled plans
	1049 sq. m internal to atrium	Single Clear Float Glass(Est. from scaled plans)
Percentage of glazing by facade	64 % North	Est.
	64 % South	Est.
	52 % East	Est.
	52 % West	Est.
Glazing (u-value)	3.4 W/m2K (Office areas)	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	fixed 1.2m perforated metal grill, located top of each glazing module	All floors and facades
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Modular curtain cladding	W/ integral rigid insulation

Wall Insulation	50mm Foam integral to panel	Est.
Wall area by façade	377.4 sq. m North	N/A
	377.4 sq. m South	N/A
	484.2 sq. m East	N/A
	484.2 sq. m West	N/A
Roof Structure	Flat	N/A
Roof Insulation	As per min spec 1985	N/A
Roof Area	2567.9 sq. m	Est. from scaled plans
Ceiling Type	Metal perforated	N/A
Ceiling Height (Typical)	aprox 2.7 m	Note 0.5 m sub-floor (Raised) all offices areas (w/ Carpet)
Floor to Floor Height (Typical)	aprox 4.2 m	

Building Occupancy and Operation:

Occupancy		
Staff Total	680	Est. from Building Mgr.
Average	612	Est. *CIBSE Guide
Typical Visitors	minimal	N/A
Normal Hours	8am to 5 PM M To F	N/A
Cleaning Hours	7am to 11 PM M to F	Lights Only (HVAC Off)
Other Usage	5% of staff 8am to 5pm Sat & Sun	HVAC Systems Off
Typical Open Office Area:	8 People	55.5 sq. m
Typical Cellular Office:	N/A	N/A

Small Power Loads:

Typical Open Office Area:	55.5 sq. m	Per Structural Bay
	8 x Personal Computers	N/A
	2 x Laptops	N/A
	1 x laser Printer	N/A
	3 x Desk Fan	N/A
	1/5th Large Photocopier	Based on whole building average
	1 Fax	N/A
Typical Cellular Office:	N/A	N/A
	N/A	N/A
	N/A	N/A
	N/A	N/A

Lighting Loads:

Typical Open Office Area:	55.5 sq. m	N/A
	8 x (1 x 5ft) Fluorescent	Recessed Ceiling w/ diffuser and switch start (1987)
Typical Cellular Office:	As above	N/A
	N/A	N/A
Lighting controls:	Switched by structural bay	Cleaners turn off
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description (Office Areas)	Centralised single duct VAV with reheat on perimeter zones only. VAV boxes are independently controlled by local ceiling mounted thermostats but are of damper only without secondary circulation fans. Additional perimeter heating elements are integral to
	System Description (Atrium)	Ventilation and comfort cooling provided by two roof mounted AHU's and 8 large air injectors ceiling mounted at high level.
Rooftop Equipment	Chillers 1 & 2	2x York international R-22 reciprocating hermetic air cooled packaged liquid chillers of 637 kW capacity each are mounted on the roof of the west block. Supplying primary chilled water to both plant rooms at 6 deg C. Each chiller has 2 compressors and a
Central Plant Room's (East & West)	AHU Atrium East	Consisting of supply & return fans (11kW/14.2kW), filter heating (105kW Duty) and cooling coils (54kW duty)
	AHU Atrium West	Consisting of supply & return fans (11kW/14.2kW), filter heating (105kW Duty) and cooling coils (54kW duty)
	AHU Central supply North	Consisting of supply & return fans (22kW/15kW), filters, heating (122kW Duty) coil
	AHU Perimeter East	Consisting of supply & return fans (15kW/15kW), filters, heating (41kW Duty) and cooling (77Kw Duty) coils

	AHU Central supply East	Consisting of supply fans (15kW), filters, heating (90kW Duty) and cooling (78Kw Duty) coils
	AHU Central supply West	Consisting of supply & return fans (15kW/15kW), filters, heating (56kW Duty) and cooling (134Kw Duty) coils
	AHU Perimeter West	Consisting of supply fans (22kW), filters, heating (100kW Duty) and cooling (145Kw Duty) coils
	AHU Perimeter South	Consisting of supply & return fans (15kW/22kW), filters, heating (104kW Duty) and cooling (160Kw Duty) coils
	AHU Central supply South	Consisting of supply fans (15kW), filters, heating (69kW Duty) coil.
	DHWS Pumps	6 @ 0.04 kW each (Pullen in line type)
	Primary HWS Pumps	2 @ 18.5 kW each (Pullen centrifugal)
	Primary Heating Pumps	2 @ 11 kW each (Pullen centrifugal)
	Perimeter Heating Pumps	4 @ 4 kW each (Pullen centrifugal)
	Chilled water Pumps	2 @ 30 kW each (Pullen centrifugal)
	Heating Circuit pressurisation	Pullen Pulpress 600 model @ 3 bar (600 litre tank)
	Cooling Circuit pressurisation	Pullen Pulpress 25 model @ 0.9 bar (20 litre tank)
	No. 1 Boiler	A Seagold, Broag Ltd natural gas boiler with 352 kW rated output with a two stage injector type burner. Located in the East wing plant room.
	No. 2 & 3 Boilers	A Seagold, Broag Ltd natural gas boilers with 724 kW rated output each with a two stage injector type burner. Located in the East wing plant room.
Refrigerant Type:	R-22	N/A
HVAC Plant Control:	BEMS	Pneumatic controls with temperature stats by each damper box, with interlock via BEMS.
Set Points	23 +/- 1 deg C	
Run times of HVAC plant	As per normal occupancy	Plant off during cleaning hours
Identify HVAC zoning of building	Building serviced by 4 cores (2 per wing) in the offices areas (i.e. NE, SE, NW, SW) with zoning by perimeter & central areas. The atrium which is serviced in two zones (East & West)	N/A
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	Canteen, Kitchen & Wash-up areas serviced separately	N/A

Computer Suite:

Serviced separately with DX splits	VAV system in this area shut-off	Area also includes print room & #3 conf. Room

Monitoring Note

All monitoring and analysis at this site was undertaken by EA Load Research Group

Building Description General:	
Building identification:	**SITE 8**

General Building Data:

Year of construction:	1996	N/A
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	N/A	N/A
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices, Call centre	N/A
Occupiers Business Type	Financial	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	1997	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Perimeter Radiators	N/A
Ventilation System	Centralised Mech. Vent.	N/A
Cooling System	Chilled Ceilings	N/A
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Daylight Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec	N/A
DHW	Elec	Localised
Annual fuel bills:	Yes	n/a
Energy Manager	Yes	On-site
HDD	2380 on 20 yr avg.	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	A 3 storey (Ground + 2) purpose built office building	N/A
Layout	1 of 5 separate rectangular buildings connected pavilion structure	N/A
Building floor plan showing north	Plans not available	N/A
Exterior elevations	See Photo's	N/A
Number of floors	3	N/A
Floor area (Gross)	3983 m2	Est. from Econ 19
Floor area (Treated)	3585 m2	SHU
Windows		
Type	Double	N/A
Total Area	Plans not available	N/A
Type of glazing	Double w/ aprox 12mm low-E	N/A
Area glazing by facade	Plans not available	N/A
	Plans not available	N/A
	Plans not available	N/A
	Plans not available	N/A
Percentage of glazing by facade	30%	Est. from photo's
Glazing (u-value)	2.1 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <50mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A
Other		
Wall Structure	Brick & block cavity, some composite metal cladding	In-situ concrete structural frame
Wall Insulation	fiberious cavity insulation per 1996 standards	Est.
Wall area by façade	N/A	N/A
Roof Structure	Composite metal cladding	N/A
Roof Insulation	Integral to panel system	per min spec 1996

Roof Area	1492 m2	Est.
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	2.7m	N/A
Floor to Floor Height (Typical)	N/A	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	319	Est. from Building Mgr.
Average	287	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	7:30AM to 18:00 PM M To Sat	N/A
Cleaning Hours	5:00PM to 19:00PM M to F	Lights Only (HVAC Off)
Other Usage	N/A	N/A

Small Power Loads:

Typical Office Area:	1195 sq. m	N/A
	178 x Personal Computers	N/A
	50 x Laptops	N/A
	3 x laser Printer	N/A
	1 x Desk Fan	N/A
	3 Large Photocopier	N/A
	3 Fax	N/A

Lighting Loads:

Typical Office Area:	1195 sq. m	N/A
	13 x Compact Fluorescent	Canister mounted
	112 x (2 x 2ft Fluorescent)	Recessed mounted
	28 x Compact Fluorescent	Wall mounted up-lighters
Lighting controls:	Switched and Occupancy sensor by structural bay	Cleaners turn off
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	HVAC systems consist of passive chilled ceilings, perimeter heating, displacement ventilations and secondary comfort cooling from DX split systems for the computer server rooms.
Ventilation Equipment	Office Supply AHU	Trane packaged AHU (rated supply of 8.5m3/s), including Elec defrost coils (92kW), Cooling coil (354kW), Supply and return heat recovery coils (72kW each), Heating coil (143kW), and fans rated at 14.5kW absorbed power.
	Office Extract AHU	Trane packaged AHU (rated 8m3/s) with absorbed fan power of 7.88kW,
Packaged Chiller	York International	2x YCAM360AQ packaged air cooled chiller with rated output of 275kW cooling, consisting of 2 compressors each and 6 fans at 1.5kW each.
Heating System	Boilers	1x Warmwell HEW140 condensing boiler of rated output of 135kW (lead boiler) 2x Purewell HP210/2/10J atmospheric boilers each rated at 132kW input / 105kW output.
Distributing Pumps	LTHW Primary	1Pair @ Startwin 80-160 rated at 1.1 kW each
	LTHW Secondary	3Pairs @ Startwin 80-160 Variable 2 rated @ 1.1kW and 1 rated @ 0.75kW each
	AHU Heat Recovery pumps	1Pair @ Startwin 80-160 rated at 1.1 kW each
	Chilled Water Primary	1Pair @ Startwin 100-250 rated at 5.3 kW each
	Chilled water secondary	2Pairs @ Startwin 50-250 rated at 3.0kW each
Refrigerant Type:	R22	N/A
HVAC Plant Control:	Centralised BEMS	Optimised on external temperature.

Set Points	N/A	N/A
Run times of HVAC plant	As per normal occupancy	Plant off during cleaning hours
Identify HVAC zoning of building	2 zones per floor	N/A
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	DX split system in comms room	Not Monitored

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.
WSA have very high confidence in the data acquired from this site

Specific:

Chiller Energy Consump	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Heating Supply & Return Temp	Data not available after 9 November 2000
Pump Activity	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Interior Temp	Gap in data from 30/7/2000 to 24/7/2000
Exterior Temp	Gap in data from 30/7/2000 to 24/7/2000 Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to Chillers	kWh @ 10 min intervals	
Internal Temperature	Deg C @ 10 min intervals	
External Temperature	Deg C @ 10 min intervals	
Heating Supply & Return Temp	Deg C @ 10 min intervals	
Pump Activity	mV @ 10 min intervals	(Proportional to pump load)

Estimated load of Primary and Secondary pumps based upon measured run-current
Note this does not include energy supply to AHU which was not monitored at landlords request.

Summary Info.

System Category	Chilled Ceilings
System Basic Description	Passive chilled ceilings
Installed Cooling Capacity (Heating)	275 kW
Rated Power Consumption	n/a
Total Cooling Capacity	275 kW
Cooling Capacity By area	76.71 w/m2

Downloading dates:

Install	13-Mar-00
Download 1	14-Apr-00
Download 2	24-Jul-00
Download 3	12-Sep-00
Download 4	12-Oct-00
Download 5	09-Nov-00
Download 6	29-Nov-00
Download 7	20-Feb-01
Download 8	10-Apr-01
Download 9	25-May-01
Download 10	17-Jul-01
end	20-Sep-01

Building Description General:

Building identification: **SITE 9**

General Building Data:

Year of construction:	1963	N/A
Refurbishment HVAC	1996	New AC system
Refurbishment Lighting	1996	N/A
Refurbishment Other	2000	Windows
Space Activity	Offices	N/A
Occupiers Business Type	Government	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1963	N/A
Caretaker / Porter	Contract	N/A
Heating System	Gas fired wet radiators	N/A
Ventilation System	Mechanical Ventilation	N/a
Cooling System	Passive Chilled Ceilings	Separate DX VRV in IT / Comms rooms
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OD Artificially Lit Open Plan Multi-Storey	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Gas	centralised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	Head-office
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Large concrete framed government building, predominantly artificially lit.	N/A
Layout	Generally cellular offices w/ some open plan spaces.	N/A
Number of floors	Ground + 8 storeys occupied	Plus basement and roof plant levels
Building Layout	See example plans	North is to the top right hand corner of the plan
Floor area (Gross)	8888 sq. m.	Scaled from plans
Floor area (Treated MVAC)	8000 sq. m.	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	8000 sq. m.	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	6400 sq. m.	Est. * Energy Consumption Guide 19
Windows		
Type	Operable	Not allowed open by management
Total Area	1320 sq m	N/A
Total Area operable	20% of total	N/A
Type of glazing	Tinted double	N/A
Area glazing by facade	664 sq m North west	N/A
	0 sq m North East	N/A
	656 sq m South East	N/A
	0 sq m South West	N/A
Percentage of glazing by facade	28% North west	N/A
	0% North East	N/A
	31% South East	N/A
	0% South West	N/A
Glazing (u-value)	3.4 W/m2K	Est. from Part L of the building regulations
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	approx 50mm	N/A
External shading devices (Size & Loc)	None	N/A
Internal shading devices (Type)	Vertical Blinds	N/a
Internal shading devices (Location)	Immediately behind glazing	N/A
Other		
Wall Structure	Cast-in-place Concrete w/ Cavity	N/A
Wall Insulation	Within Cavity	N/A

Wall area by façade	2374 sq m North west	N/A
	0 sq m North East	Internal to other building only
	2118 sq m South East	N/A
	0 sq m South West	Internal to other building only
Roof Structure	Built up roofing	(Coal-tar pitch)
Roof Insulation	N/a	N/A
Roof Area	1105 sq. m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	3.2 m	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	upto 1000	N/A
Average	approx 900	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	9:20 am to 5:10pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	Minimal out-of-hours use	N/A
Typical Open Office Area	23 people	186sq. m
Typical Cellular Office	1 person	16 sq. m

Small Power Loads:

Typical Open Office Area:	186 sq. m	N/A
	23 x Personal Computers	N/A
	1 x Scanner	N/A
	5 x laser Printer	N/A
	1x Fax	
	5 x Desk Fan	N/A
Typical Cellular Office	16 sq. m	N/A
	1 x Personal Computer	N/A
	1 Laser printer	N/A

Lighting Loads:

Typical Open Office Area	186 sq. m 36 x 2 Compact Fluorescent	Normal occupancy 23 people Ceiling mounted w/ diffuser
Typical Cellular Office	Size Various See plan 2 x 2 Compact Fluorescent 1 x 40w T. Halogen Task	Normal occupancy = 1 person x normal hours Ceiling mounted w/ diffuser
Lighting controls:	Local by bank or cellular space	Thorn, day light photocell dimming and computer controlled switch-off "sweeps", hourly during out-of hours periods.
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	Chilled ceiling and beams with perimeter heating and night-time ice storage	N/A
List of HVAC plant by location:		
Rooftop Plant Enclosure	2x GNA Axial fan air cooled chillers	4 stage unit consisting of 2 compressors and 6 variable speed axial condenser fans with a total cooling capacity rated @ 195kW per chiller.
	3x Calmac Ice storage vassals	Total storage capacity of 1710 kWh
Rooftop plant room	Primary Chilled water pumps	2x Pullen constant speed @ 10.8kW each
	Secondary Chilled water pumps	2x Pullen constant speed @ 3.7kW each
	AHU circuit chilled water pumps	2x Pullen constant speed @ 6.7 kW each
	Chilled ceiling circuit pumps	2x Pullen variable speed @ 10.8 kW each
Ground Floor Ceiling Void	Passive chilled ceilings	By Trox Ltd rated at 49watts each with floe temp of 15 Deg C
	Passive chilled beams	By Clima Therm Trox Ltd rated at 191watts each with floe temp of 15 Deg C (Used in perimeter zones only)

Ground Floor Plant Room	Hovel Gas-fired boilers	4x condensing boilers with a rated output of 500kW each
	Constant temp heating pumps	1x pair rated @ 2.02kW each.
	Compensated heating pumps	4x pair rated @ 0.34, 0.14, 2.02, 1.35kW each pair.
	DHW Pumps	1x pair rated @ 0.4kW each.
	Heat recovery pumps	1x pair rated @ 1.36kW each.
	Supply AHU	Consisting of 22kW fan Filters, heating and cooling coils and heat recovery run-a-round coil system.
	Return AHU	Consisting of an 11kW fan and heat recovery run-a-round coil system.
	Humidification Units	To supply AHU, rated at22.8 kW
Refrigerant Type:	R717 (Ammonia)	N/A
HVAC Plant Control:	Timed On/Off to match occupancy	Night-time ice storage
Set Points	212 deg C +/- 1	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	North South by floor	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	Additional separate DX split VRV system in IT/comms area	This system not monitored

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.
WSA have very high confidence in the data acquired from this site

Specific:

Chiller Energy Consump	High confidence in this data throughout the monitoring period
Interior Temp	High confidence in interior temperature data throughout the monitoring period
Exterior Temp	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.
Primary Pump Activity	Not available until 7/6/00

Monitoring Points:

Energy supply to Chillers	kWh @ 10 min intervals
Primary Pump Activity	mV proportional to pump load @ 15 min intervals
Internal Temperature	Deg C @ 10 min intervals
External Temperature	Deg C @ 10 min intervals
Heating Supply & Return Temp	Deg C @ 10 min intervals

Estimated load of all Primary and Secondary pumps based upon measured run-current

General Notes

System Category	Chilled ceilings
System Basic Description	chilled Beams w/ night ice storage
Installed Capacity (Heating)	2x 195kW
Rated Power Consumption	2x 56kW
Total Cooling Capacity	390kW
Cooling Capacity By area	48.75 W/m2

Downloading dates:

Install	5-May-00
Download 1	7-Jun-00
Download 2	21-Jul-00
Download 3	7-Sep-00
Download 4	23-Oct-00
Download 5	14-Dec-00
Download 6	2-Feb-01
Download 7	21-Mar-01
Download 8	15-May-01
Download 9	9-Jul-01
End	10-Oct-01

Building Description General:

Building identification: **SITE 10**

General Building Data:

Year of construction:	1980's	N/A
Refurbishment Fabric	1994	Interior fit
Refurbishment HVAC	1994	Heating System
Refurbishment Lighting	1994	entire building
Refurbishment Other	1998	Chilled ceilings & beams added
Space Activity	Offices, small gym.	N/A
Occupiers Business Type	Government Offices	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	1994	N/A
Caretaker / Porter	Occupiers Own	Contract
Heating System	Perimeter Radiators	N/a
Ventilation System	Passive + Mech in stairwells only	Mixed mode by area within building
Cooling System	Chilled beams	Additional packaged DX in Comms rooms
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Daylit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec	N/A
DHW	Gas (Elec. Summer)	Centralised integrated with heating during winter.
Annual fuel bills:	Yes	n/a
Energy Manager	Yes	Head Office
HDD	2276 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	A 4 storey (Ground + 3) purpose built office building	N/A
Layout	"L" shaped 2 floors open plan, 2 floors cellular.	N/A
Building floor plan showing north	See Plan	North is to the upper right hand corner of the plans
Exterior elevations	See Photo & Plans	N/A
Number of floors	4	N/A
Floor area (Gross)	2414.5 m2	Excluding exterior walls
Floor area (Treated)	2195.3 m2	N/A
Windows		
Type	Double	12 mm air cavity
Total Area	364.9 sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void	N/A
Area glazing by facade	80.7 m2 North East	Est. from scaled plans
	63.5 m2 North west	Est. from scaled plans
	116.5 m2 South East	Est. from scaled plans
	104.2 m2 South West	Est. from scaled plans
Percentage of glazing by facade	23.9% North East	Est.
	16.3 % North West	Est.
	29.9 % South East	Est.
	30.8 % South west	Est.
Glazing (u-value)	3.4 W/m2K (Office areas)	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A
Other		
Wall Structure	Brick & block cavity	Cast-in-place concrete structural frame
Wall Insulation	fiberious cavity insulation per 1994 standards	Est.
Wall area by façade	338 m2 North East	Mansard roof considered wall

