ENERGY CONSUMPTION OF AIR CONDITIONING SYSTEMS IN UK OFFICE ENVIRONMENTS

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ABSTRACT

Interim findings are presented from a 3-year field-monitoring programme researching the energy consumption of air-conditioning (A/C) systems in UK Offices. The premise of the work is that little published data exists concerning the energy use of A/C systems in practice.

Preliminary findings from the work indicate that laboratory system efficiency tests are not sufficient to predict whether one A/C system will be more efficient than another when installed in a real building. The work suggests instead that the primary factors affecting A/C system energy performance "as installed" are system design, system control, and the loads served by the system.

Further analysis using dynamic thermal modelling is planned to assess the heating and cooling loads throughout the monitoring period and the resulting system efficiencies, including the effects of plant sizing and part-load performance.

INDEX TERMS

Air Conditioning, Energy Consumption, Monitoring, Office Environments, United Kingdom

INTRODUCTION

Future projections of UK market trends suggest a large increase in the use of air conditioning, along with the resulting increase in energy demand and associated carbon emissions. (BSRIA 2000) Growth in the use of air conditioning threatens the UK government's commitment to reduce greenhouse gas emissions under the Kyoto protocol (Hitchin 2000) and has serious implications for the UK electricity supply infrastructure. (National Grid Company 2001)

In a market where economic, legislative and environmental issues are often in conflict, the ability to select air-conditioning systems that consume the least energy "in practice" is of vital importance if we are to minimise future carbon emissions. Although testing is undertaken to assess the efficiency of air conditioning and refrigeration components under laboratory conditions, (Eurovent 2001) comparatively little is known in the UK about how these efficiencies translate into real world energy consumption.

This research will provide energy consumption information for 34 air-conditioning systems, "as found" in UK office accommodation. The results will highlight those areas of design and operation of air-conditioning systems that were found to be crucial in terms of energy consumption.

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REVIEW OF SYSTEM EFFICIENCIES

Current design advice, based primarily on laboratory testing, (DETR1998) identifies the six main factors affecting the efficiency and power consumption of air-conditioning systems as: load placed on the system; environmental operating conditions; component technology; defrost method; control of the system; and type of refrigerant utilised.

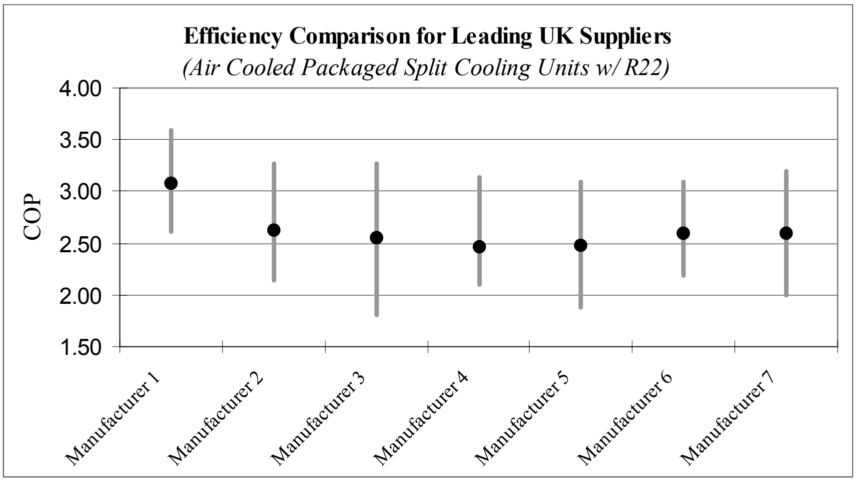

Figure 1. Comparison of system efficiency range by manufacturer

We have produced figures 1 – 4, which show the effects of the type of refrigerant, system capacity and system configuration on the laboratory efficiencies of air-conditioning refrigeration. This data makes allowances for the ancillary items associated with each of the system types, and is based on equipment marketed under the Toshiba, Carrier, Daikin, Mitsubishi, Hitachi, Fujitsu, and Clivet brands. (Eurovent 2001)