	390 m2 North west	Mansard roof considered wall
	390 m2 South East	Mansard roof considered wall
	338 m2 South West	Mansard roof considered wall
Roof Structure	Mixed built-up flat & mansard w/ slate tiles	N/A
Roof Insulation	Fiberious blanket type	Thickness per min spec 1994
Roof Area	408 m2	Mansard roof considered wall
Ceiling Type	Suspended perforated metal	N/A
Ceiling Height (Typical)	aprox 2.75 m	N/A
Floor to Floor Height (Typical)	aprox 3.25 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	80-100	Est. from Building Mgr.
Average	90	Est. *CIBSE Guide
Typical Visitors	Various to enquires office in lobby	N/A
Normal Hours	7:30AM to 18:00 PM M To F	felxi
Cleaning Hours	5:00PM to 19:00PM M to F	Lights Only (HVAC Off)
Other Usage	Rare weekend usage	HVAC Systems off

Small Power Loads:

Typical Office Area:	67.8 sq. m	N/A
	4 x Personal Computers	N/A
	1 x Laptops	N/A
	1 x laser Printer	N/A
	1 x Desk Fan	N/A
	1/12th Large Photocopier	Based on whole building average
	1/5 Fax	Based on whole building average

Lighting Loads:

Typical Open Office Area:	67.8 sq. m	N/A
	12 x (4 x 2ft) Fluorescent	Recessed Ceiling w/ diffuser, HF elec. Ballast
Typical Cellular Office:	As above	N/A
	N/A	N/A
Lighting controls:	Switched and Occupancy sensors by structural bay	Cleaners turn off
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Passive chilled beams supplied from a packaged air-cooled chiller with integral distribution pumps. Ventilation is still provided naturally and the heating system utilises perimeter radiators with TRV's. Controls are Satchwell and include optimisation b
Ventilation Equipment	Stair well ventilation	Nu Aire, Single pack inline single fan QSP 400.
	Smoke room	Nu Aire Squrbo inline Centrifugal fan, ss-250
Packaged Chiller	Unico A EW 96 E2 G7	Air cooled R407C with cooling capacity of 91.7 normal & 110kW max. Package includes all compressors, heat rejection fans and system distribution pumps with a total max. rated input of 50kW (88amps) Compressors x2 each rated at 29.4kW (28amps) normal load (39amps max load). 4 Condenser fans rated @ 0.96kW in total. Chilled water temps of 14 deg C flow & 18.4 Deg C rtn. @ 5.8 l/s.
Heating System	Boilers	2x Powermatic Sime RS9 atmospheric rated @ 217.5kW each (173kW input)
	Heating pumps	Grundfos twin UPCD 80-120
	DHW Pumps	Grundfos up20-07N
	Domestic hot water heater	Lochinvar LG50T, gas fired rated @ 80.5 BTU/hr

Refrigerant Type:	R-407c	N/A
HVAC Plant Control:	Satchwell SUT 4201	Optimised on external temperature.
Set Points	Heating 18 deg C	
	Cooling localised floor controllers	Centralised override = no cooling if external temp <10 deg C
Run times of HVAC plant	As per normal occupancy	Plant off during cleaning hours
Identify HVAC zoning of building	3 zones per floor	N/A
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	DX split system in comms room	Type & details unknown

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.

Specific:

Chiller Energy Consump.	gap from 26/5/00 to 23/7/00 & 15/09/00 to 9/11/00
Interior Temp Exterior Temp	We have high confidence in the accuracy of this data as representative of this site in general Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to Chiller	kWh @ 10 min intervals
Internal Temperature	Deg C @ 10 min intervals
External Temperature	Deg C @ 10 min intervals
Heating Temp	Deg C @ 10 min intervals

General Notes

System Category	Chilled Ceilings
System Basic Description	Packaged Air-Water Chiller w/ Passive Chilled beams
Installed Cooling Capacity (Heating)	1x 110kW (n/a)
Rated Power Consumption	1x 50kW
Total Cooling Capacity	110kW
Cooling Capacity By area	50.1W/m2

Downloading dates:

Install	10-Mar-00
Download 1	14-Apr-00
Download 2	26-May-00
Download 3	24-Jul-00
Download 4	15-Sep-00
Download 5	9-Nov-00
Download 6	20-Feb-01
Download 7	10-Mar-01
Download 8	25-May-01
Download 9	17-Jul-01
Un-installed	20-Sep-01

Building Description General:

Building identification: **SITE 11**

General Building Data:

Year of construction:	1997	N/A
	N/A	N/A
Refurbishment HVAC	N/A	N/A
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices, Small Call centre, cafeteria	N/A
Occupiers Business Type	Financial & Assurance	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1998	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Gas fired wet radiators	Whole building
Ventilation System	Mechanical Ventilation	Phase 2 only
Cooling System	Chilled Beams	Phase 2 only
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan strip	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Elec.	Localised
Annual fuel bills:	Yes	Available at request
Energy Manager	Yes	On-site
HDD	2276 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Large 2 storey steel framed office building.	N/A
Layout	Generally open plan office w/ some larger cellular spaces. Generally day lit with hybrid natural / mechanical ventilation	N/A
Building floor plan showing north	North is to the top of plan	N/A
Exterior elevations	See Image	N/A
Number of floors	Ground + 1	N/A
Floor area (Gross)	7708 sq. m.	Scaled from plans
Floor area (Treated MVAC)	6937 sq. m.	Scaled from plans
Floor area (Treated MV)	6937 sq. m.	Scaled from plans
Floor area (Nett Usable Office)	5549 sq. m.	Est. * Energy Consumption Guide 19
Windows		
Type	Operable	Motorised on BEMS control
Total Area	1482 sq. m	N/A
Total Area operable	326 sq. m	N/A
Type of glazing	Double Clear	N/A
Area glazing by facade	246 sq. m North West	N/A
	286 sq. m North East	N/A
	246 sq. m South East	N/A
	704 sq. m South West	N/A
Percentage of glazing by facade	26% North West	N/A
	26% North East	N/A
	26% South East	N/A
	64% South West	N/A
Glazing (u-value)	2.1 w/m2k	Est. from Part L of the Building regulations
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	Eves aprox 0.5m overhang	N/A
External shading devices (Size & Loc)	Various	Motorised and controlled by BEMS
Internal shading devices (Type)	Vertical Blinds	N/a
Internal shading devices (Location)	inside glazing	N/A
Other		
Wall Structure	Brick and block	N/A

Wall Insulation	Integral to cavity	N/A
Wall area by façade	946 sq. m North West	N/A
	1101 sq. m North East	N/A
	946 sq. m South East	N/A
	1101 sq. m South West	N/A
Roof Structure	Composite metal, pitch of aprox 20-45 deg.	N/A
Roof Insulation	Integral to cladding roofing system	N/A
Roof Area	4239 sq. m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	3.4 m typical	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	562	Including 58 part-time
Average	506	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	6:35 am to 22:30pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	8 am to 5:00pm Weekend	limited staff only
Typical Open Office Area	51 people	600 sq. m
Typical Cellular Office	1 to 4 person	Various size

Small Power Loads:

Typical Open Office Area:	600 sq. m	N/A
	51 x Personal Computers	N/A
	10 x Laptop Computers	N/A
	1 x Photocopiers	N/A
	8 x laser Printer	N/A
	1x Desk fans	N/A
Typical Cellular Office	Various sq. m	N/A
	1 to 4 Personal Computers	N/A
	1 x Laser printer	N/A

Lighting Loads:

Typical Open Office Area	600 sq. m	N/A
	78 x (1 x 65ft) Fluorescent	Ceiling mounted w/ diffuser
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	Passive chilled ceiling system, with mixed mode displacement and natural ventilation by season.	Mixed mode ventilation system optimised by BEMS and also includes motorised sun shades all windows.

List of HVAC plant by location:

Rooftop Enclosure	2x Packaged Delonghi reciprocating air cooled chillers	Each chiller rated at 300kW each with 2 compressor per chiller and includes 6 fans.
Boiler Room	3x Potterton gas-fired modular boilers	rated output of 226kW and input of 281kW each.
Air Handling Units	4x custom built air handling units serving office cores	Each consisting of heating and cooling coils, steam injection humidification, served by variable speed centrifugal supply and return fans. Office area AHU' are rated for 2.6 to 2.8 m3/s
	2x custom built air handling units serving core areas and toilet facilities	Each consisting of heating and cooling coils, steam injection humidification, served by variable speed centrifugal supply and return fans. Office area AHU' are rated for 0.65 and 1.05 m3/s respectively
Pump room	Primary Heating	3x Single speed centrifugal pumps rated @ 0.65kW each
	Secondary Heating	4x Single speed centrifugal pumps rated @ 0.25kW each
	Secondary constant temp LTHW	2x Variable speed centrifugal pumps rated @ 3kW each
	DHW pump	3x Single speed centrifugal pumps rated @ 0.14kW each
	Primary chilled water pumps	2x Single speed centrifugal pumps rated @ 3k each

	Secondary constant temp Chilled water	2x Variable speed centrifugal pumps rated @ 11kW each
	Secondary chilled ceiling pumps	4x Single speed centrifugal pumps rated @ 1.5kW each
Refrigerant Type:	R22	N/A
HVAC Plant Control:	BEMS	Includes motorised natural ventilation for mixed mode operation.
Set Points	21deg C +/- 2	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	Four service cores by quadrant of building	NW, NE, SE, SW etc
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	On-site staff generally provide a very high standard of facilities management.
Additional Information:	Separate stand-a-lone DX split systems serving IT / comms rooms	N/A
	Large conference rooms serviced by fancoil units not chilled ceilings	N/A

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.
WSA have very high confidence in the data acquired from this site

Specific:

Chiller Energy Consump	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Heating Supply & Return Temp	Not available after 29/11/2000
Interior Temp	High confidence in this data through-out monitoring
Exterior Temp	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high. Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to Chillers	kWh @ 10 min intervals
Internal Temperature	Deg C @ 10 min intervals
External Temperature	Deg C @ 10 min intervals
Heating Supply & Return Temp	Deg C @ 10 min intervals

Estimated load of Primary and Secondary pumps based upon measured run-current
Note this does not include energy supply to AHU since ventilation is not integral to the delivery of cooling in this system type.

Summary Info.

System Category	Chilled ceilings
System Basic Description	Chilled ceilings w/ mixed mode ventilation
Installed Capacity (Heating)	2x 300kW
Rated Power Consumption	2x 91.4kW
Total Cooling Capacity	600kW
Cooling Capacity By area	86.5 W/m2

Downloading dates:

Install	22-Mar-00
Download 1	17-Apr-00
Download 2	01-Jun-00
Download 3	07-Jul-00
Download 4	25-Aug-00
Download 5	12-Oct-00
Download 6	29-Nov-00
Download 7	08-Mar-01
Download 8	30-Apr-01
Download 9	25-Jun-01
End	19-Sep-01

Building Description General:

Building identification: SITE 12

General Building Data:

Year of construction:	1991	N/A
Refurbishment HVAC	As Built	N/A
Refurbishment Lighting	As Built	N/A
Refurbishment Other	As Built	N/A
Space Activity	Offices, Café, restaurant / bar	N/A
Occupiers Business Type	Marketing	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1996	N/A
Caretaker / Porter	Landlords	N/A
Heating System	Fancoils	All office areas
Ventilation System	Mechanical Ventilation	All office areas
Cooling System	Fancoils	All office areas
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OD4 - Daylit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1882 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Steel framed office building, offices on 1st and 2nd floors, Bar / Restaurant and Café on ground floor	Bar / Restaurant and café serviced separately and not monitored in this study
Layout	Generally open plan office w/ some larger cellular spaces.	Office areas only
Building floor plan showing north	North is towards the top of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	ground + 2	N/A
Floor area (Gross)	707.3 sq m	Scaled from plans
Floor area (Treated MVAC)	650.3 sq m	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	650.3 sq m	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	520.2 sq m	Est. * Energy Consumption Guide 19

Windows

Type	Opening	N/A
Total Area	155.8 sq m	N/A
Total Area operable	22.8 sq m	N/A
Type of glazing	Double Clear	N/A
Area glazing by facade	North none	N/A
	South 87.4 sq m	N/A
	East 34.2 sq m	N/A
	West 34.2 sq m	N/A
Percentage of glazing by facade	39.20%	N/A
Glazing (u-value)	2.8 w/m2k	N/a
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	aprox 75 mm	N/A
External shading devices (Size & Loc)	See photos	similar on south. East & west sides
Internal shading devices (Type)	Vertical blind	N/a
Internal shading devices (Location)	inside of window	N/A

Other

Wall Structure	Brick and block with cavity	N/A
Wall Insulation	Installed in cavity	N/A
Wall area by façade	223.2 sq. m North	Party wall to next building
	223.2 sq. m South	N/A
	93.6 sq. m East	N/A
	93.6 sq. m West	N/A

Roof Structure	Composite metal cladding and decking	Pitch 20-45 deg (double pitch & hitch)
Roof Insulation	Rigid below cladding	N/A
Roof Area	858 sq m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	2.72 m	Typical

Building Occupancy and Operation:

Occupancy

Staff Total	30	N/A
Average	27	Est. *CIBSE Guide
Typical Visitors	upto 5 daily	N/A
Normal Hours	8:30 am to 17:00 M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	N/a	N/a
Typical Open Office Area	6 people	72 sq m
Typical Cellular Office	1 person	12.6 sq. m

Small Power Loads:

Typical Open Office Area:	72 sq m	N/A
	4 x Personal Computers	N/A
	2x Laptop	N/A
	1 x fax	N/A
	2 x laser Printer	N/A
	1x shredder	N/A
	1x scanner	N/A
	1x photocopier	N/A
Typical Cellular Office	12.6 sq. m	N/A
	1 x Personal Computer	N/A

Lighting Loads:

Typical Open Office Area	72 sq m	N/A
	18 x (2x2ft) Fluorescent recessed	N/A
	1 x Compact Fluorescent recessed	N/A
Typical Cellular Office	12.6 sq. m	N/A
	2 x (6ft) Fluorescent recessed	N/A
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	4 pipe "non-change over" fancoil system	Served from gas boilers, chiller and central Mech ventilation.
	Additional perimeter heating system, for condensation control	Radiant fin tubes mounted in floor trench with grill below all window surfaces, served by MPHW circuit from central boilers

List of HVAC plant by location:

Plant room	Boilers	2x Strebel boilers rated @ 95kW each
	Primary Htg pumps	1 pair rated @ 250watts each
	Perimeter heating pumps	1 pair @ 250 W each
	Secondary Htg pumps	1 pair @ 250 W each
	Ahu Htg pumps	1 pair @ 370watta each
	Chiller	Ciat custom chiller with 2 compressors and 2 fans, ducted air-side heat-rejection, with 183.3kW cooling capacity.
	Chilled water pumps	1 pair @ 2.2 kW each
	Ahu Cooling pumps	1 pair @ 750watts each
	AHU	Consisting of heating and cooling coils, supply and return fans each rated at 3 kW

Office area ceiling voids	28 x 4 pipe fancoil units	fan ratings @ 375watts each.(typical)
Refrigerant Type:	R22	N/A
HVAC Plant Control:	BEMS to match occupancy	Optimised to external temperature
Set Points	23 deg C cooling / 21 deg C heating	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	Per floor	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.
WSA have very high confidence in the data acquired from this site

Specific:

Chiller Energy Consump	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
MCC Supply	High confidence in the Mcc consumption profile and controls appear un-changed through-out monitoring
Interior Temp	Gap in data from 28/8/01 to 7/9/01 due to access un available to building for download
Exterior Temp +RH:	Gap in data from 30/8/01 to 7/9/01 due to access un available to building for download Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to Chillers	kWh & kVarh @ 15 min intervals
Energy supply Mcc Panel	kWh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

Mcc Panel: Supplies all Fan's, Pumps associated with this Fancoils system, but Mech. Vent system.

General Notes

System Category	Fancoils
System Basic Description	4-pipe non-changeover fancoil system
Installed Cooling Capacity (Heating)	183kW (n/a)
Rated Power Consumption	n/a
Total Cooling Capacity	183 kw
Cooling Capacity By area	281.4 w/m2

Downloading dates:

Install	06-Dec-00
Download 1	04-Jan-01
Download 2	27-Mar-01
Download 3	07-Jun-01
Download 4	28-Aug-01
Download 5	17-Nov-01
Download 6	05-Feb-02
Un-Install	May-02

Building Description General:

Building identification: **SITE 13**

General Building Data:

Year of construction:	1988	N/A
	N/A	N/A
Refurbishment HVAC	As Built	N/A
Refurbishment Lighting	As Built	N/A
Refurbishment Other	As Built	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Publishers	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1997	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Fancoils	Whole building
Ventilation System	Mechanical Ventilation	Whole building
Cooling System	Fancoils	Whole building
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OD4 - Daylit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1882 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Large steel framed office building, predominantly artificially lit.	N/A
Layout	Generally open plan office w/ some larger cellular spaces.	N/A
Building floor plan showing north	North is top left hand corner of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	Basement + 4	N/A
Floor area (Gross)	3148.9 sq m	Scaled from plans
Floor area (Treated MVAC)	2862.6 sq m	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	2862.6 sq m	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	2290.1sq m	Est. * Energy Consumption Guide 19
Windows		
Type	Double opening clear	N/A
Total Area	N/a	N/A
Total Area operable	N/a	N/A
Type of glazing	N/a	N/A
Area glazing by facade	North 129.5 sq m	N/A
	South 126 sq m	N/A
	East 35 sq m	N/A
	West 63 sq m	N/A
Percentage of glazing by facade	22.20%	N/A
Glazing (u-value)	2.8 w/m2k	N/a
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	aprox 75 mm	N/A
External shading devices (Size & Loc)	none	N/A
Internal shading devices (Type)	Vertical blind	N/a
Internal shading devices (Location)	inside of window	N/A
Other		
Wall Structure	Brick and block with cavity	N/A
Wall Insulation	Installed in cavity	N/A
Wall area by façade	924 sq. m North	N/A
	840 sq. m South	N/A
	476 sq. m East	N/A
	392 sq. m West	N/A

Roof Structure	Concrete tiles, on steel trusses	N/A
Roof Insulation	Blanket tile above ceiling	N/A
Roof Area	858 sq m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	2.74 m	Typical

Building Occupancy and Operation:

Occupancy

Staff Total	220	N/A
Average	198	Est. *CIBSE Guide
Typical Visitors	upto 10 daily	N/A
Normal Hours	7:30 am to 19:00 M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	N/a	N/a
Typical Open Office Area	40 people	338.5 sq m
Typical Cellular Office	1 person	14.8 sq. m

Small Power Loads:

Typical Open Office Area:	338.5 sq m	N/A
	40 x Personal Computers	N/A
	3 x fax	N/A
	7 x laser Printer	N/A
	13 x Desk Fan	N/A
	1x scanner	N/A
	2x photocopier	N/A
Typical Cellular Office	14.8 sq. m	N/A
	1 x Personal Computer	N/A

Lighting Loads:

Typical Open Office Area	338.5 sq m	N/A
	56 x (6ft) Fluorescent recessed	N/A
	7 x (4ft) Fluorescent recessed	N/A
	4 x 100w T. Halogen Task	N/A
Typical Cellular Office	Size Various See plan	N/A
	2 x (6ft) Fluorescent recessed	N/A
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	4 pipe "non-change over" fancoil system	Served from gas boilers, chillers and central Mech ventilation.
List of HVAC plant by location:		
Basement plant room	Boilers	2x Dietrect DTG 408's rated output 203 kW (81.9 % efficiency)
	Primary Htg pumps	1 pair rated @ 500watts each
	Secondary Htg pumps	1 pair @ 1.5 kW each
	Ahu Htg pumps	1 pair @ 370watta each
Chiller enclosure	2x Trane CGCA 207Z's	Each having 2 compressors and rated 159 kW cooling capacity per chiller
	Primary Cooling pumps	1 pair rated @ 3 kw each
	Secondary Cooling pumps	1 pair @ 5.5 kW each
	Ahu Cooling pumps	1 pair @ 370watts each
Roof top plant room	AHU	Consisting of heating and cooling coils, supply and return fans each rated at 5.5 kW
Office area ceiling voids	149x 4 pipe fancoil units	fan ratings between 45 & 80 watts each.
Refrigerant Type:	R22	N/A

HVAC Plant Control:	BEMS to match occupancy	N/A
Set Points	23 deg C cooling / 21 deg C heating	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	Per floor	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.
WSA have very high confidence in the data acquired from this site

Specific:

Chiller Energy Consump	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
MCC Supply	High confidence in the Mcc consumption profile and controls appear un-changed through-out monitoring
Interior Temp	High confidence in interior temperature data throughout the monitoring period
Exterior Temp +RH:	Gap in data from 30/8/01 to 7/9/01 due to access un available to building for download Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to Chillers	kWh & kVarh @ 15 min intervals
Energy supply Mcc Panel	kWh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

Mcc Panel: Supplies all Pumps and control equipment associated with this Fancoils system.
Note this does not include energy supply to AHU which was not monitored.

General Notes

System Category	Fancoils
System Basic Description	4-pipe non-changeover fancoil system
Installed Capacity (Heating)	2x 159kW
Rated Power Consumption	n/a
Total Cooling Capacity	318 kw
Cooling Capacity By area	111.1 W/m2

Downloading dates:

Install	06-Dec-00
Download 1	04-Jan-01
Download 2	27-Mar-01
Download 3	07-Jun-01
Download 4	28-Aug-01
Download 5	17-Nov-01
Download 6	05-Feb-02
Un-Install	May-02

Building Description General:

Building identification: SITE 14

General Building Data:

Year of construction:	1901	N/A
	N/A	N/A
Refurbishment HVAC	1986	Complete re-build as new
Refurbishment Lighting	1986	Complete re-build as new
Refurbishment Other	1986	Complete re-build as new
Space Activity	Offices, Small Cafeteria	N/A
Occupiers Business Type	Banking / Financial	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1990	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	4 pipe fancoil	N/A
Ventilation System	Mechanical Ventilation	N/A
Cooling System	4 pipe fancoil	N/A
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OD4 - Daylight Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Gas	Centralised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1882 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Large heavy weight masonry structure	N/A
Layout	Generally cellular plan office w/ some open plan areas.	N/A
Building floor plan showing north	North is right hand side of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	Ground + 3 storeys	N/A
Floor area (Gross)	7668 sq. m	Est. * Energy Consumption Guide 19
Floor area (Treated MVAC)	6541 sq. m	SHU survey
Floor area (Treated MV)	6541 sq. m	SHU survey
Floor area (Nett Usable Office)	5233 sq. m.	Est. * Energy Consumption Guide 19
Windows		
Type	Double Opening	Mgr. Requires windows kept closed
Total Area	727 sq m	N/A
Total Area operable	Approx 50% of total	N/A
Type of glazing	Double	N/A
Area glazing by facade	None North	N/A
	91.1 sq m South	N/A
	364 sq m West	N/A
	271 sq m East	N/A
Percentage of glazing by facade	0% North	N/A
	25% South	N/A
	23% East	N/A
	24% West	N/A
Glazing (u-value)	2.8 w/m2k	Indicative
Size & location of trickle vents	N/a	N/A
Window Reveals & Overhangs (Size & Loc)	Various	N/A
External shading devices (Size & Loc)	None	N/A
Internal shading devices (Type)	Vertical blinds	N/a
Internal shading devices (Location)	Immediately behind glazing	N/A
Other		
Wall Structure	Cut stone with cavity & conc. Block inner leaf.	N/A
Wall Insulation	Rock wool in cavity	Installed during refurb

Wall area by façade	257 sq. m North	N/A
	358 sq. m South	N/A
	1217 sq. m East	Plus 286 common wall w/ next building
	1503 sq. m West	N/A
Roof Structure	pitched slate roof with two small areas of flat roof	N/A
Roof Insulation	Blanket type between trusses / beams	N/A
Roof Area	2304 sq. m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	Typically 3m (2.6m corridors and service areas)	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	336 fulltime /40 part-time	N/A
Average	320	Total daily
Typical Visitors	10 to 20 daily	Est. from blg. mgr.
Normal Hours	7 am to 9pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	8am to 4pm SAT	N/A
Typical Open Office Area	12 people	39.2 sq. m
Typical Cellular Office	5 persons	9.8 sq. m

Small Power Loads:

Typical Open Office Area:	39.2 sq. m	N/A
	12 x Personal Computers	N/A
	12x laptops	
	1 x Scanner	N/A
	2 x laser Printer	N/A
	2 x Desk Fan	N/A
Typical Cellular Office	9.8 sq. m	N/A
	5 x Personal Computer	N/A
	5x Laptop	N/A
	1 Laser printer	N/A

Lighting Loads:

Typical Open Office Area	39.2 sq. m	Normal occupancy 12 people
	8 x (4 x 4ft) Fluorescent	Ceiling mounted w/ diffuser
Typical Cellular Office	9.8 sq. m	Normal occupancy 5 people
	2 x (4 x 4ft) Fluorescent	Ceiling mounted w/ diffuser
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	4 pipe non change-over fancoil system	Mains gas boilers, centralised water-cooled chiller, centralised mechanical ventilation.

List of HVAC plant by location:

Perimeter fancoil boxes	Fancoils, perimeters mounted under windows.	each containing circulation fan rated at 22Watts, heating & cooling coils.
Ground Floor Chiller room	Chiller	1x Diakin water cooled 300kW chiller dating from 1990, with 3 (BUC7521LB-YE) compressors
	Condenser Pump	1 pair @ 11kW each.
	Primary chilled water	1 pair @ 11kW each
	Secondary Chilled water pumps	2 @ 2.2kW 1 @ 1kW 1 @ 1.3kW
1st Floor Boiler Room	Space heating Boilers	5x Hamworthy gas boilers each rated @ 124.8kW input / 95.8 kW output

	DHW boilers	2x Hamworthy gas boilers each rated @ 124.8kW input / 95.8 kW output
	Boiler pumps	7 @ 110 to 435W each (variable)
	Heating pumps	2 @ 1.5kW each & 2 @ 3kW each
	Secondary DHW pumps	2 @ 85W each
2nd floor flat roof enclosure	Cooling tower	Wet cooling tower (Not fan assisted) connect to centralised chiller
	Dx split condensers	Airdale cooling only DX splits serving kitchen and server rooms
3rd floor plant room	Air handling unit	3x units each consisting of supply & extract fans, heating & cooling coils. No ratings availble. No heat recovery 10-20% fresh air mixing
Refrigerant Type:	R22	N/A
HVAC Plant Control:	Timed On/Off to match occupancy	N/A
Set Points	22 deg C +/- 1	N/A
Run times of HVAC plant	5am to 8pm 7Day	N/A
Identify HVAC zoning of building	8 areas	North & south by floor
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.
WSA have very high confidence in the data acquired from this site

Specific:

Chiller Energy Consump	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Interior Temp	High confidence in interior temperature data throughout the monitoring period
Exterior Temp	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to Chillers	kWh @ 10 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals

Estimated load of Fancoil units, Primary, Secondary and condenser pumps based upon measured run-current

Summary Info.

System Category	Fancoils
System Basic Description	4 Pipe non-change over system, with gas boilers and centralised water cooled chiller
Installed Capacity (Heating)	1x 300kW
Rated Power Consumption	1x 90kW
Total Cooling Capacity	300 kW
Cooling Capacity By area	45.9 W/m2

Downloading dates:

Install	07-Mar-00
Download 1	26-Apr-00
Download 2	19-Jun-00
Download 3	10-Aug-00
Download 4	18-Sep-00
Download 5	10-Nov-00
Download 6	04-Jan-01
Download 7	27-Mar-01
Download 8	07-Jun-01
Download 9	28-Aug-01
Download 10	16-Nov-01
Download 11	05-Feb-02
End	14-May-02

Building Description General:

Building identification: **SITE 15**

General Building Data:

Year of construction:	1990	N/A
	N/A	N/A
Refurbishment HVAC	1999	Overhaul fancoils per original design
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices, Sm. Print shop, Staff canteen	N/A
Occupiers Business Type	Utility Supplier	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1990	N/A
Caretaker / Porter	Occupiers Own	By contract
Heating System	Fancoils & Wet Convectors	Convectors perimeter only
Ventilation System	Mechanical Ventilation	Plenum supply, ducted return whole building
Cooling System	Fancoils	Whole building
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OA Artificial-lit, Open-plan, Multi-story	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	Boilers by Floor
Cooling	Elec.	Centralised Roof Mounted Packaged Chillers
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	Head-Office
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Three story office block, one of four identical and interconnecting blocks	N/A
Layout	Open plan office w/ central light-well and muti-story lobby	N/A
Building floor plan showing north	See Plans	N/A
Exterior elevations	See Images	N/A
Number of floors	Ground + 2	N/A
Floor area (Gross)	4860 sq. m.	Source: buildings facilities mgr.
Floor area (Treated MVAC)	4374 sq. m.	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	4374 sq. m.	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	3499 sq. m.	Est. * Energy Consumption Guide 19
Windows		
Type	Manual Opening	N/A
Total Area	1452 sq. m	Est.
Total Area operable	363 sq. m	Est.
Type of glazing	Blue tinted double glazing w/ approximate 10mm air void	N/A
Area glazing by facade	423 sq. m North	Est.
	423 sq. m South	Est.
	303 sq. m East	Est.
	303 sq. m West	Est.
Percentage of glazing by facade	75 % North	Est.
	75 % South	Est.
	74 % East	Est.
	74 % West	Est.
Glazing (u-value)	2.8 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	Reveals <50 mm / Eves 100 mm	N/A
External shading devices (Size & Loc)	None Specific	N/A
Internal shading devices (Type)	Horizontal blinds	local manual control
Internal shading devices (Location)	all facades	N/A

Other

Wall Structure	Non-Load Bearing curtain wall & some brick veneer ground floor	N/A
Wall Insulation	Integral per 1990 min spec	Cavity insulation behind veneer brick per min 1990 code
Wall area by façade	564 sq. m North	N/A
	564 sq. m South	N/A
	405 sq. m East	N/A
	405 sq. m West	N/A
Roof Structure	Composite metal, low pitch of aprox 15 deg and light colour.	N/A
Roof Insulation	Integral per 1990 min spec	N/A
Roof Area	1845 sq. m	Est.
Ceiling Type	Suspended	N/A
Ceiling Height	3.5 m	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	400	N/A
Average	360	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	8 am to 5pm M-F	N/A
Cleaning Hours	5 pm to 7 pm M-F	N/A
Other Usage	Staggered Half-day Saturday use	10 - 20 Persons only
Typical Open Office Area	12 people	54 sq. m
Typical Cellular Office	1 person	Size Various See plan
Small Conference Room	upto 6 people	Size Various See plan
Large Conference Room	10 to 12 people	Size Various See plan

Small Power Loads:

Typical Open Office Area:	54 sq. m	N/A
	12 x Personal Computers	N/A
	1/4 x Scanner	Based on whole building average
	2 x laser Printer	N/A
	1 x Desk Fan	N/A
	1/4th Large Photocopier	Based on whole building average
	1/4th Fax	Based on whole building average
Typical Cellular Office	Size Various See plan	N/A
	1 x Personal Computer	N/A
	1/2 Laser printer	Based on whole building average
	1/2 x Fax	Based on whole building average
Small Conference Room	OHP as required	Normally one or other
	Slide Projector as required	Normally one or other
Large Conference Room	Audio / Visual projector as required	Normally one or other
	OHP as required	Normally one or other
	Slide Projector as required	Normally one or other

Lighting Loads:

Typical Open Office Area	54 sq. m	Normal occupancy 12 people
	18 x (2 x 5ft) Fluorescent	Ceiling mounted w/ diffuser
	2 x 100w T. Halogen Task	
Typical Open Office Area (Cat 2)	54 sq. m	Area Marked Cat 2 (Information systems area) See Plan
	10 x (4 x 2ft) Fluorescent	CAT 2 for use with monitors
	5 x (2 x 6ft) Fluorescent	CAT 2 for use with monitors
Typical Cellular Office	Size Various See plan	Normal occupancy = 1 person x normal hours (Nat vent)
	1 x (2 x 5ft) Fluorescent	Ceiling mounted w/ diffuser
Small Conference Room	4 x 5ft Fluorescent Wall Washer	N/A
Large Conference Room	8 x (2 x 5ft) Fluorescent	N/A
Lighting controls:	Local by bank or cellular space	Cleaner switch off at night
Special energy uses:	Kitchen	Ground Floor See Plan
	1 x Oven & range	N/A
	1 x Hot Plate	N/A
	1 x Grill	N/A
	1 x Dish Washer	N/A
	1 x Chest Freezer	N/A
	1 x Large Fridge	N/A

	1 x Cooled Servery	N/A
	Lighting	20 x (2x compact fluorescent recessed down-lighters)

Building HVAC plant:

General HVAC System Description:	Ceiling mounted 4-Pipe Non-change over fancoil units supplied from wet constant temp heating and cooling circuits. Perimeter wet convection heating of compensated temperature.	Plenum supply ventilation with ducted return and partial recirculation in the fancoil units
List of HVAC plant by location:		
Floor Plant Room	3 Identical sets of plant one per floor	Each room contains as follows.
	Boiler 1, 2 & 3	Regency GBS Series 2, each having ratings of 84 kW Input and 67 kW Output
	Heating Pumps (FCU)	1 Pair @ 3.7 kW each (Constant Temp)
	Heating Pumps (Perimeter)	1 Pair @ 3.7 kW each (Compensated Temp)
	Secondary Cooling Pumps	1 Pair @3.0 kW each
	Floor AHU	Consisting of 1 heating & cooling coil from water circuits, supply fan rated @ 4.0kw and return fan rated @ 3.0kw
Roof Top Equipment:	2 x Carrier Packaged air cooled chillers	Model 30GB050A original from 1989 build, power input rated @ 71.3 kW each.
	1 x Delchi Air cooled chiller	Model PN60, max rated input power @ 96kw.
	Primary Cooling Pumps	Assumed to included in packaged chiller units
Refrigerant Type:	R22	(24.5kg charge each carrier chiller & 30 kg charge Delchi)
HVAC Plant Control:	on / off 8am to 5 pm M-F	Optimised for external conditions
Set Points	N/A	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	By Floor	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	New AHU added to supply kitchen / Restaurant in 1999 refurbishment	Size / ratings etc unknown

Computer Suite:

Floor area:	aprox 100 sq. m.	Ground Floor SW corner see plan "Cat 2" Area
Energy consumption (If monitored)	None	N/A
Local HVAC system:	Local Splits	Ceiling Mounted no info available
Estimated equipment heat gain:	Normal Office + 20 %	Estimate
Hours of operation:	Normal	See General data

Monitoring Notes

Monitoring and analysis of this data was undertaken by EA Load research group

WSA have questions over the accuracy of the data from April 2002 onwards as energy consumption seems very low, suspected monitoring or analysis error
However this period also corresponds to the closing of the site in Dec 2002 with transfer of staff starting from June 2002

Building Description General:

Building identification: **SITE 16**

General Building Data:

Year of construction:	1959	N/A
Refurbishment Fabric	none	Listed Building
Refurbishment HVAC	new fancoil systems 1999	N/a
Refurbishment Lighting	2001 to 2002	Rolling refit
Refurbishment Other	N/A	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Corporate HQ Offices	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1959	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	fancoils	N/A
Ventilation System	Mech vent	N/A
Cooling System	fancoils	N/A
Econ 19 Category	Type 4 - Air Conditioned	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan strip	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Oil	N/A
Cooling	Elec.	Centralised chiller & pumps, AHU's by conditioned space
DHW	Oil	N/A
Annual fuel bills:	Yes	Available at request
Energy Manager	Yes	Head-Office
HDD	2194 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	3 storey (Ground +2) custom built HQ building	N/A
Layout	building almost entirely open-plan with a some cellular spaces arranged around 2 courtyards and 3 service cores	N/A
Building floor plan showing north	See Plans	North is to the bottom left hand corner
Exterior elevations	See Photo	Note all facades have identical glazing modules
Number of floors	Ground + 2	N/A
Floor area (Gross)	9440 sq. m.	N/A
Floor area (Treated MVAC)	8496 sq. m.	* Energy Consumption Guide 19
Floor area (Nett Usable Office)	7174 sq. m.	* Energy Consumption Guide 19

Windows

Type	Sealed	N/A
Total Area	3693 sq. m	Est.
Type of glazing	Clear single	N/A
Area glazing by facade	1016.4 sq. m North	Est.
	1016.4 sq. m South	Est.
	830.8 sq. m East	Est.
	838.8 sq. m West	Est.
Percentage of glazing by facade	84 % North	Est.
	84 % South	Est.
	84 % East	Est.
	84 % West	Est.
Glazing (u-value)	5.7 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Modular Curtain Wall	N/A
Wall Insulation	minimal insulation	N/A
Wall area by façade	1210 sq. m North	N/A
	1210 sq. m South	N/A