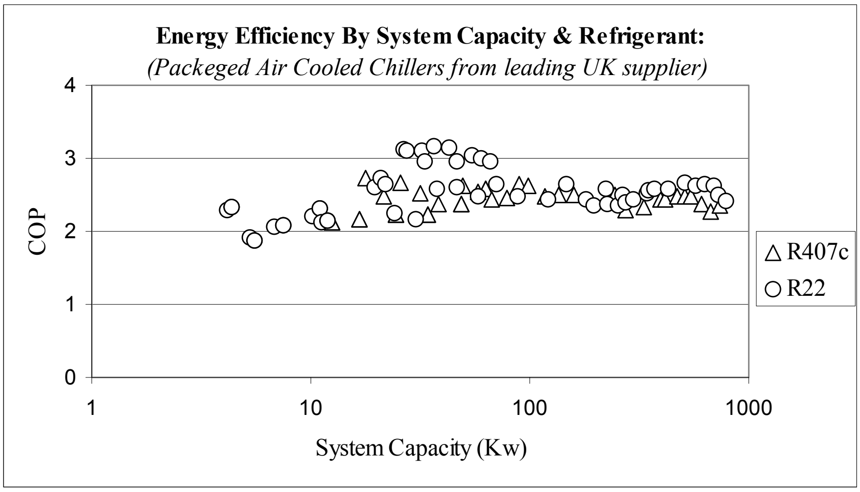

Figure 2. Efficiency variation by system capacity and refrigerant

Figure 1 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 similar equipment.

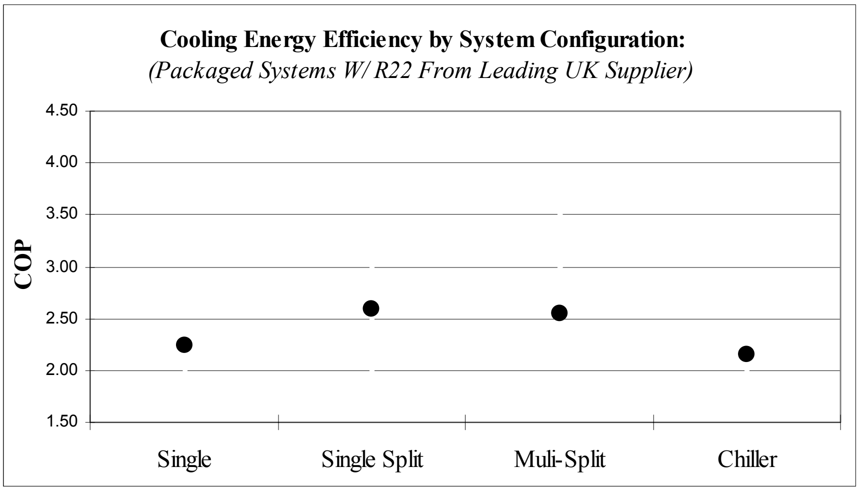

Figure 3. Efficiency variation by System configuration

Differences of 30% in the laboratory efficiencies were also observed between comparable equipment from different manufacturers (Duttine 2000).