	989 sq. m East	N/A
	989 sq. m West	N/A
Roof Structure	Flat	N/A
Roof Insulation	As per min spec 1985	N/A
Roof Area	3304 sq. m	Est.
Ceiling Type	Suspended	Perforated metal
Ceiling Height (Typical)	aprox 3 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	upto 820	Est. from bldg mgr.
Average	600	Est. from bldg mgr.
Typical Visitors	upto 50 per day	N/A
Normal Hours	6am to 8:45 PM M To F	N/A
Cleaning Hours	Within Normal hours	N/A
Other Usage	Minimal regular out-of-hours operation	Plant off except computer suite
Typical Open Office Area:	88 People	944 sq. m
Typical Cellular Office:	1	Size Various See plan
Small Power Loads:		
Typical Open Office Area:	944 sq. m	Per HVAC Zone
	88 x Personal Computers	N/A
	20 x Laptops	N/A
	10 x laser Printer	N/A
	5 x Desk Fan	N/A
	2x Large Photocopier	Based on whole building average
	1x Fax	Based on whole building average
Typical Cellular Office:	Size Various See plan	N/A
	1 x Personal Computer	Either Desktop or Laptop
Lighting Loads:		
Typical Open Office Area:	944 sq. m	N/A
	188 x (3 x 18W) Fluorescent	Ceiling mounted w/ diffuser and H.F. Ballast
Lighting controls:	Centralised lighting control with on / off per bay and photocell perimeter areas	N/a
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Partially centralised 2-pipe 'change over' fancoil system with perimeter electric reheaters
Chillers	Chiller #1	Carrier Global 1.2MW water cooled screw chiller with dry coolers
	Chiller #2	Carrier Aquasnap 100kW reverse-cycle air cooled heat-pump, serves 2nd floor NW zone only
AHU Rooftop service cores	3 brick built air handling rooms	Each containing supply and return fans at 2.4kW each, heater / cooling coil and filter packs. Fans are centrifugal with inverter drives operated at constant speed.
Ceiling Voids	Fancoil cassettes	42 per zone, various size, perimeter units with elect reheat
Basement pump room	Primary Chilled Water Pumps	1 Pair running @ 48.8kW
	Condenser Pumps#	1 Pair running @ 18.6kW
	Secondary chilled water pumps	4 Pairs running @ 19.6kW total
Refrigerant Type:	R134a	N/A
HVAC Plant Control:	BEMS	CCN controls system
Set Points	23 +/- 1 deg C	N/A
Run times of HVAC plant	As per occupancy	Except comms suite plant which is 24hrs
Identify HVAC zoning of building	The building is divided into 3 zones per floor plus perimeter zones operate with additional reheat.	N/A
Details of planned maintenance	Onsite contract maintenance as per normal standards and documentation available on request.	N/A

Additional Information:	N/A	N/A

Computer Suite:

Corporate computer suite located in this building and has 24hrs essential services including air conditioning serviced from main chiller. Access has NOT been provided to this facility so loads served by the AC system have not been assessed, although they

Monitoring Notes:

General:

Building management is highly aware of energy management as well as thermal comfort issues
Some minor controls changes may have resulted from feedback in the monitoring

Specific:

DX Split Energy Consump	Highly confident in the quality and accuracy of this data over the entire monitoring period
Interior Temp's	Highly confident in the quality and accuracy of this data over the entire monitoring period
Exterior Temp +RH:	Gap in data to due to lost / stolen logger from 13/8/01 to 12/11/01 RH Data considered faulty from 12/11/01 to 17/01/02 Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to Chiller	kWh & kVarh @ 15 min intervals
Energy supply to Fancoils	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

System Category	Fancoil System
System Basic Description	Global Screw chiller supplying 2 Pipe change over fancoils w/ elec re-heat
Installed Capacity (Heating)	n/a
Rated Power Consumption	289.2kW
Total Cooling Capacity	1290kW
Cooling Capacity By area	151.8 w/m2

Downloading dates:

Install	16-Mar-01
Download 1	24-May-01
Download 2	13-Aug-01
Download 3	30-Oct-01
Download 4	17-Jan-02
Download 5	10-Apr-02
Download 6	27-Jun-02
Download 7	31-Oct-02
End	14-Jan-02

Building Description General:

Building identification: SITE 17

General Building Data:

Year of construction:	1999	N/A
	N/A	N/A
Refurbishment HVAC	2000	Air conditioning and Mech. Ventilation added.
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices, Small Call centre, document archive.	N/A
Occupiers Business Type	Marketing	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1999	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Gas fired wet radiators	Whole building
Ventilation System	Mechanical Ventilation	Phase 2 only
Cooling System	DX Multi-Split	Phase 2 only
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	HA Artificial-lit Hall	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Large steel framed light industrial building, predominantly artificially lit.	N/A
Layout	Generally open plan office w/ some larger cellular spaces.	Production and archive store serviced separately
Building floor plan showing north	North is top right hand corner of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	Ground + mezzanine	N/A
Floor area (Gross)	n/a whole building	N/A
Floor area (Treated MVAC)	978.2 sq. m.	Scaled from plans
Floor area (Treated MV)	978.2 sq. m.	Scaled from plans
Floor area (Nett Usable Office)	782.5 sq. m.	Est. * Energy Consumption Guide 19
Windows		
Type	None	N/A
Total Area	N/a	N/A
Total Area operable	N/a	N/A
Type of glazing	N/a	N/A
Area glazing by facade	N/a	N/A
	N/a	N/A
	N/a	N/A
	N/a	N/A
Percentage of glazing by facade	N/a	N/A
	N/a	N/A
	N/a	N/A
	N/a	N/A
Glazing (u-value)	N/a	N/a
Size & location of trickle vents	N/a	N/A
Window Reveals & Overhangs (Size & Loc)	N/a	N/A
External shading devices (Size & Loc)	N/a	N/A
Internal shading devices (Type)	N/a	N/a
Internal shading devices (Location)	N/a	N/A
Other		
Wall Structure	Composite metal cladding system on steel frame and purlings.	N/A

Wall Insulation	Integral to cladding system	N/A
Wall area by façade	N/A North East	(Internal Walls Only)
	156.75 sq. m South-East	N/A
	85.5 sq. m South-West	N/A
	N/A North-West	(Internal Walls Only)
Roof Structure	Composite metal, low pitch of aprox 15 deg and light colour.	N/A
Roof Insulation	Integral to cladding roofing system	N/A
Roof Area	N/A part of larger building	N/A
Ceiling Type	Suspended	N/A
Ceiling Height	3.5 m	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	upto 80	In phase 2 serviced areas only
Average	70	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	9 am to 5:30pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	9 am to 5:30pm SAT	10 - 20 Persons only
Typical Open Office Area	24 people	140 sq. m
Typical Cellular Office	4 person	36 sq. m

Small Power Loads:

Typical Open Office Area:	140 sq. m	N/A
	48 x Personal Computers	N/A
	1 x Scanner	N/A
	2 x laser Printer	N/A
	2 x Desk Fan	N/A
Typical Cellular Office	36 sq. m	N/A
	4 x Personal Computer	N/A
	1 Laser printer	N/A

Lighting Loads:

Typical Open Office Area	140 sq. m	Normal occupancy
	38 x (3 x 4ft) Fluorescent	Ceiling mounted w/ diffuser
Typical Cellular Office	36 sq. m	Normal occupancy
	6 x (3 x 4ft) Fluorescent	Ceiling mounted w/ diffuser
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	Toshiba VRF 2-pipe heating and cooling "change over" Multi-split DX system.	Plenum return ventilation with ducted supply and partial re-circulation in the fancoil units

List of HVAC plant by location:

Exterior Enclosure	3x Toshiba VRF super multi condensers	All refrigeration, distribution and controls are integral to the condenser unit
Ground Floor Ceiling Void	6x Internal ceiling cassettes	7.1 kW cooling (7.9 heating) each
1st Floor Ceiling Void	9x Internal ceiling cassettes	6 @ 7.1 kW cooling (7.9 heating) each 3 @ 4.5 kW cooling (5.0 heating) each
	Supply AHU	Consisting of in-duct axial fan, filter pack and elec. Heater battery.
	Extract fan	Vent-axial type
Refrigerant Type:	R407c	N/A
HVAC Plant Control:	Timed On/Off to match occupancy	N/A
Set Points	23 deg C	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	By Condenser unit	Ground floor / 1st Floor Cellular / 1st Floor open plan

Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

Some controls changes may have occurred from the monitoring and feedback discussions, not a change in strategy but a occupant override issue (Control F
Occupancy level in terms of people, IT equip. and hours of operation increased steadily until fib 01 (Until intended occupancy pattern was met)

Specific:

DX-Split Energy Consume	High confidence in the consumption profile and controls appear un-changed through-out monitoring
Mechanical Ventilation	14/11/2001 controls change, system switched on? (Only min. consumption until then) 23/05/2001 system appears to on off again, consuming only min. levels of energy 19/7/01 system switched back on (Consumption profile back to normal)
Interior Temp	High confidence in the into temp data throughout monitoring period
Exterior Temp +RAH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high. Relative Humidity Data should be disregarded as the recorded profile appears to be highly unlikely to be acc

Monitoring Points:

Energy supply to DX Splits	kWh & kVarh @ 15 min intervals
Energy supply to Mech. Vent.	kWh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RAH @ 15or 30 min intervals

Summary Info.

System Category	Multi-Splits DX
System Basic Description	Toshiba 2-Pipe VRF (Heating and Cooling 'Change-over' system)
Installed Capacity (Heating)	3x 25kW (28kW heating)
Rated Power Consumption	3x 11.8kW
Total Cooling Capacity	75kW
Cooling Capacity By area	76.7 W/m2

Downloading dates:

Install	15-Sep-00
Download 1	26-Oct-00
Download 2	05-Apr-01
Download 3	09-Aug-01
End	25-Jan-02
Un-Install	06-Mar-02

Building Description General:

Building identification: **SITE 18**

General Building Data:

Year of construction:	1992	N/A
	N/A	N/A
Refurbishment HVAC	2000	Air conditioning and Mech. Ventilation added 2nd floor
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices	Hot-desk system
Occupiers Business Type	Property holdings	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1992	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Gas fired wet radiators	Whole building
Ventilation System	Mechanical Ventilation	2nd floor only w/ elec. reheat
Cooling System	DX Multi-Split	2nd floor only
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OD4 Day-lit (Side) Open plan strip 1-4 storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Gas	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1882 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Steel framed, side-day lit 3 storey office building	N/A
Layout	Generally open plan office w/ some larger cellular spaces.	N/A
Building floor plan showing north	North is top right hand corner of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	Ground + 2	N/A
Floor area (Gross)	2550 sq. m.	Scaled from plans
Floor area (Treated MVAC)	508 sq. m.	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	765 sq. m.	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	1836 sq. m.	Est. * Energy Consumption Guide 19

Windows

Type	Operable w/ metal frames	N/A
Total Area	289.4 sq. m	N/A
Total Area operable	144 sq. m	50% of total
Type of glazing	Clear Double	N/A
Area glazing by facade	125.6 sq. m North	N/A
	65.5 sq. m South	N/A
	65.5 sq. m East	N/A
	32.8 sq. m West	N/A
Percentage of glazing by facade	27%	N/A
	15%	N/A
	20%	N/A
	10%	N/A
Glazing (u-value)	2.8 W/m2K	N/a
Size & location of trickle vents	N/a	N/A
Window Reveals & Overhangs (Size & Loc)	50mm approx	N/A
External shading devices (Size & Loc)	None	N/A
Internal shading devices (Type)	Vertical Blinds	N/a
Internal shading devices (Location)	behind glazing	N/A

Other

Wall Structure	Brick & block cavity wall	N/A
Wall Insulation	Rock wool in cavity	N/A

Wall area by façade	454 sq. m North 454 sq. m South 318 sq. m East 318 sq. m West	N/A N/A N/A N/A
Roof Structure	Concrete tile, on pitched timber trusses	N/A
Roof Insulation	200mm+ rockwool above ceiling	N/A
Roof Area	1190 sq. m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	2.6 m	N/A

Building Occupancy and Operation:

Occupancy

	up to 83	N/A
Average	75	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	8 am to 6pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	9 am to 5:30pm SAT	10 - 20 Persons only
Typical Office Area	83 people	508 sq. m

Small Power Loads:

Typical Open Office Area:	504 sq. m	N/A
	86 x Personal Computers	N/A
	10 x Laptops	
	25 x Fax	N/A
	5 x laser Printer	N/A
	2 x L. Photo copiers	N/A

Lighting Loads:

Typical Open Office Area	504 sq. m 88 x (4 x 2ft) Fluorescent 18w each	Normal occupancy 83 people Ceiling mounted w/ diffuser
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	Toshiba VRF 2-pipe heating and cooling "change over" Multi-split DX system.	Plenum return ventilation with ducted supply and partial recirculation in the fancoil units

List of HVAC plant by location:

Exterior Enclosure	3x Toshiba VRF super multi condensers	All refrigeration, distribution and controls are integral to the condenser unit
Ceiling Void	Internal ceiling cassettes	7.1 kW cooling (7.9 heating) each
Loft space	Supply AHU	Consisting of ducted axial fan, filter pack and elec. Heater battery.
	Extract fan	Ducted axial fan.
Refrigerant Type:	R407c	N/A
HVAC Plant Control:	Trend BEMS	Interlock heating and cooling
Set Points	24 deg C	Cooling
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	By Condenser unit	By floor
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

System control provide for an economiser cycle (Free Cooling) using the Mechanical Ventilation

Specific:

DX Split Energy Consump	Highly confident in the qualityy and accuracy of this data over the entire monitoring period
Mech Vent Energy Consump	Highly confident in the qualityy and accuracy of this data over the entire monitoring period
Interior Temp's	Gap in data from 24/12/01 to 10/01/02
Exterior Temp +RH:	Gap in data from 26/12/01 to 10/01/02 Subject to local building conditions and possible interfearance from building fabric and equipment Particularly on peak summer temperarures which appear high.

Monitoring Points:

Energy supply to DX Multi-Splits	kWh & kVarh @ 15 min intervals
Energy supply to Mech. Vent.	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 30 min intervals
External Temperature	Deg C @ 30 min intervals
External Relative Humidity	%RH @ 30 min intervals

Mechanical Ventilation loads are monitored but not considered in the consumption analysis since not used in the delivery of cooling

General Notes

System Category	Multi-Splits DX
System Basic Description	Toshiba 2-pipe VRF
Installed Capasity (Heating)	n/a
Rated Power Consumption	23.4kW (3@11.8kW ea.)
Total Cooling Capacity	75kW (3@25kW ea.)
Cooling Capacity By area	147.6 W/m2

Downloading dates:

install	15-Aug-01
Download 1	03-Oct-01
Download 2	10-Jan-02
Download 3	27-Mar-02
End	19-Jun-02
Un-Install	18-Jul-02

Building Description General:

Building identification: SITE 19

General Building Data:

Year of construction:	1969	N/A
	N/A	N/A
Refurbishment HVAC	1998	N/A
Refurbishment Lighting	1998-2000	N/A
Refurbishment Other	1998	New glazing system
Space Activity	Offices	N/A
Occupiers Business Type	Insurance	N/A
Type of tenancy	Rented	N/A
Tenancy Since	1997	N/A
Caretaker / Porter	Buildings own	N/A
Heating System	Induction system	Whole building
Ventilation System	Induction system	Whole building
Cooling System	VRV DX Splits	By floor as required
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OA - Artificially Lit Open Plan Multi-storey	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	N/A
Cooling	Elec.	N/A
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1882 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Large tower shell & Core office building	N/A
Layout	Generally open plan office w/ some larger cellular spaces.	N/A
Building floor plan showing north	North is towards the top of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	23 office levels	N/A
Floor area (Gross)	6862 sq m	Scaled from plans
Floor area (Treated MVAC)	6176 sq m	Area in monitoring study only (8 floors)
Floor area (Treated MV)	6176 sq m	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	4488sq m	Est. * Energy Consumption Guide 19

Windows

Type	Sealed	small openings for smoke evac only
Total Area	1740 sq m	N/A
Total Area operable	10%	N/A
Type of glazing	Tinted double argon filled	N/A
Area glazing by facade	North 435 sq m	N/A
	South 435 sq m	N/A
	East 435 sq m	N/A
	West 435 sq m	N/A
Percentage of glazing by facade	67%	N/A
Glazing (u-value)	2.4 w/m2k	N/a
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	aprox 100 mm	N/A
External shading devices (Size & Loc)	none	N/A
Internal shading devices (Type)	Vertical blind	N/a
Internal shading devices (Location)	inside of window	N/A

Other

Wall Structure	Pre-cast concrete panels on conc. Structural frame	N/A
Wall Insulation	Installed in cavity	N/A
Wall area by façade	649 sq. m North	N/A
	649 sq. m South	N/A
	649 sq. m East	N/A

	649 sq. m West	N/A
Roof Structure	Concrete tiles, on steel trusses	N/A
Roof Insulation	Blanket type above ceiling on top floor	N/A
Roof Area	1020 sq m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	2.7 m	Typical

Building Occupancy and Operation:

Occupancy

Staff Total	2000 on shift	Est. from Mgr.
Average	1000 peak daily	Est. from Mgr.
Typical Visitors	Minimal	N/A
Normal Hours	8 am to 10pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	N/a	N/a
Typical Open Office Area	26 people	124 sq m
Typical Cellular Office	1 person	N/a

Small Power Loads:

Typical Open Office Area:	124 sq m	N/A
	26 x Personal Computers	N/A
	2 x laser Printer	N/A
	2 x Desk Fan	N/A
	1/4x photocopier	N/A
Typical Cellular Office	Size Various	N/A
	1 x Personal Computer	N/A

Lighting Loads:

Typical Open Office Area	124 sq m	N/A
	24 x (3x18watt) Fluorescent	N/A
Typical Cellular Office	Size Various See plan	N/A
	2 x (6ft) Fluorescent recessed	N/A
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	Original induction units used to provide tempered ventilation and primary heating, while a secondary DX VRV comfort system provides cooling in the monitored area	Note: Only DX VRV system monitored and listed here
List of HVAC plant by location:	Monitored system only	
Description	Hitachi VRV	2 pipe change over reverse cycle system, used for cooling only. Designed to provide 50W/m2 cooling.
Roof Top	Hitachi VRV Condenser units	8x Condenser units (1 per floor) at 23kW each
Office area ceiling voids	4-way ceiling mounted cassette units	6 to 8 per floor
Refrigerant Type:	R22	N/A
HVAC Plant Control:	BEMS to match occupancy	N/A
Set Points	23 deg C =/- 1 deg C	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	4 zones per floor Per floor	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

This is a secondary DX system put in the supplement original perimeter 2-pipe induction units to meet new higher internal gains

Specific:

VRV Energy Consump	High confidence in the accuracy of this data throughout the monitoring period
Interior Temp 7th Fl	High confidence in the accuracy of this data throughout the monitoring period Some gaps in data
Interior Temp 9th Fl	High confidence in the accuracy of this data throughout the monitoring period Some gaps in data
Exterior Temp +RH:	Gaps in the data from 18/01/01 to 22/02/01 and 17/05/01 to 25/05/01 Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points

Energy supply to VRV #1	kWh @ 15 min intervals
Energy supply to VRV #2	kWh @ 15 min intervals
Internal Temperature 7th Fl	Deg C @ 15or30 min intervals
Internal Temperature 9th Fl	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External RH	%RH @ 15or30 min intervals

General Notes

System Category	Dx Split
System Basic Description	Diakin VRV Multi-Split cooling only
Installed Cooling Capacity (Heating)	8 x 23kW
Rated Power Consumption	n/a
Total Cooling Capacity	184 kW
Cooling Capacity By area	29.78 Wm2

Downloading dates:

Install	15-May-00	
Download 1	16-Jun-00	pulse ratio change
Download 2	19-Sep-00	pulse ratio change
Download 3	09-Jan-01	change recording interval
Download 4	22-Jun-01	
Download 5	07-Dec-01	
Download 6	19-Jun-02	
Un-installed	21-Nov-02	

Building Description General:

Building identification: **SITE 20**

General Building Data:

Year of construction:	1985 & 1997	Phase 1 & 2 respectively (Only Phase 2 Monitored and therefore presented in this survey beyond general building data)
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	Various Splits added	Phase 1 only
Refurbishment Lighting	N/A	N/A
Refurbishment Other	Phase two built aprox 1997	See above
Space Activity	Offices, Conference, National Control Room, Canteen	Phase two only includes Offices, Conference, small gym
Occupiers Business Type	Utility Supplier	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	1985	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Electric Convection fins	Perimeter mounted
Ventilation System	AHU	N/A
Cooling System	VRV 2-pipe Cooling (Phase 2 Only)	N/A
Econ 19 Category	Cat 3 - Air conditioned Standard (Phase Two Only)	* Energy Consumption Guide 19
Building Category BRE	OA (Artificially lit Open plan multi storey)	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elec.	Convector fins perimeter
Cooling	Elec.	VRV multi-splits
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Phase 2 is a two story rectangular offices block, probably steel framed with non-load bearing walls	N/A
Layout	Mainly open plan offices areas with cellular core containing support services and spaces etc.	N/A
Building floor plan showing north	See Plans	N/A
Exterior elevations	See Photo	N/A
Number of floors	Ground + 1	N/A
Floor area (Gross)	4531 sq. m.	EST from scale drawings
Floor area (Treated HVAC)	4078 sq. m.	EST * Energy Consumption Guide 19
Floor area (Nett Usable Office)	3262 sq. m.	EST * Energy Consumption Guide 19
Windows		
Type	Sealed	Fac.. Mgr. controls chuck type key
Total Area	790 sq. m	Est. assuming 20% by area
Total Area operable	158 sq. m	N/A
Type of glazing	Tinted Double w/ aprox 6mm air void	N/A
Area glazing by facade	145 sq. m North	Est.
	145 sq. m South	Est.
	250 sq. m East	Est.
	250 sq. m West	Est.
Percentage of glazing by facade	50 % North	EST
	50 % South	Est.
	50 % East	Est.
	50 % West	Est.
Glazing (u-value)	2.8 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <100mm / Eves 700mm	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	250 mm in side of glazing	N/A

Other

Wall Structure	Non-load bearing w/ Brick veneer & cavity, plus glazing system metal framed.	N/A
Wall Insulation	As per 1997 code	Installed cavity
Wall area by façade	290 sq. m North	N/A
	290 sq. m South	N/A
	500 sq. m East	N/A
	500 sq. m West	N/A
Roof Structure	Pitched 20 degs, mid grey colour metal roofing	N/A
Roof Insulation	As per min 1997 code	N/A
Roof Area	2767 sq. m	Est.
Ceiling Type	Suspended	N/A
Ceiling Height	3.0 m	EST
HVAC Spaces Data:	All spaces	
Ground Floor	Treated Floor Area	2039 sq. m
	Glazing Area	395 sq. m
	Ceiling Height	3.0 m
1st Floor	Treated Floor Area	2039 sq. m
	Glazing Area	395 sq. m
	Ceiling Height	3.0 m

Building Occupancy and Operation:

Occupancy

Staff Total	205	N/A
Average	181	Est. *CIBSE Guide
Typical Visitors	20	N/A
Normal Hours	8am to 6pm M-F	70% total staff
Other Hours	24 hrs operation, 7 days per week	20% staff
Other Usage	8am to 6pm Any 5 days per week	10% staff on staggered week
Typical Open Office Area	8 persons normal Hours	93.7 sq. m
Typical Cellular Office	1 person normal hours	Size Various See plan
Typical Conference Room	12 average persons, 50% utilisation over normal hours	Size Various See plan
Staff Gym	5 persons for 1 hour per day	EST

Small Power Loads:

Typical Open Office Area	93.7 sq. m	Structural Bay
	8 x Personal Computers	N/A
	1/2 x Scanner	Based on whole building average
	1 x laser Printer	N/A
	1/2 x Desk Fan	Based on whole building average
	1/4th Large Photocopier	Based on whole building average
	1/5th Fax	Based on whole building average
Typical Cellular Office	Size Various See plan	N/A
	1 x Personal Computer	N/A
Typical Conference Room	Audio / Visual projector etc	Normally one or other
	OHP as required	Normally one or other
	Slide Projector as required	Normally one or other
Staff Gym	1 x Elec. treadmill	Gym occupancy see above
	1 x Elec. Rowing machine	Gym occupancy see above
	1 x Water Cooler	Maintains water temp 24hrs / 7days / week
	2 x Fan floor standing	Gym occupancy see above
	1 x Stereo / Radio (70w)	Gym occupancy see above

Lighting Loads:

Typical Open Office Area	93.7 sq. m	Structural Bay
	12 x (2 x 4ft) Fluorescent	Ceiling mounted w/ diffuser
	3 x Compact fluorescent recessed ceiling mounted spots	In circulation areas only
Typical Cellular Office	Size Various See plan	N/A
	4 x (2 x 4ft) Fluorescent	Ceiling mounted w/ diffuser
Typical Conference Room	Size Various See plan	Structural Bay
	12 x (2 x 4ft) Fluorescent	same lighting load as open plan by area
Staff Gym	8 x (2 x 4ft) Fluorescent	N/A

	4 x Compact fluorescent recessed ceiling mounted spots	N/A
Lighting controls:	Dalematic Computerised light management system. All Florescent is H.F. w/ Elec. ballast.	Timed off at end of day, override from security desk.
Special energy uses:	Kitchen	Located in phase one
	N/A x Oven & range	N/A
	N/A x Hot Plate	N/A
	N/A x Deep Fryer	N/A
	N/A x Dish Washer	N/A
	N/A x Chest Freezer	N/A
	N/A x Large Fridge	N/A
	N/A x Cooled Servery	N/A

Building HVAC plant:

List of HVAC plant by location:	(Phase Two Only)	
Packaged Roof Top Units:	Custom Built AHU manufactured by Mallard UK Ltd. containing supply and return constant speed fans of unknown size, a 4 stage 10Kw elec. defrost, a 70kw Elec. Heater battery and a 4 stage DX cooling coil and integral condensers running on R22	Supplies tempered fresh air supply via the ceiling plenum with ducted return.
	14 x Modular Diakin VRV condensers, 2 pipe Cooling only. Utilising R22.	Believed to be operating as modular banks of 7 per floor.
	Misc.: Extract fans for toilets and kitchenette areas	Assume one per area.
Ground Floor Ceiling Void:	26 x Diakin VRV ceiling cassettes.	
First Floor Ceiling Void:	30 x Diakin VRV ceiling cassettes.	
Perimeter Floor:	Linear Elec. convection perimeter heating throughout under manual (Central) control.	Used for condensation control and to offset heat lost through glazing.
Refrigerant Type:	R22	all VRV & AHU DX units
HVAC Plant Control:	BEMS	Optimised based on external temperature
Set Points	22 +/- 3 degrees	Note 2 -3 degree deadband between heating and cooling mode by unit, designed to maintain overall temperature of setpoint.
Run times of HVAC plant	As per occupancy +/- Optimisation	N/A
Identify HVAC zoning of building	By Floor in Perimeter and other areas	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	Except AHU done in house.
Additional Information:	N/A	N/A

Computer Suite:

Floor area:	None sq. m.	Located in phase one
Energy consumption (if monitored)	N/A	N/A
Local HVAC system:	N/A	N/A
Estimated equipment heat gain:	N/A	N/A
Hours of operation:	Normal	See General data

Monitoring Notes

All Monitoring and Analysis at this site was undertaken by EA Load Research Group

Building Description General:

Building identification: **SITE 21**

General Building Data:

Year of construction:	1920's	N/A
Refurbishment Fabric	1995	New glazing and interior fit-out.
Refurbishment HVAC	1995	New Mech ventilation & refurbished heating system
Refurbishment Lighting	1995	entire building
Refurbishment Other	1997	Added Dx split cooling system
Space Activity	Small Commercial Office	N/A
Occupiers Business Type	Professional Services	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	1984	N/A
Caretaker / Porter	Occupiers Own	As part of the larger building / complex
Heating System	Perimeter Radiators	N/a
Ventilation System	Tempered mechanical ventilation	providing min. fresh air only
Cooling System	Dx splits	N/a
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	n/a	n/a
Types of fuel used: Heating	Gas	N/A
Cooling	Elec	N/A
DHW	Elec	Localised
Annual fuel bills:	Yes	Available on request for entire building
Energy Manager	Yes	On-site
HDD	1882 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	A small office on the 2nd floor of an historic 5 storey (Lower Ground, Ground +2, Mezzanines) civic building.	N/A
Layout	The building is based around a central courtyard, wit the office itself consisting of the main office area and adjacent smaller storage and copier rooms.	All other facilities and services i.e. toilets etc are shared with the main building and located centrally.
Building floor plan showing north	See Plan	North is to the lower right hand corner of the plans
Exterior elevations	See Photo & Plans	N/A
Number of floors	1 (5 whole building)	N/A
Floor area (Gross)	83.2 m2	Excluding exterior walls
Floor area (Treated Heating)	83.2 m2	N/a
Floor area (Treated Mech Vent & AC)	67.2 m2	N/a

Windows

Type	Double	Skylights @ a slope of aprox. 30 deg.
Total Area	50.4 sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 10mm air void	Skylights @ a slope of aprox. 30 deg.
Area glazing by facade	50.4 sq. m (roof)	Est. from scaled plans
Percentage of glazing	48.6% roof	Est. from scaled plans
Glazing (u-value)	4.2 W/m2K (Office areas)	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	N/a	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Horizontal (adjustable) Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Stone outer and brick inner with cavity.	N/A
Wall Insulation	None known	Est.
Wall area by façade	43.8 m2 North East	Est. from scaled plans
	North West internal walls only	Est. from scaled plans

	31.5 m2 South East	Est. from scaled plans
	South West internal walls only	Est. from scaled plans
Roof Structure	Mixed slate tiles and skylights	N/A
Roof Insulation	Fiberious blanket type	Thickness per min spec 1994
Roof Area	103.7 m2	N/A
Ceiling Type	Plaster	N/A
Ceiling Height (Typical)	Varies aprox. 6m (centre) to 3.5m (walls)	N/A
Floor to Floor Height (Typical)	N/A	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	6	N/A
Average	4	N/a
Typical Visitors	Few & rare	N/A
Normal Hours	9:00AM to 17:00 PM M To F	N/a
Cleaning Hours	5:00am to 07:00am Sun to Thurs	Lights Only (HVAC Off)
Other Usage	Rare weekend usage	HVAC Systems off

Small Power Loads:

Typical Office Area:	67.2 sq. m	N/A
	6 x Personal Computers	N/A
	2 x Laptops	N/A
	2 x laser Printer	N/A
	1 x Desk Fan	N/A
	1 Large Photocopier	Oversized printer type
	1 Fax	N/A
	1x Plotter	N/A

Lighting Loads:

Typical Open Office Area:	67.2 sq. m	N/A
	12 x 6ft Fluorescent	Suspended linear fittings w/ diffuser, HF elec. Ballast
Lighting controls:	Switched and Occupancy sensors by bank	N/A
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	The office in serviced by a perimeter radiator heating system and mechanical ventilation system providing tempered fresh air (min. only) which are both part of the main building's systems are not monitored here. In addition the office has a DX split comf
Ventilation Equipment	Central to the main building	Not considered in the monitoring
Packaged Dx Splits	2x Mitsubishi Mr Slim	The pair of single split DX systems have roof mounted condensers and wall mounted slim-line cassettes. Each rated at 7.9kW cooling and 9.1kW Heating with a rated input power of 3.14kW each. Note these are reverse cycle machines, but are used for cooling only.
Heating System	Central to the main building	Not considered in the monitoring
Refrigerant Type:	R-22	N/A
HVAC Plant Control:	Integral to units	Localised and independent, with the on/off and set-point temperature being controlled directly by the occupants.
Set Points	Various	N/A
Run times of HVAC plant	Various	N/A
Identify HVAC zoning of building	2 Units serve entire office area	N/A

Details of planned maintenance	**Contract maintenance per normal standards and documentation available on request.**	**N/A**
Additional Information:	**N/A**	**N/A**

Monitoring Notes:

General:

Building occupant is concerned about the thermal comfort of the office, and therefore utilises localised control.

Specific:

Splits Energy Consump	High confidence as to the quality of the energy consumption data throughout the entire monitoring period
Interior Temp	Gaps in the data from 17/01/01 to 22/02/01 and 15/05/01 to 25/05/01
Exterior Temp +RH:	Gaps in the data from 18/01/01 to 22/02/01 and 17/05/01 to 25/05/01 Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to VRF	kWh @ 15 min intervals
Internal Temperature	Deg C @ 10or15 min intervals
Internal Relative Humidity	%RH @ 10 or 15 min intervals (added late in monitoring)
External Temperature	Deg C @ 10or15 min intervals
External Relative Humidity	%RH @ 10 or 15 min intervals

General Notes

System Category	DX Split
System Basic Description	2x packaged single split reverse cycle DX systems.
Installed Cooling Capacity (Heating)	2x 7.9kW (9.1kW)
Rated Power Consumption	2x 3.14kW
Total Cooling Capacity	15.8kW
Cooling Capacity By area	232.35 W/m2

Downloading dates:

Install	23-Nov-00
Download 1	22-Feb-01
Download 2	25-May-01
Download 3	7-Aug-01
Download 4	25-Oct-01
Download 5	10-Jan-02
Download 6	27-Mar-02
Download 7	19-Jun-02
Download 8	18-Jul-02
Download 9	16-Aug-02
Download 10	6-Sep-02
End	31-Oct-02
Un-installed	10-Dec-02

Building Description General:

Building identification: **SITE 22**

General Building Data:

Year of construction:	1910's	N/A
Refurbishment Fabric	1994	New glazing and interior fit-out.
Refurbishment HVAC	1994	New Mech ventilation & refurbished heating system
Refurbishment Lighting	1994	entire building
Refurbishment Other	n/a	n/a
Space Activity	Office	N/A
Occupiers Business Type	Public sector	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	1910	N/A
Caretaker / Porter	Occupiers Own	As part of the larger building / complex
Heating System	Perimeter Radiators	N/a
Ventilation System	Natural	Opening windows + passive vent to ceiling plenum
Cooling System	Dx splits	N/a
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	n/a	n/a
Types of fuel used: Heating	Gas	N/A
Cooling	Elec	N/A
DHW	Elec	Localised
Annual fuel bills:	Yes	Available on request for entire building
Energy Manager	Yes	On-site
HDD	1882 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	A small office on the 2nd floor of an historic 5 storey civic building.	N/A
Layout	Large masonry building, of cellular layout.	All other facilities and services I.e. toilets etc are shared with the main building and located centrally.
Building floor plan showing north	See Plan	North is to the lower right hand corner of the plans
Exterior elevations	See Photo & Plans	N/A
Number of floors	1 (5 whole building)	N/A
Floor area (Gross)	36.9 m2	Excluding exterior walls
Floor area (Treated Heating)	32.6 m2	N/a
Floor area (Treated Mech Vent & AC)	32.6 m2	N/a
Windows		
Type	Double	N/a
Total Area	2.64 m2	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void	N/a
Area glazing by facade	2.64 m2 faces lightwell	Est. from scaled plans
Percentage of glazing	16.70%	Est. from scaled plans
Glazing (u-value)	4.2 W/m2K (Office areas)	*The building act 1984, DETR June 2000
Size & location of trickle vents	Into ceiling void	used as plenmun
Window Reveals & Overhangs (Size & Loc.)	150mm approx	N/A
External shading devices (Size & Loc.)	None	N/A
Internal shading devices (Type)	Vertical blinds	N/A
Internal shading devices (Location).	Immediately Inside of Glazing	N/A
Other		
Wall Structure	Stone outer and brick inner with cavity.	700mm total thickness
Wall Insulation	None known	Probably none
Wall area by façade	15.8 m2 North	Est. from scaled plans
	Internal only all other facades	Est. from scaled plans
Roof Structure	N/a	Occupied floor above
Roof Insulation	n/a	Occupied floor above
Roof Area	as floor area	Occupied floor above

Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	2.75m	N/A
Floor to Floor Height (Typical)	3.2 m aprox	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	3	N/A
Average	2	N/a
Typical Visitors	1or 2 at any given time	N/A
Normal Hours	9:00AM to 17:00 PM M To F	N/a
Cleaning Hours	5:00am to 07:00am Sun to Thurs	Lights Only (HVAC Off)
Other Usage	Rare weekend usage	HVAC Systems off

Small Power Loads:

Office Area:	32.6 m2	N/A
	2 x Personal Computers	N/A
	1 x laser Printer	N/A
	1 x Desk Fan	N/A
	1x Large Photocopier	N/a
	1x kettle	
	1x Fax	N/A

Lighting Loads:

Typical Open Office Area:	32.6 m2	N/A
	5 x (3 x 2ft) Fluorescent	w/ diffuser, HF elec. Baliast
Lighting controls:	Switched	N/A
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	A single DX split cooling only system, heating is via a separate perimeter radiator system. Ventilation is passive via operable windows and passive vents into the ceiling plenum.
Packaged Dx Splits	1x Carrier DX split	Single split DX system with roof mounted condenso6 and 4-way ceiling mounted cassette.
Heating System	Central to the main building	Not considered in the monitoring
Refrigerant Type:	R-22	N/A
HVAC Plant Control:	Integral to units	Localised and independent, with the on, off and set-point temperature being controlled directly by the occupants.
Set Points	Various	N/A
Run times of HVAC plant	Various	N/A
Identify HVAC zoning of building	1 Units serve entire office area	N/A
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

Building occupant is concerned about the thermal comfort of the office, and therefore utilises localised control.