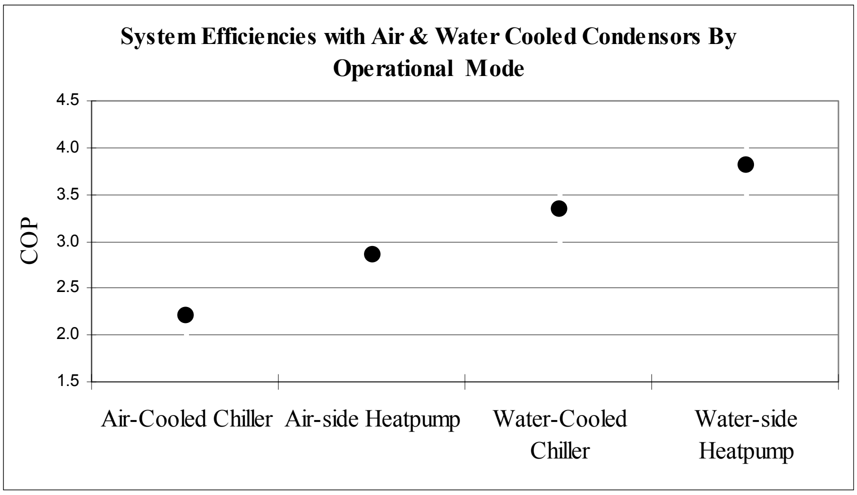

Figure 4. Efficiency by condenser type and operational mode

Figure 2 indicates that system capacity and choice of traditional refrigerant has little impact on the COP of a given system type. The maximum variation in performance is about 16% in this example. Other refrigerants such as ammonia would increase this.

Figure 3 looks at the laboratory data by type of system configuration. It shows some variation between the types, the most significant of which is that the liquid chiller packaged systems appear to be the most inefficient, and almost always less efficient than the multi-split systems.

Figure 4 shows that water-cooled chillers and heat pumps are more efficient than air-cooled systems.

What all four figures, and the data, are unable to tell us though, is exactly how well these systems and all their ancillaries will perform in practice. Current attempts to do this require modelling the proposed system, but there is little empirical data yet available against which the modelling results can be judged.

MEASURING A/C SYSTEM EFFICIENCIES IN PRACTICE

The research aims to establish typical ranges of energy performance that might be expected from the five most common generic A/C system types installed in UK Offices. These system types are: All-Air Systems; Fancoils; Chilled Ceilings; Direct Expansion (DX) Split systems; and DX Variable Refrigerant Flow (VRF) Heat Recovery Systems.

The research involves monitoring the individual energy performance of 34 air conditioning systems in offices around the UK. The number of each system type monitored is summarised in Table 1. Monitoring commenced in April 2000 and is expected to continue until at least summer 2003, aiming to obtain at least 18 months continuous data for each site.

Table1. Numbers of systems by system category

System type	*All - air*	*Fancoils*	*Chilled Ceilings*	*DX - Splits*	*DX - VRF*
Number of sites	9	7	5	9	4

The monitoring undertaken at each site is summarised in Table 2. Typically the energy consumption and power factor of all refrigeration plant, heat rejection equipment and distribution loads associated with the delivery of cooling within each system are measured directly. In some cases loads are estimated, where the monitoring of secondary loads such as distribution pumps is impractical and reliable estimations can be made.

Additionally, detailed meteorological data has been monitored or obtained on a regional basis to determine ambient conditions (i.e. not subject to building micro-climates) to include temperature, humidity, solar irradiance, wind speed and direction. Only the energy consumption and floor area data has been used in this paper.

Table 2. Summary of monitored parameters at each site

Monitoring Parameters	*Measured units*	*Intervals*
Refrigeration, heat rejection & distribution loads associated with the cooling system	KWh & kVArh	10, 15,or 30 minutes
Internal temperature	Deg C	10, 15,or 30 minutes
Local external temperature	Deg C	10, 15,or 30 minutes
Local external relative humidity	%RH	10, 15,or 30 minutes

A detailed building survey has also been undertaken based on the CIBSE Energy Assessment and Reporting Methodology for Offices (CIBSE 1999) for each site monitored. The surveys collect sufficient information to determine: building form and fabric; occupancy levels and patterns; estimated thermal loads; HVAC system details and control regime.

INITIAL FINDINGS FROM THE MONITORING

The initial findings are based upon the energy consumption data by floor area from the first 28 buildings in the sample, recorded between March 2000 and December 2001. Crucially, this data has not yet been adjusted to account for the loads placed upon the system, or the hours of operation. Hence the general nature of the observations presented.

The findings generally show much wider variations in the energy consumption than would be expected from the laboratory system component data for the systems studied. Assuming that the laboratory data accurately reflects component performance in-use, then it would appear that the wide variation in energy consumption must be due to the effects of load imposed on the individual A/C systems, along with the effects of their control regimes and their design.

Figure 5 illustrates by generic system type, the range of average monthly cooling energy consumption found in the buildings studied.

These initial findings only consider cooling during June to August in order to avoid the issue of simultaneous heating and cooling, which can occur in some systems.