Specific:

Splits Energy Consump	High confidence as to the quality of the energy consumption data throughout the entire monitoring period
	Caution with regard to kVarh data, possible repeat of kWh with small interval offset.
Interior Temp	Gaps in the data from 19/05/01 to 29/05/01
Exterior Temp +RH:	Gaps in the data from 18/01/01 to 22/02/01 and 17/05/01 to 25/05/01
	Subject to local building conditions and possible interference from building fabric and equipment
	Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to VRF	kWh & kVarh @ 15 min intervals Caution over Kvarh data, see above
Internal Temperature	Deg C @ 10or15 min intervals
External Temperature	Deg C @ 10or15 min intervals
External Relative Humidity	%RH @ 10 or 15 min intervals

General Notes

System Category	DX Split
System Basic Description	Carrier Single cooling only DX split
Installed Cooling Capacity (Heating)	n/a
Rated Power Consumption	n/a
Total Cooling Capacity	n/a
Cooling Capacity By area	n/a

Downloading dates:

Install	14-Dec-00
Download 1	29-May-01
Download 2	7-Aug-01
Download 3	26-Oct-02
Download 4	10-Jan-02
Download 5	28-Mar-02
end	12-Sep-02

Building Description General:

Building identification: SITE 23

General Building Data:

Year of construction:	1996	N/A
	N/A	N/A
Refurbishment HVAC	N/A	N/A
Refurbishment Lighting	N/A	N/A
Refurbishment Other	N/A	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Property Development	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1997	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Underfloor & perimeter radiators	N/a
Ventilation System	Active Chilled beams	N/a
Cooling System	Active Chilled beams	Except Comms / server room
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elec.	N/A
Cooling	Elec.	N/A
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Purpose built office building, connected to an existing building via a pavilion that serves as a joint reception	N/A
Layout	Generally open plan	N/A
Building floor plan showing north	North is bottom of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	4 stories (Ground + 3)	N/A
Floor area (Gross)	3122 sq. m.	Est. * Energy Consumption Guide 19
Floor area (Treated MVAC)	2810 sq. m.	SHU survey
Floor area (Treated MV)	2810 sq. m.	SHU survey
Floor area (Nett Usable Office)	2248 sq. m.	Est. * Energy Consumption Guide 19

Windows

Type	Curtain wall	N/A
Total Area	N/a	N/A
Total Area operable	None	N/A
Type of glazing	Clear Double 16mm Low E	N/A
Area glazing by facade	353 sq. m North	N/A
	353 sq. m South	N/A
	0 sq. m East	Internal only
	34sq. m West	N/A
Percentage of glazing by facade	91% North	N/A
	91% South	N/A
	0% East	Internal only
	8% West	N/A
Glazing (u-value)	2.1 w/m2k	N/a
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	Floors over hang each other by approx 1m	N/A
External shading devices (Size & Loc)	Floors over hang each other by approx 1m	N/A
Internal shading devices (Type)	Vertical Blinds	N/a
Internal shading devices (Location)	Immediately inside glazing	N/A

Other

Wall Structure	Pre-cast concrete panels	N/A
Wall Insulation	Between conc. Cladding and structural frame	To 1996 min standards
Wall area by façade	389 sq. m North	N/A
	389 sq. m South	N/A
	428 sq. m East	N/A
	428sq. m West	N/A
Roof Structure	Flat	N/A
Roof Insulation	Between roof structure	Min 1996 standards
Roof Area	963 sq. m	Est. from plans, phase 2 office block only
Ceiling Type	Suspended	N/A
Ceiling Height	3.0 m	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	90	In phase 2 serviced areas only
Average	81	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	8 am to 6pm M-F	N/A
Cleaning Hours	5:30pm to 7:30pm M-F	N/A
Other Usage	Some out of hours access	HVAC off
Typical Open Office Area	24 people	140 sq. m
Typical Cellular Office	4 person	36 sq. m

Small Power Loads:

Typical Open Office Area:	765 sq. m	Normal occupancy 42 people
	42 x Personal Computers	N/A
	5x Laptop	N/A
	1 x Scanner	N/A
	18 x laser Printer	N/A
	2x photocopier	N/A
	1x fax	N/A

Lighting Loads:

Typical Open Office Area	765 sq. m	Normal occupancy 42 people
	120 x (2 x 2ft) Fluorescent	Ceiling mounted w/ diffuser
	42 x 50W T. Halogen Spots	Recessed ceiling mounts
Lighting controls:	Daylight linked & occupancy sensors	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	Active chilled beams, with under floor heating with displacement ventilation, perimeter radiators serviced from reverse cycle heat-pumps	N/A

List of HVAC plant by location:

Chilled water system	2x York International AWHP 65 L50 951SD Chiller Heatpump	Single packaged air to water chiller heat pump, with 1 six cylinder 4 stage compressor each, 4 integrated fans rated 2kW each .
	Pressurisation Unit	Pullen 2-pump unit rated at 275 W
	Primary Chilled Water pumps	Pullen centrifugal, in-line pump rated 1.5kW
	Secondary chilled water pumps	2x Pullen centrifugal, in-line pump rated 7.5 kW & 0.55 kW
Air Handling system	Dalair supply and return AHU serving entire building	Consisting of Heating, Cooling, humidification, and run-a-round heat recovery coils. Fan's rated 11kW supply and 7.5kW return. Heat-recovery pump rated 1.85kW
Ceiling Void	Halton Active chilled beams	180x chilled beam units, various ratings
Heating system	Pressurisation Unit	Pullen 2-pump unit rated at 275 W
	Primary heating pumps	Pullen centrifugal, in-line pump rated 0.75kW

	Secondary heating pumps	3x Pullen centrifugal, in-line pump rated 1.1kW, 0.25kW & 0.2kW
	Perimeter heating	99x perimeter mounted radiator units, various ratings
	Under floor heating	By Wirsbo Ltd (UK)
Refrigerant Type:	R22	N/A
HVAC Plant Control:	BEMS	optimised to outside temp
Set Points	24 deg C	N/A
Run times of HVAC plant	6:00 to 21:00 M-F	N/A
Identify HVAC zoning of building	North South by floor	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	Stand-a-lone DX split system serving	Not monitored in this study

Monitoring Notes:

General:

In general this building has been consistently occupied and controlled over the entire monitoring period.
WSA have very high confidence in the data acquired from this site

Specific:

Heat Pump Energy Consump	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Heating Supply & Return Temp	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Cooling Supply & Return Temp	High confidence in the Chiller consumption profile and controls appear un-changed through-out monitoring
Interior Temp	This data not available until 6/7/00 (Possible corruption of file by external data)
Exterior Temp	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Heat Pump Energy Consump	kWh @ 10 min intervals
Internal Temperature	Deg C @ 10 min intervals
External Temperature	Deg C @ 10 min intervals
Heating Supply & Return Temp	Deg C @ 10 min intervals
Cooling Supply & Return Temp	Deg C @ 10 min intervals

Estimated load of Primary and Secondary pumps based upon measured run-current
Note includes energy supply to AHU since it is integral to delivery of cooling system..

Summary Information

System Category.	Chilled Ceilings
System Basic Description	Active Chilled Beams
Installed Capacity (Heating)	2x 350kw (2x 300kW)
Rated Power Consumption	2x 72.6 kW
Total Cooling Capacity	700kW
Cooling Capacity By area	249.1

Downloading dates:

Install	20-Apr-00
Download 1	24-May-00
Download 2	06-Jul-00
Download 3	23-Aug-00
Download 4	11-Oct-00
Download 5	17-Nov-00
Download 6	05-Jan-01
Download 7	27-Feb-01
Download 8	25-Apr-01
End	12-Jun-01

Building Description General:

Building identification: **SITE 24**

General Building Data:

Year of construction:	1999	N/A
Refurbishment Fabric	none	N/A
Refurbishment HVAC	2000	Different Air Con system fitted
Refurbishment Lighting	None	entire building
Refurbishment Other	None	N/A
Space Activity	Corporate Offices & Training rooms	N/A
Occupiers Business Type	Multi-national corporation	N/A
Type of tenancy	Tenant	N/A
Tenancy Since	2000	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Centralised Heat-pumps & Fancoils w/ elec. re-heat	N/a
Ventilation System	Tempered Mechanical ventilation	(Min. fresh-air supply only)
Cooling System	Centralised liquid chiller & Fancoils	Additional packaged DX in Comms rooms
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elec	N/A
Cooling	Elec	N/A
DHW	Gas	Centralised
Annual fuel bills:	Yes	n/a
Energy Manager	Yes	Head Office
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	A 2 storey (Ground + 1) speculative built office building	This site comprises just the ground floor of the building.
Layout	Mixture of open plan and cellular, including a number of larger training and conference rooms.	N/A
Building floor plan showing north	See Plan	North is to the upper right hand corner of the plans
Exterior elevations	See Photo & Plans	N/A
Number of floors	1 (2 whole building)	N/A
Floor area (Gross)	812.7 m2	Excluding exterior walls
Floor area (Treated)	738.8 m2	N/A

Windows

Type	Double	12 mm air cavity
Total Area	92.9 sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void, aluminium frames and grey tint.	N/A
Area glazing by facade	9.65 m2 North East	Est. from scaled plans
	31.5 m2 North west	Est. from scaled plans
	31.5 m2 South East	Est. from scaled plans
	20.3 m2 South West	Est. from scaled plans
Percentage of glazing by facade	12.5% North East	Est.
	21.8 % North West	Est.
	21.8 % South East	Est.
	26.3 % South west	Est.
Glazing (u-value)	2.8 W/m2K (3.4 w/m2 w/ metal frames)	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Brick & block cavity	Steel structural frame
Wall Insulation	fiberious cavity insulation per 1999 standards	Est.
Wall area by façade	77.1 m2 North East	N/A
	144.3 m2 North west	N/A
	144.3 m2 South East	N/A
	77.1 m2 South West	N/A
Roof Structure	Wood framed (Eng. Trusses), w/ OSB sheathing, felt and tiles	N/A
Roof Insulation	Fiberious blanket type	Thickness per min spec 1999
Roof Area	None	other floor above this site
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 2.75 m	N/A
Floor to Floor Height (Typical)	aprox 3.25 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	47 nominal total	Est. from Building Mgr.
Average	65% of total at any given time	Est. from Building Mgr.
Typical Visitors	Training event upto 100 people	Infrequent use
Normal Hours	7AM to 8PM M To F	felxi
Cleaning Hours	5:00PM to 19:00PM M to F	N/A
Other Usage	Some individual & evening weekend usage	HVAC Systems off

Small Power Loads:

Typical Office Area:	126.1 sq. m	N/A
	15 x Personal Computers	N/A
	5 x Laptops	N/A
	2 x laser Printer	N/A
	1 x Desk Fan	N/A
	1x Large Photocopier	N/A
	1x Fax	N/A
	1x Plotter	N/A
Typical Cellular Office:	11.6 sq. m	N/A
	1x Personal Computers	N/A
	1x Laptops	N/A
	1x laser Printer	N/A
	1 x Desk Fan	N/A

Lighting Loads:

Typical Open Office Area:	15 W/m2 heat gain	Standard fit throughout building
	(4 x 2ft) Fluorescent	Recessed Ceiling w/ diffuser, HF elec. Ballast
Typical Cellular Office:	As above	N/A
	N/A	N/A
Lighting controls:	Switched zone	Cleaners turn off
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	A 2-pipe 'Change-over' fancoil system with the electrical reheat, supplied by two Carrier Heat Pumps air-cooled reverse cycle air-cooled chillers. Distribution pumps are integrated into the chiller. The system uses R-407c refrigerant and CCN control syst
	Ventilation Equipment	The entire building is mechanically ventilated with a 2-duct supply and return system, within the air handling the unit located in the roof top plant room. The ceiling voids are used as supply plenum.
Heating & Cooling system	2x Carrier Heat Pumps 30RH050	Packaged air cooled reverse cycle heat pump with 2 hermetic scroll compressors in each unit and rated at 45kW cooling 48 kW heating with a nominal input of 19.2 kW. The package includes all heat rejection fans and distribution pumps.
	Fancoils	Carrier two pipe ceiling mounted cassettes with elec re-heat on the perimeter units.

DHW	Centralised system for the entire building using instantaneous gas boilers	This system is not monitored as part of the study.
Refrigerant Type:	R-407c	N/A
HVAC Plant Control:	Carrier CCN system	Optimised on external temperature.
Set Points	Heating 18 deg C Cooling 24 deg C	N/A N/A
Run times of HVAC plant	As per normal occupancy	Plant off during cleaning hours
Identify HVAC zoning of building	2 per floor north & south (Half floor)	Each chiller / heat-pump serves a single zones as a stand-a-lone system.
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	DX split system in comms room	Carrier cooling only single split system

Monitoring Notes:

General:

New a new building occupancy and systems from dec 2000, and appears commissioning / occupancy move in continued through jan 01, as chiller and fancoil energy profiles dic
Client in very aware of the monitoring and wishes the site to look good, thus system changes have been made through out the year to consistently reducing consumption.
Fancoil reheat control changes as part of feedback from monitoring occurred late 2001.
Internal Relative Humidity available from aug 2002 onwards only.

Specific:

Chiller kW Data:	Possible controls changes end jan 01 and aug 01
Fancoil kW Data:	Possible controls changes end April 01 and mid sept 01
Interior Temp:	Gap in data from 30 April to 24 May
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Gap in data from 3 to 24 May 01

Energy supply to Chillers	kWh & kVarh @ 15 min intervals
Energy supply to fancoil units	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15 & 30 min intervals
Internal Relative Humidity	%RH @ 15 min intervals
External Temperature	Deg C @ 15 & 30 min intervals
External Relative Humidity	%RH @ 15 & 30 min intervals

General Notes

System Category	Fancoils
System Basic Description	Chiller HP and 2-pipe fancoils w/ perimeter elec. Reheat.
Installed Cooling Capacity (Heating)	2x 45kW (48kW)
Rated Power Consumption	4x 19.2kW
Total Cooling Capacity	90kW
Cooling Capacity By area	64.97 W/m2

Downloading dates:

Install	16-Nov-00
Download 1	24-Jan-01
Download 2	24-May-01
Download 3	13-Aug-01
Download 4	30-Oct-01
Download 5	17-Jan-02
Download 6	10-Apr-02
Download 7	27-Jun-02
Download 8	6-Aug-02
Download 9	31-Oct-02
Un-installed	21-Jan-03

Building Description General:

Building identification: **SITE 25**

General Building Data:

Year of construction:	1964	N/A
Refurbishment Fabric	1990	N/A
Refurbishment HVAC	2000	AC system fitted
Refurbishment Lighting	1990	entire building
Refurbishment Other	None	N/A
Space Activity	Corporate Offices	N/A
Occupiers Business Type	Multi-national corporation	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1990	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Toshiba reverse cycle split DX systems	Multiple single splits by area
Ventilation System	Passive ventilations	Through roof mounted vents into ceiling void
Cooling System	Toshiba reverse cycle split DX systems	Multiple single splits by area
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elect.	N/A
Cooling	Elect.	N/A
DHW	Gas	Centralised
Annual fuel bills:	Yes	n/a
Energy Manager	Yes	Head Office
HDD	2330 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Two story (ground +1) office block with a central courtyard and a single story warehouse wing.	This site comprises just one area of this building
Layout	Mixture of open plan, cellular, and conference rooms.	N/A
Building floor plan showing north	See Plan	North is to the right of the plans
Exterior elevations	See Photo & Plans	N/A
Number of floors	1 (2 whole building)	N/A
Floor area (Gross)	1851 m2	Excluding exterior walls
Floor area (Treated)	1666 m2	N/A
Windows		
Type	Clear Double	12 mm air cavity
Total Area	382 sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void, aluminium frames	N/A
Area glazing by facade	54 m2 North	Est. from scaled plans
	102 m2 South	Est. from scaled plans
	114 m2 East	Est. from scaled plans
	112 m2 West	Est. from scaled plans
Percentage of glazing by facade	22% North	Est.
	43% South	Est.
	37% East	Est.
	36% West	Est.
Glazing (u-value)	3.4 w/m2 w/ metal frames	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A
Other		

Wall Structure	Brick & block cavity	Conc. structural frame
Wall Insulation	fiberious cavity insulation per 1999 standards	Est.
Wall area by façade	238 m2 North	N/A
	238 m2 South	N/A
	308 m2 East	N/A
	308. m2 West	N/A
Roof Structure	Conc. structural frame	N/A
Roof Insulation	Fiberious blanket type above ceiling	Thickness per min spec 1999
Roof Area	926 sq m	N/A
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 3m	N/A
Floor to Floor Height (Typical)	aprox 3.9 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	205 nominal total	Est. from Building Mgr.
Average	90% of total at any given time	Est. from Building Mgr.
Typical Visitors	Minimal	
Normal Hours	8AM to 6PM M To F	N/A
Cleaning Hours	Inside normal	N/A
Other Usage	Some evening and weekend usage	HVAC Systems off

Small Power Loads:

Typical Office Area:	75 sq. m	Normal occupancy 7
	7 x Personal Computers	N/A
	2 x Laptops	N/A
	1 x laser Printer	N/A
	1 x Desk Fan	N/A
	0.2x Large Photocopier	N/A
	0.2x Fax	N/A

Lighting Loads:

Typical Open Office:	12 x (3 x 36 watts fluorescent	Standard fit throughout building
Lighting controls:	Switched zone	N/a
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	This area is conditioned by Toshiba reverse cycle single split DX systems. The condensers are located on the roof with internal ceiling mounted cassettes.
	Ventilation Equipment	The ceiling void is used as a fresh air supply plenum from roof mounted passive vents. This unit provides minimum fresh air supply only.
Heating & Cooling system	Toshiba 3-pipe Heat Recovery VRF	Various unit configuration depending upon space The monitored area was serviced by a condenser units rated @ 3.6kW cooling capacity and 4.2kW heating.
	The original gas fired wet-perimeter heating system has been retained.	This system is NOT typically used, except as back up and for condensation control during particularly cold periods. (Used less than 10hours in 2001)
DHW	All domestic hot water is supplied locally from direct electric water heaters.	This system is not monitored as part of the study.
Refrigerant Type:	R-407c	N/A
HVAC Plant Control:	Trend BEMS and Toshiba integrated controls	Trend optimised on external temperature and interlocks to separate heating system.
Set Points	Heating 18 deg C Cooling 24 deg C	N/A N/A
Run times of HVAC plant	As per normal occupancy	Plant off during cleaning hours

Identify HVAC zoning of building	Internal units grouped by area (cellular or open)	Each chillier / heat-pump serves a single zones as a stand-a-lone system.
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	Separate DX split system in other areas of this complex.	Toshiba cooling only single split systems

Monitoring Notes:

General:

Building Owner is generally pleased with the energy performance of the system as compared to previous system.
Some controls changes may have from the monitoring and feedback discussions.
Passive Ventilation in this area

Specific:

DX Split Energy Consump	Highly confident in the quality and accuracy of this data over the entire monitoring period kVarh data appears as zero throughout which is questionable but no equipment faults could be found.
Interior Temp + RH	Highly confident in the quality and accuracy of this data over the entire monitoring period
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to DX Split	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

General Notes

System Category	DX Split System
System Basic Description	Toshiba Reverse Cycle DX split
Installed Cooling Capacity (Heating)	1x 3.6kW (4.2 Heat)
Rated Power Consumption	n/a
Total Cooling Capacity	3.6 kW
Cooling Capacity By area	47.7 W/m2

Downloading dates:

Install	08-Mar-01
Download 1	23-May-01
Download 2	09-Aug-01
Download 3	30-Oct-01
Download 4	17-Jan-02
Download 5	12-Apr-02
Download 6	11-Jul-02
Un-installed	26-Dec-02

Building Description General:

Building identification: **SITE 26**

General Building Data:

Year of construction:	1973	N/A
Refurbishment Fabric	none	N/A
Refurbishment HVAC	2000	AC system fitted
Refurbishment Lighting	1990's	entire building
Refurbishment Other	None	N/A
Space Activity	Computer centre	N/A
Occupiers Business Type	Local council	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1973	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Reverse cycle split DX systems	Multiple single splits by area
Ventilation System	Local thru wall fan ventilations	Local control
Cooling System	Reverse cycle split DX systems	Multiple single splits by area
	Airedale close control on computer suite	stand-a-lone system this area only
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elect.	N/A
Cooling	Elect.	N/A
DHW	Elect.	Localised
Annual fuel bills:	Yes	On request
Energy Manager	Yes	Head Office
HDD	2434 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General		
Configuration	Two story (ground +1) office block.	This site comprises just one area of this building
Layout	Mixture of open plan, cellular, and computer suite	Computer suite has serviced separately
Building floor plan showing north	See Plan	North is to the bottom right hand corner of the plans
Exterior elevations	Not available	At request of client for security reasons
Number of floors	2	N/A
Floor area (Gross)	1114 m2	N/A
Floor area (Treated)	1003 m2	N/A
Windows		
Type	Tinted Double	12 mm air cavity
Total Area	sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void, aluminium frames	N/A
Area glazing by facade	10.5 m2 North West	Est. from scaled plans
	25.5 m2 North East	Est. from scaled plans
	23.1 m2 South East	Est. from scaled plans
	10.5 m2 South West	Est. from scaled plans
Percentage of glazing by facade	8% North West	Est.
	24% North East	Est.
	17% m2 South East	Est.
	10% South West	Est.
Glazing (u-value)	3.4 w/m2 w/ metal frames	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A
Other		
Wall Structure	Brick & block cavity	Conc. Slab and masonry

Wall Insulation	fiberious cavity insulation per 1973 standards	Est.
Wall area by façade	134.9 m2 North West	N/A
	106.8 m2 North East	N/A
	134.9 m2 South East	N/A
	106.8 m2 South West	N/A
Roof Structure	Conc. structural frame	N/A
Roof Insulation	Fiberious blanket type above ceiling	Thickness per min spec 1973
Roof Area	757 sq m	N/A
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 2.7m	N/A
Floor to Floor Height (Typical)	aprox 3.3 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	100 nominal total	Est. from Building Mgr.
Average	80% of total at any given time	Est. from Building Mgr.
Typical Visitors	Minimal	
Normal Hours	6AM to 9:35PM M To F	N/A
	7AM to 2PM weekend	10-20% staff only
Cleaning Hours	Inside normal hours	N/A
Other Usage	Some evening and weekend usage	HVAC Systems off in office areas
Small Power Loads:		
Typical Office Area:	13 sq. m	Normal occupancy 2
	3 x Personal Computers	N/A
	1 x laser Printer	N/A
	1 x Desk Fan	N/A
Lighting Loads:		
Typical Open Office:	3 x (2 x 58 watts fluorescent	Standard fit throughout building
Lighting controls:	Switched zone / room	N/a
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location: (Office Areas Only)	System Description	This area is conditioned by Daikin reverse cycle single split DX systems. The condensers are located on the roof with internal wall mounted cassettes.
	Ventilation Equipment	Localised thru wall ventilators are provided in each space. The units are on local control for on/off, supply and extract. These units are sized to meet min. ventilation requirements only.
Heating & Cooling system	Daikin reverse cycle single DX split systems	Various unit sizes all on local occupant control. The monitored area was serviced by a single split unit with a cooling capacity of 2.5kW.
DHW	All domestic hot water is supplied locally from direct electric water heaters.	This system is not monitored as part of the study.
Refrigerant Type:	R-22	N/A
HVAC Plant Control:	Local	No interlocks on unit controls even within common occupancy spaces.
Set Points	Heating 18 deg C	N/A
	Cooling 25 deg C	N/A
Run times of HVAC plant	As per normal occupancy	N/a
Identify HVAC zoning of building	Localised	N/a
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	Airedale close control forced-air DX system in comms suite	This is a separate and stand-a-lone system.

Monitoring Notes:

General:

Building Owner is generally pleased with the energy performance of the system as compared to previous system.

Specific:

DX Split Energy Consump	Highly confident in the quality and accuracy of this data over the entire monitoring period
Interior Temp's	Highly confident in the quality and accuracy of this data over the entire monitoring period
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to DX Split	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals Average reading of 3 areas covered by the system
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

Summary Info.

System Category	Dx Split
System Basic Description	Multiple Single reverse cycle DX split systems on local control
Installed Capacity (Heating)	2.5kW (2.6kW)
Rated Power Consumption	1.73kW
Total Cooling Capacity	2.5kW
Cooling Capacity By area	144.51 W/m2

Downloading dates:

Install	26-Apr-01
Download 1	12-Jul-01
Download 2	02-Oct-01
Download 3	10-Dec-01
End	28-Feb-02
Un-Install	21-May-02
	21-Jun-02
	05-Oct-02

Building Description General:

Building identification: **SITE 27**

General Building Data:

Year of construction:	1973	N/A
Refurbishment Fabric	none	N/A
Refurbishment HVAC	2000	AC system fitted
Refurbishment Lighting	1990's	entire building
Refurbishment Other	None	N/A
Space Activity	Computer centre	N/A
Occupiers Business Type	Local council	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1973	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Reverse cycle split DX systems	Multiple single splits by area
Ventilation System	Local thru wall fan ventilations	Local control
Cooling System	Reverse cycle split DX systems	Multiple single splits by area
	Airedale close control on computer suite	stand-a-lone system this area only
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elect.	N/A
Cooling	Elect.	N/A
DHW	Elect.	Localised
Annual fuel bills:	Yes	On request
Energy Manager	Yes	Head Office
HDD	2434 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Two story (ground +1) office block.	This site comprises just one area of this building
Layout	Mixture of open plan, cellular, and computer suite	Computer suite has serviced separately
Building floor plan showing north	See Plan	North is to the bottom right hand corner of the plans
Exterior elevations	Not available	At request of client for security reasons
Number of floors	2	N/A
Floor area (Gross)	1114 m2	N/A
Floor area (Treated)	1003 m2	N/A

Windows

Type	Tinted Double	12 mm air cavity
Total Area	sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void, aluminium frames	N/A
Area glazing by facade	10.5 m2 North West	Est. from scaled plans
	25.5 m2 North East	Est. from scaled plans
	23.1 m2 South East	Est. from scaled plans
	10.5 m2 South West	Est. from scaled plans
Percentage of glazing by facade	8% North West	Est.
	24% North East	Est.
	17% m2 South East	Est.
	10% South West	Est.
Glazing (u-value)	3.4 w/m2 w/ metal frames	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Brick & block cavity	Conc. Slab and masonry

Wall Insulation	fiberious cavity insulation per 1973 standards	Est.
Wall area by façade	134.9 m2 North West	N/A
	106.8 m2 North East	N/A
	134.9 m2 South East	N/A
	106.8 m2 South West	N/A
Roof Structure	Conc. structural frame	N/A
Roof Insulation	Fiberious blanket type above ceiling	Thickness per min spec 1973
Roof Area	757 sq m	N/A
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 2.7m	N/A
Floor to Floor Height (Typical)	aprox 3.3 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	100 nominal total	Est. from Building Mgr.
Average	80% of total at any given time	Est. from Building Mgr.
Typical Visitors	Minimal	
Normal Hours	6AM to 9:35PM M To F	N/A
	7AM to 2PM weekend	10-20% staff only
Cleaning Hours	Inside normal hours	N/A
Other Usage	Some evening and weekend usage	HVAC Systems off in office areas
Small Power Loads:		
Typical Office Area:	17 sq. m	Normal occupancy 5
	5 x Personal Computers	N/A
	1 x laser Printer	N/A
	1 x Desk Fan	N/A
Lighting Loads:		
Typical Open Office:	4 x (2 x 58 watt) fluorescent	Standard fit throughout building
Lighting controls:	Switched zone / room	N/a
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location: (Office Areas Only)	System Description	This area is conditioned by Daikin reverse cycle single split DX systems. The condensers are located on the roof with internal wall mounted cassettes.
	Ventilation Equipment	Localised thru wall ventilators are provided in each space. The units are on local control for on/off, supply and extract. These units are sized to meet min. ventilation requirements only.
Heating & Cooling system	Daikin reverse cycle single DX split systems	Various unit sizes all on local occupant control. The monitored area was serviced by 6 single split DX units.
DHW	All domestic hot water is supplied locally from direct electric water heaters.	This system is not monitored as part of the study.
Refrigerant Type:	R-22	N/A
HVAC Plant Control:	Local	No interlocks on unit controls even within common occupancy spaces.
Set Points	Heating 18 deg C	N/A
	Cooling 25 deg C	N/A
Run times of HVAC plant	As per normal occupancy	N/a
Identify HVAC zoning of building	Localised	N/a
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	Airedale close control forced-air DX system in comms suite	This is a separate and stand-a-lone system.

Monitoring Notes:

General:

Building Owner is generally pleased with the energy performance of the system as compared to previous system.

Specific:

DX Split Energy Consump	Highly confident in the quality and accuracy of this data over the entire monitoring period
Interior Temp's	Highly confident in the quality and accuracy of this data over the entire monitoring period
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to DX Split	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals Average reading of 3 areas covered by the system
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

Summary Info.

System Category	Dx Split
System Basic Description	Multiple Single reverse cycle DX split systems on local control
Installed Capacity (Heating)	18kW (18.7kW)
Rated Power Consumption	9.57kW
Total Cooling Capacity	18kW
Cooling Capacity By area	309.7 W/m2

Downloading dates:

Install	26-Apr-01
Download 1	12-Jul-01
Download 2	02-Oct-01
Download 3	10-Dec-01
Download 4	28-Feb-02
Download 5	21-May-02
End	21-Jun-02
Un-Install	05-Oct-02

Building Description General:

Building identification: SITE 28

General Building Data:

Year of construction:	1999	N/A
Refurbishment Fabric	none	N/A
Refurbishment HVAC	2000	Different Air Con system fitted
Refurbishment Lighting	None	entire building
Refurbishment Other	None	N/A
Space Activity	Corporate Offices	N/A
Occupiers Business Type	Multi-national corporation	N/A
Type of tenancy	Tenant	N/A
Tenancy Since	2000	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Toshiba 3-pipe heat recovery VRF multi-split DX system	N/a
Ventilation System	Tempered Mechanical ventilation	(Min. fresh-air supply only)
Cooling System	Toshiba 3-pipe heat recovery VRF multi-split DX system	Additional packaged DX in Comms rooms
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Daylit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elec	N/A
Cooling	Elec	N/A
DHW	Gas	Centralised
Annual fuel bills:	Yes	n/a
Energy Manager	Yes	Head Office
HDD	1977 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	A 2 storey (Ground + 1) speculative built office building	This site comprises just the 1st floor of the building.
Layout	Mixture of open plan, cellular, and conference rooms.	N/A
Building floor plan showing north	See Plan	North is to the upper right hand corner of the plans
Exterior elevations	See Photo & Plans	N/A
Number of floors	1 (2 whole building)	N/A
Floor area (Gross)	812.7 m2	Excluding exterior walls
Floor area (Treated)	738.8 m2	N/A

Windows

Type	Double	12 mm air cavity
Total Area	113.2 sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void, aluminium frames and grey tint.	N/A
Area glazing by facade	9.65 m2 North East	Est. from scaled plans
	31.5 m2 North west	Est. from scaled plans
	40.5 m2 South East	Est. from scaled plans
	31.55 m2 South West	Est. from scaled plans
Percentage of glazing by facade	12.5% North East	Est.
	21.8 % North West	Est.
	28.1 % South East	Est.
	40.1 % South west	Est.
Glazing (u-value)	2.8 W/m2K (3.4 w/m2 w/ metal frames)	*The building act 1984, DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Brick & block cavity	Steel structural frame
Wall Insulation	fiberious cavity insulation per 1999 standards	Est.
Wall area by façade	77.1 m2 North East	N/A
	144.3 m2 North west	N/A
	144.3 m2 South East	N/A
	77.1 m2 South West	N/A
Roof Structure	Wood framed (Eng. Trusses), w/ OSB sheathing, felt and tiles	N/A
Roof Insulation	Fiberious blanket type	Thickness per min spec 1999
Roof Area	None	other floor above this site
Ceiling Type	Suspended	Plywood sub-ceiling from roof structure above
Ceiling Height (Typical)	aprox 2.75 m	N/A
Floor to Floor Height (Typical)	aprox 3.25 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	54 nominal total	Est. from Building Mgr.
Average	65% of total at any given time	Est. from Building Mgr.
Typical Visitors	Mixed	
Normal Hours	7AM to 8PM M To F	felxi
Cleaning Hours	5:00PM to 19:00PM M to F	N/A
Other Usage	Some individual & evening weekend usage	HVAC Systems off

Small Power Loads:

Typical Office Area:	126.1 sq. m	N/A
	15 x Personal Computers	N/A
	5 x Laptops	N/A
	2 x laser Printer	N/A
	1 x Desk Fan	N/A
	1x Large Photocopier	N/A
	1x Fax	N/A
	1x Plotter	N/A
Typical Cellular Office:	11.6 sq. m	N/A
	1x Personal Computers	N/A
	1x Laptops	N/A
	1x laser Printer	N/A
	1 x Desk Fan	N/A

Lighting Loads:

Typical Open Office Area:	15 W/m2 heat gain	Standard fit throughout building
	(4 x 2ft) Fluorescent	Recessed Ceiling w/ diffuser, HF elec. Ballast
Typical Cellular Office:	As above	N/A
	N/A	N/A
Lighting controls:	Switched zone	Cleaners turn off
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	The first floor is a conditioned by Toshiba VRF units of the 3 pipe heat recovery type. The condensers are roof mounted with internal ceiling mounted cassettes. The cassettes draw air from the ceiling void that is also supplied with fresh tempered air f
	Ventilation Equipment	The entire building is mechanically ventilated with a 2-duct supply and return system, within the air handling the unit located in the roof top plant room. The ceiling voids are used as supply plenum.
Heating & Cooling system	Toshiba 3-pipe Heat Recovery VRF	A bank of 4 condenser units each rated @ 25kW cooling capacity and 28kW heating. With a nominal rated input of 11.8kW.
		15x ceiling mounted cassettes of various sizes

DHW	Centralised system for the entire building using instantaneous gas boilers	This system is not monitored as part of the study.
Refrigerant Type:	R-407c	N/A
HVAC Plant Control:	Toshiba integrated controls	Optimised on external temperature.
Set Points	Heating 18 deg C Cooling 24 deg C	N/A N/A
Run times of HVAC plant	As per normal occupancy	Plant off during cleaning hours
Identify HVAC zoning of building	Internal units grouped by area (cellular or open)	Each chiller / heat-pump serves a single zones as a stand-a-lone system.
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	Separate DX split system in comms room (Dedicated VRF internal unit acts as backup)	Carrier cooling only single split system

Monitoring Notes:

General:

New a new building occupancy and systems from dec 2000, and appears commissioning / occupancy move in continued through jan 01, as chiller and fancoil energy profiles dic
Client in very aware of the monitoring and wishes the site to look good, thus system changes have been made through out the year to consistently reducing consumption.

Specific:

VRF Energy	Control change, 7 Day Timer installed 13 /8 / 2001 (24 hr / 7day operation until now)
Interior Temp	Gap in data from 29 April to 24 May 01
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment
	Gap in data from 3 to 24 May 01

Energy supply to VRF HR system	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15 min intervals
Internal Relative Humidity	%RH @ 15 min intervals
External Temperature	Deg C @ 15 min intervals
External Relative Humidity	%RH @ 15 min intervals

General Notes

System Category	VRF HR
System Basic Description	Toshiba DX 3-pipe Heat Recovery VRF
Installed Cooling Capacity (Heating)	4x 25kW (28kW)
Rated Power Consumption	4x 11.8kW
Total Cooling Capacity	100kW
Cooling Capacity By area	135.35 W/m2

Downloading dates:

Install	16-Nov-00
Download 1	24-Jan-01
Download 2	24-May-01
Download 3	13-Aug-01
Download 4	30-Oct-01
Download 5	17-Jan-02
Download 6	10-Apr-02
Download 7	27-Jun-02
Download 8	6-Aug-02
Download 9	31-Oct-02
Un-installed	21-Jan-03

Building Description General:

Building identification: **SITE 29**

General Building Data:

Year of construction:	1940	N/A
Refurbishment HVAC	1996	VRF HR system added
Refurbishment Lighting	1997	All new services
Refurbishment Other	1997	Complete re-build
Space Activity	Offices	N/A
Occupiers Business Type	Engineering & sales	N/A
Type of tenancy	Occupier Owned	N/A
Tenancy Since	1996	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	VRF Hest Recovery	Whole building
Ventilation System	Natural	N/a
Cooling System	VRF Hest Recovery	Whole building
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	HA Artificial-lit Hall	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elec.	N/A
Cooling	Elec.	N/A
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	2380 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Small 2 storey office building.	N/A
Layout	Mixture of cellular spaces on the ground floor and mainly open plan on the 1st floor	N/A
Building floor plan showing north	North is bottom right hand corner of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	Ground + 1	N/A
Floor area (Gross)	386 sq m	Scaled from plans
Floor area (Treated MVAC)	347.4 sq m	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	none	N/a
Floor area (Nett Usable Office)	277.9 sq m	Est. * Energy Consumption Guide 19

Windows

Type	None	N/A
Total Area	N/a	N/A
Total Area operable	N/a	N/A
Type of glazing	12mm double clear	N/A
Area glazing by facade	North 11.13 sq m	N/A
	South 13.43 sq m	N/A
	East none	N/A
	West 3.31 sq m	N/A
Percentage of glazing by facade	15% north	N/A
	18% south	N/A
	0% east	N/A
	5.3 % west	N/A
Glazing (u-value)	2.7 w/m2K	N/a
Size & location of trickle vents	one per window	Integral into uPVC window frame
Window Reveals & Overhangs (Size & Loc)	100mm aprox	N/A
External shading devices (Size & Loc)	none	N/A
Internal shading devices (Type)	Vertical blinds	N/a
Internal shading devices (Location)	immediately behind windows	N/A

Other

Wall Structure	Rendered brick & block with cavity	N/A
Wall Insulation	Injected foam in cavity	N/A
Wall area by façade	74 sq. m North	N/A
	74 sq. m South	N/A

	62.5 sq. m East	N/A
	62.5 sq. m West	N/A
Roof Structure	Concrete tiles on pitched area, felt or asphalt on flat roof area	N/A
Roof Insulation	Integral to cladding roofing system	N/A
Roof Area	1845 sq. m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	2.3 m ground floor	1st floor 1.76m sloping to aprox 4 m

Building Occupancy and Operation:

Occupancy

Staff Total	25	In phase 2 serviced areas only
Average	22	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	08:00 am to 22:00 M-F	upto 20% working late daily
Cleaning Hours	within normal hours	N/A
Other Usage	none	10 - 20 Persons only
Typical Open Office Area	6 people	90 sq. m
Typical Cellular Office	1 person	11.9 sq. m

Small Power Loads:

Typical Open Office Area:	90 sq. m	N/A
	6 x Personal Computers	N/A
	1 x laser Printer	N/A
	1 x Photocopier	N/A
Typical Cellular Office	11.9 sq. m	N/A
	1 x Personal Computer	N/A

Lighting Loads:

Typical Open Office Area	90 sq. m	N/A
	10 x 100watt Tungsten Halogen	Up-lighter wall mounted
	10 x 100watt Tungsten Halogen	Ceiling mounted uplighter
Typical Cellular Office	11.9 sq. m	N/A
	2x (2x 2ft) Fluorescent recessed	N/A
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

General HVAC System Description:	Toshiba VRF 3-pipe heating and cooling Multi-split DX system, with heat recovery allowing simultaneous heating and cooling.	Natural ventilation

List of HVAC plant by location:

Exterior Enclosure	2x Toshiba 3 pipe VRF HR super multi condensers	All refrigeration, distribution and controls are integral to the condenser unit
Ground Floor Ceiling Void	5x Internal ceiling cassettes	7.1 kW cooling (7.9 heating) each
1st Floor Ceiling Void	5x Internal ceiling cassettes	7.1 kW cooling (7.9 heating) each
Refrigerant Type:	R407c	N/A
HVAC Plant Control:	Timed On/Off to match occupancy	Local control on room stats
Set Points	Range from 18 to 28 Deg C	As per occupants control and season
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	By floor and cellular space	Each condenser serves an individual floor, each internal cassette unit is controlled individually
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Monitoring Notes:

General:

Building Owner is generally pleased with the energy performance of the system as compared to previous system.
Some controls changes may have from the monitoring and feedback discussions.

Specific:

VRF Energy Consump	Distinct change in VRF energy consumption profile on 26/02/01, probable setting of 7 day timer. Shutting of
Interior Temp	Interior temperature logger shows distinct change in temperature profiles corresponding to setting of 7 day t
Exterior Temp +RH:	Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to VRF	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

Summary Info.

System Category	VRF Heat Recovery
System Basic Description	Toshiba 3-Pipe Heat Recovery Multi-split DX system (Heating & Cooling)
Installed Capacity (Heating)	50kW (56kW)
Rated Power Consumption	23.6kW
Total Cooling Capacity	50kW
Cooling Capacity By area	143.9 W/m2

Downloading dates:

Install	14-Sep-00
Download 1	30-Nov-00
Download 2	20-Feb-01
Download 3	11-Jul-01
Download 4	11-Dec-01
Download 5	01-Mar-02
Un-Install	22-May-00

Building Description General:

Building identification: SITE 30

General Building Data:

Year of construction:	1960's	N/A
	N/A	N/A
Refurbishment HVAC	1999	New Air Conditioning system
Refurbishment Lighting	1999	New in this area of the building
Refurbishment Other	N/A	N/A
Space Activity	Offices	N/A
Occupiers Business Type	Engineering	N/A
Type of tenancy	Owned	Office space within larger industrial building
Tenancy Since	This area new use 1999	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	VRF HR	This area only
Ventilation System	Mechanical Ventilation	For entire building
Cooling System	VRF HR	This area only
Econ 19 Category	Type 3 (Air Conditioned Standard)	* Energy Consumption Guide 19
Building Category BRE	HD Top-lit Hall	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elec.	This area only
Cooling	Elec.	This area only
DHW	Elec.	Localised
Annual fuel bills:	No	Available at request
Energy Manager	Yes	On-site
HDD	2276 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Large steel framed light industrial building top lit from skylights	N/A
Layout	Generally large open plan areas w/ some smaller cellular	N/A
Building floor plan showing north	North is top right hand corner of plans	N/A
Exterior elevations	See Image	N/A
Number of floors	Ground + mezzanine	N/A
Floor area (Gross)	469.7 sq m	Scaled from plans
Floor area (Treated MVAC)	427.7 sq m	Est. * Energy Consumption Guide 19
Floor area (Treated MV)	427.7 sq m	Est. * Energy Consumption Guide 19
Floor area (Nett Usable Office)	342.2 sq m	Est. * Energy Consumption Guide 19

Windows

Type	Single glazed fixed	Mezzanine level only
Total Area	144.3	N/A
Total Area operable	0	N/A
Type of glazing	Single frosted	N/A
Area glazing by facade	67.5 sq m North	Est. from plans
	67.5 sq m North	Est. from plans
	0 sq m East	Est. from plans
	0 sq m West	Est. from plans
Percentage of glazing by facade	N/a	Part of larger structure
	N/a	Part of larger structure
	N/a	Part of larger structure
	N/a	Part of larger structure
Glazing (u-value)	4.8 w/m2K	N/a
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc)	Minimal	N/A
External shading devices (Size & Loc)	None	N/A
Internal shading devices (Type)	Vertical blinds	N/a
Internal shading devices (Location)	Immediately behind glazing	N/A

Other

Wall Structure	Metal cladding system on steel frame and purlins.	N/A
Wall Insulation	100mm rock wool	N/A

Wall area by façade	81 sq m North	(plus 16.3 sq m to other internal space)
	81 sq m North	(plus 16.3 sq m to other internal space)
	89.9 sq m East	To internal space only
	97.5 sq m West	To internal space only
Roof Structure	see walls	N/A
Roof Insulation	see walls	N/A
Roof Area	405 sq m	Est. from plans
Ceiling Type	Suspended	N/A
Ceiling Height	2.5 & 3.5m	N/A

Building Occupancy and Operation:

Occupancy

Staff Total	78	In phase 2 serviced areas only
Average	70	Est. *CIBSE Guide
Typical Visitors	Minimal	N/A
Normal Hours	9 am to 5:30pm M-F	N/A
Cleaning Hours	within normal hours	N/A
Other Usage	N/A	n/A
Typical Open Office Area	6 people	38 sq m
Typical Cellular Office	1 person	Various see plan

Small Power Loads:

Typical Open Office Area:	38 sq m	N/A
	6 x Personal Computers	N/A
	1 x Scanner	N/A
	1 x laser Printer	N/A
	1 x Desk Fan	N/A
Typical Cellular Office	Various see plan	N/A
	1 x Personal Computer	N/A
	1 Laser printer	N/A

Lighting Loads:

Typical Office Area	38 sq m	Normal occupancy 6 people
	3 x (3 x 4ft) Fluorescent	Ceiling mounted w/ diffuser
Lighting controls:	Local by bank or cellular space	N/a
Special energy uses:	None	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	Toshiba VRF units of the 3 pipe heat recovery type. The condensers are roof mounted with internal ceiling mounted cassettes. The cassettes draw air from the ceiling void that is also supplied with fresh tempered air from the mechanical ventilation syste
	Ventilation Equipment	The entire building is mechanically ventilated with a 2-duct supply and return system, within the air handling the unit located in the roof top plant room. The ceiling voids are used as supply plenum. This system is not monitored as part of the study.
Heating & Cooling system	Toshiba 3-pipe Heat Recovery VRF	A bank of 4 condenser units each rated @ 25kW cooling capacity and 28kW heating. With a nominal rated input of 11.8kW. 28x ceiling mounted cassettes of various sizes
DHW	Localised elec. Point of use	This system is not monitored as part of the study.
Refrigerant Type:	R-407c	N/A
HVAC Plant Control:	Toshiba integrated controls	N/a
Set Points	Heating 18 deg C	N/A
	Cooling 24 deg C	N/A

Run times of HVAC plant	As per normal occupancy	N/a
Identify HVAC zoning of building	Internal units grouped by area (cellular or open)	Each chiller / heat-pump serves a single zones as a stand-a-lone system.
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	N/a	N/a

Monitoring Notes:

General:

Building Owner is generally very energy conscious with an active M&T policy leading to reduced out-of-hours plant operation.
Some controls changes may have from the monitoring and feedback discussions.
Initially occupant comfort was a problem, installation faults were found end of summer 2001, energy consumption and thermal comfort have improved greatl

Specific:

VRF Energy Consump	Possible control changes from 24hrs/7day to timer set on 15/11/01 (7Day timer set later in year)
Interior Temp	High confidence in the quality of this data thought out the monitoring period
Exterior Temp +RH:	RH data should be disregarded as faulty logger provided un-reliable data before failing completely Subject to local building conditions and possible interference from building fabric and equipment Particularly on peak summer temperatures which appear high.

Monitoring Points:

Energy supply to VRF	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

Summary Info.

System Category	VRF Heat Recovery
System Basic Description	Toshiba 3-Pipe Heat Recovery Multi-split DX system (Heating & Cooling)
Installed Capacity (Heating)	100kW (112kW)
Rated Power Consumption	47.2kW
Total Cooling Capacity	100kW (112kW)
Cooling Capacity By area	233.8W/m2

Downloading dates:

Install	14-Sep-00
Download 1	30-Nov-00
Download 2	20-Feb-01
Download 3	14-Sep-00
Download 4	11-Jul-01
Download 5	11-Dec-01
Download 6	01-Mar-02
Download 7	22-May-02
End	06-Nov-02

Building Description General:

Building identification: **SITE 31**

General Building Data:

Year of construction:	1964	N/A
Refurbishment Fabric	1990	N/A
Refurbishment HVAC	2000	AC system fitted
Refurbishment Lighting	1990	entire building
Refurbishment Other	None	N/A
Space Activity	Corporate Offices	N/A
Occupiers Business Type	Multi-national corporation	N/A
Type of tenancy	Owner occupied	N/A
Tenancy Since	1990	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Toshiba 3-pipe heat recovery VRF multi-split DX system	N/a
Ventilation System	Tempered Mechanical ventilation	(Min. fresh-air supply only)
Cooling System	Toshiba 3-pipe heat recovery VRF multi-split DX system	N/a
Econ 19 Category	Type 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip 1 to 4 Storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Elect.	N/A
Cooling	Elect.	N/A
DHW	Gas	Centralised
Annual fuel bills:	Yes	n/a
Energy Manager	Yes	Head Office
HDD	2330 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	Two story (ground +1) office block with a central courtyard and a single story warehouse wing.	This site comprises just one area of this building
Layout	Mixture of open plan, cellular, and conference rooms.	N/A
Building floor plan showing north	See Plan	North is to the right of the plans
Exterior elevations	See Photo & Plans	N/A
Number of floors	1 (2 whole building)	N/A
Floor area (Gross)	1851 m2	Excluding exterior walls
Floor area (Treated)	1666 m2	N/A

Windows

Type	Clear Double	12 mm air cavity
Total Area	382 sq. m	Est. from scaled plans
Type of glazing	Double w/ aprox 12mm air void, aluminium frames	N/A
Area glazing by facade	54 m2 North	Est. from scaled plans
	102 m2 South	Est. from scaled plans
	114 m2 East	Est. from scaled plans
	112 m2 West	Est. from scaled plans
Percentage of glazing by facade	22% North	Est.
	43% South	Est.
	37% East	Est.
	36% West	Est.
Glazing (u-value)	3.4 w/m2 w/ metal frames	*The building act 1984; DETR June 2000
Size & location of trickle vents	None	N/A
Window Reveals & Overhangs (Size & Loc.)	Reveals <25mm / Eves none	N/A
External shading devices (Size & Loc.)	None Specific	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately Inside of Glazing	N/A

Other

Wall Structure	Brick & block cavity	Conc. structural frame
Wall Insulation	fiberious cavity insulation per 1999 standards	Est.
Wall area by façade	238 m2 North	N/A
	238 m2 South	N/A
	308 m2 East	N/A
	308. m2 West	N/A
Roof Structure	Conc. structural frame	N/A
Roof Insulation	Fiberious blanket type above ceiling	Thickness per min spec 1999
Roof Area	926 sq m	N/A
Ceiling Type	Suspended	N/A
Ceiling Height (Typical)	aprox 3m	N/A
Floor to Floor Height (Typical)	aprox 3.9 m	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	205 nominal total	Est. from Building Mgr.
Average	90% of total at any given time	Est. from Building Mgr.
Typical Visitors	Minimal	
Normal Hours	8AM to 6PM M To F	N/A
Cleaning Hours	Inside normal	N/A
Other Usage	Some evening and weekend usage	HVAC Systems off

Small Power Loads:

Typical Office Area:	450 sq. m	Normal occupancy 55
	53 x Personal Computers	N/A
	3 x Laptops	N/A
	3 x laser Printer	N/A
	4 x Desk Fan	N/A
	1x Large Photocopier	N/A
	1x Fax	N/A

Lighting Loads:

Typical Open Office:	72 x (3 x 36 watts fluorescent	Standard fit throughout building
Lighting controls:	Switched zone	N/a
Special energy uses:	N/A	N/A

Building HVAC plant:

List of HVAC plant by location:	System Description	This area is conditioned by Toshiba VRF units of the 3 pipe heat recovery type. The condensers are located in the courtyard with internal ceiling mounted cassettes.
	Ventilation Equipment	The ceiling void is used as a fresh air supply plenum from a small packaged air handling unit, which is roof mounted. This unit provides minimum fresh air supply only.
Heating & Cooling system	Toshiba 3-pipe Heat Recovery VRF	A bank of 2 condenser units each rated @ 25kW cooling capacity and 28kW heating. With a nominal rated input of 11.8kW.
		15x Ceiling mounted cassettes of various sizes
	The original gas fired wet-perimeter heating system has been retained.	This system is NOT typically used, except as back up and for condensation control during particularly cold periods. (Used less than 10hours in 2001)
DHW	All domestic hot water is supplied locally from direct electric water heaters.	This system is not monitored as part of the study.
Refrigerant Type:	R-407c	N/A
HVAC Plant Control:	Trend BEMS and Toshiba integrated controls	Trend optimised on external temperature and interlocks to separate heating system.
Set Points	Heating 18 deg C	N/A
	Cooling 24 deg C	N/A
Run times of HVAC plant	As per normal occupancy	Plant off during cleaning hours

Identify HVAC zoning of building	Internal units grouped by area (cellular or open)	Each chillier / heat-pump serves a single zones as a stand-a-lone system.
Details of planned maintenance	Contract maintenance per normal standards and documentation available on request.	N/A
Additional Information:	Separate DX split system in other areas of this complex.	Toshiba cooling only single split systems

Monitoring Notes:

General:

Building Owner is generally pleased with the energy performnace of the system as compared to previous system.
Some controls changes may have from the monitoring and feedback discussions.
Mechanical Ventilation this area, Load Estimated from Measured Current and Run-Times assuming power factor of 0.70

Specific:

DX Split Energy Consump	Highly confident in the qualityy and accuracy of this data over the entire monitoring period
Interior Temp + RH	Highly confident in the qualityy and accuracy of this data over the entire monitoring period
Exterior Temp +RH:	Subject to local building conditions and possible interfearance from building fabric and equipment Particularly on peak summer temperarures which appear high.

Monitoring Points:

Energy supply to DX Split	kWh & kVarh @ 15 min intervals
Internal Temperature	Deg C @ 15or30 min intervals
External Temperature	Deg C @ 15or30 min intervals
External Relative Humidity	%RH @ 15or 30 min intervals

General Notes

System Category	VRF - HR
System Basic Description	Toshiba 3-pipe VRF Heat Recovery
Installed Cooling Capasity (Heating)	2x 25kW (28kW)
Rated Power Consumption	2x 11.8kW
Total Cooling Capacity	50.0
Cooling Capacity By area	117.7

Downloading dates:

Install	08-Mar-01
Download 1	23-May-01
Download 2	09-Aug-01
Download 3	30-Oct-01
Download 4	17-Jan-02
Download 5	12-Apr-02
Download 6	11-Jul-02
Un-installed	26-Dec-02

Building Description General:

Building identification: **SITE 32**

General Building Data:

Year of construction:	1985	N/A
Refurbishment Fabric	N/A	N/A
Refurbishment HVAC	1999	TRV on perimeter heating, new modular boilers and new ceiling mounted cooling only Versatemp Air Conditioning.
Refurbishment Lighting	1999	New H.F. Elec. ballast 3 x 18watt ceiling mounted fluorescent lighting throughout.
Refurbishment Other	N/A	N/A
Space Activity	Office	N/A
Occupiers Business Type	Insurance & Financial services	N/A
Type of tenancy	Owner Occupied	N/A
Tenancy Since	1985	N/A
Caretaker / Porter	Occupiers Own	N/A
Heating System	Boilers / wet perimeter heating	N/A
Ventilation System	Minimum Mechanical ventilation supply	N/A
Cooling System	Versatemp cooling only	N/A
Econ 19 Category	Cat 3 - Air Conditioned Standard	* Energy Consumption Guide 19
Building Category BRE	OD4 - Day lit Open Plan Strip upto 4 storeys	* Non-Domestic Building Energy Fact File
Types of fuel used: Heating	Gas	Boiler and wet perimeter heating
Cooling	Elec.	Centralised chiller & pumps, AHU's by conditioned space
DHW	Elec.	Localised point of use heaters
Annual fuel bills:	No	Available at request
Energy Manager	Yes	Head Office
HDD	2194 Yearly Total on 20 year average	*eebpp web-site
CDD	N/A	N/A

Building Structure and Layout:

General

Configuration	U-shaped 5 storey custom built office building of cast-in-place concrete structure and curtain wall non-load bearing envelope.	N/A
Layout	Mainly Open plan with some cellular	N/A
Building floor plan showing north	See Plans	North is to the top of the plan
Exterior elevations	See Photo	N/A
Number of floors	Ground + 4	N/A
Floor area (Gross)	4326.1 sq. m.	N/A
Floor area (Treated MVAC)	3893.5 sq. m.	N/A
Floor area (Nett Usable Office)	3114.8 sq. m.	N/A

Windows

Type	Sealed	As part of 99/00 refurbishment
Total Area	949.1 sq. m	Est.
Type of glazing	Clear Double w/ aprox 12mm air void	N/A
Area glazing by facade	257.9 sq. m North	Est.
	257.9 sq. m South	Est.
	379.21 sq. m East	Est.
	54.128 sq. m West	Est.
Percentage of glazing by facade	32 % North	Est.
	32 % South	Est.
	61 % East	Est.
	13 % West	Est.
Glazing (u-value)	2.8 W/m2K	*The building act 1984, DETR June 2000
Size & location of trickle vents	none	N/A
Window Reveals & Overhangs (Size & Loc)	Reveals <50mm / Eves none	N/A
External shading devices (Size & Loc)	none	N/A
Internal shading devices (Type)	Vertical Blinds	N/A
Internal shading devices (Location)	Immediately behind glazing	Manual control

Other		
Wall Structure	Cast-in-place concrete	N/A
Wall Insulation	Cavity glass fibre insulation	per 1985 building regulations
Wall area by façade	808.2 sq. m North	N/A
	808.2 sq. m South	N/A
	626.4 sq. m East	N/A
	441.8 sq. m West	N/A
Roof Structure	Flat	N/A
Roof Insulation	Styrofoam rigid insulation	per 1985 building regulations
Roof Area	980 sq. m	Est.
Ceiling Type	Suspended	new 1999
Ceiling Height	3 m	Except ground floor 3.5m
HVAC Spaces Data:		
1	All areas MVAC	N/A

Building Occupancy and Operation:

Occupancy		
Staff Total	225	N/A
Average	203	Est. *CIBSE Guide
Typical Visitors	minimal	N/A
Normal Hours	7am to 8 PM M To F	N/A
Cleaning Hours	Within Normal hours	N/A
Other Usage	7am to 1 PM SAT	N/A
Typical Open Office Area:	10 people	55.6 sq. m (Structural Bay)
Typical Cellular Office:	1 person	Size Various See plan
Small Power Loads:		
Typical Open Office Area:	55.6 sq. m	(Structural Bay)
	10 x Personal Computers	N/A
	6 x laptops	N/A
	1/2 x laser Printer	Based on whole building average
	2 x Desk Fan	N/A
	1/4th Large Photocopier	Based on whole building average
	1/8th Fax	Based on whole building average
Typical Cellular Office:	Size Various See plan	N/A
	1 x Personal Computer	N/A
	1 x Laptop	N/A
Lighting Loads:		
Typical Open Office Area:	55.6 sq. m	(Structural Bay)
	6 x (3 x 18watt) Florescent	Ceiling mounted w/ diffuser (recessed)
Typical Cellular Office:	Size Various See plan	Normal occupancy = 1 person x normal hours (Nat vent)
	2 x (3 x 18watt) Florescent	Ceiling mounted w/ diffuser (recessed)
Lighting controls:	Local switching by bank / room	N/A
Special energy uses:	None	N/A

Building HVAC plant:

General Description:	Unitary Air conditioning system with water-side condensers from water cooling circuit and heat rejection through dry-coolers. Wet perimeter heating system and minimum freshair mechanical ventilation.	
List of HVAC plant by location:		
Boiler Room:	5 x Ideal Concord Super 50-300 series 4 modular boilers	Each rated at 50 kW output and 58.8 Input (Mains Gas), plus 0.9kW electrical control load for the entire bank.
	Primary Heating Pumps	1 x Pair @ 1.5 kW each
	Secondary Heating Pumps	1 x Pair @ 0.55 kW each
Rooftop Equipment:	Packaged AHU	Packaged AHU supply only for minimum tempered freshair ducted to plenum, containing single fan, filter and heating battery of unknown size / rating.

	Dry Cooler	Packaged unit with 14 two stage fans rated @ 1.45 kW and 0.85 kW each.
	Cooling Circuit Pumps	1 x Pair @ 7.5kW each.
Distributed Equipment:	Verstemp unitary air conditioning units.	Ceiling mounted with all office areas on local thermostat control and cooling only from common water condenser water circuit with heat rejection via the dry coolers listed above. All units are R407c working fluid and rated at 1.65kWeach.
Refrigerant Type:	R407c	N/A
HVAC Plant Control:	BEMS	Optimised Honeywell system on all heating and cooling plant.
Set Points	22 +/- 1 deg C	N/A
Run times of HVAC plant	As per occupancy	N/A
Identify HVAC zoning of building	All versatemp operate independently, while perimeter heating is centrally controlled and regulated locally by TRV's.	N/A
Details of planned maintenance	Contract maintenance as per normal standards and documentation available on request.	N/A
Additional Information:	N/A	N/A

Computer Suite:

Floor area:	Located in another building with dedicated services.	Located in another building with dedicated services.

Monitoring Notes

Monitoring by EA, Survey by WSA

All monitoring and analysis at this site was undertaken by EA Load Research Group