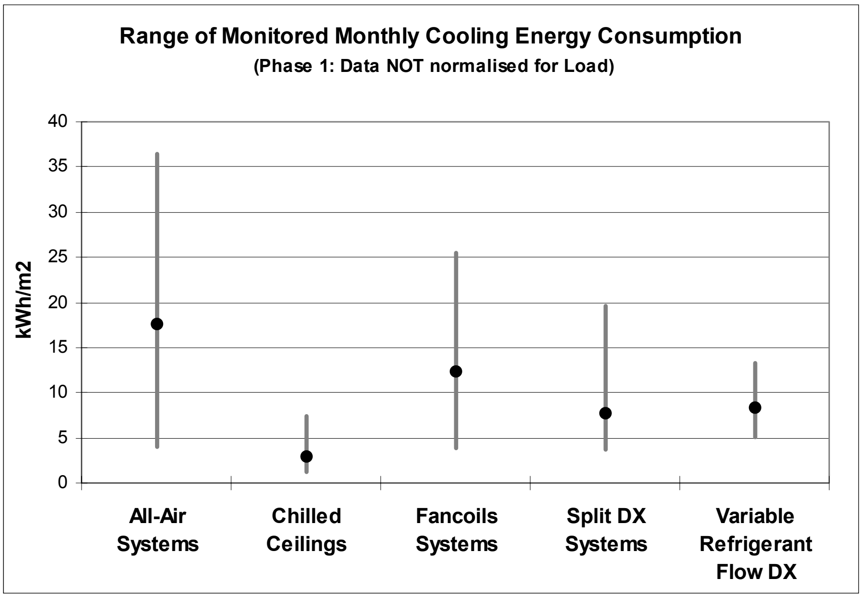

Figure 5. Monthly ranges of energy consumption by system type

The mean monthly energy consumption can be seen to range from 3.0 kWh/m^2 for chilled ceiling systems to 17.6 kWh/m^2 for All-Air systems.

The lowest energy consumer was a passive chilled ceiling system that utilised natural ventilation and a packaged air-cooled chiller, with typical summer cooling consumption of $5W/m^2$ ($15\ W/m^2$ Peak). By comparison the highest energy consumption was a Variable Air Volume system with a typical summer cooling consumption of 84W/m2 ($136\ W/m^2$ Peak)

Overall the monitored data suggests significant differences in energy performance by the different generic types of system and in particular in the ranges of energy performance. In particular the chilled ceiling sites were all very low consumers and the VRF Heat Recovery systems had a relatively small range of consumptions. But of course these different types also provide different level of services and are not necessarily suited to all applications.

OVERALL OBSERVATIONS AND CONCLUSIONS

This study has generated a unique set of real-world data that provides insight into the current energy performance of air conditioning in UK office buildings and there are apparent significant differences in the energy performance and the range of energy performance between the different generic AC system types.

As stated earlier, the figures presented here are not yet normalised for load and it is clear that building loads are one of the main driving factors of the actual energy consumption of the systems studied. However, we know enough about the buildings and their occupancy types to be fairly confident that the figures shown would encompass the majority of Offices found in the UK.

Applying these broad observations to the data, we find that the range of expected monthly energy use by an A/C system would be between 2 and 35 kWh/m^2, which equates to a range of electrical input loads of between 5 W/m^2 and 87 W/m^2 during occupancy hours. Assuming a range of 'as installed' A/C system COP's of between 1.5 and 3, this equates to potential building loads of between 8 W/m^2 and 260 W/m^2, though a range of 15 W/m^2 to 180 W/m^2 is more likely.

In the UK, typical practice for A/C system sizing assumes loads of 100 – 120 W/m^2 (Hayward 1988), which is in the middle of the potential range of loads encountered during this research. However, the majority of systems studied here used less than 8 kWh/m^2 or 22 W/m^2, which equates to an average cooling load of between 30 and 70 W/m^2.

Therefore, it is apparent that the energy consumption by the various AC systems can vary significantly for similar cooling loads. Observations noted during the monitoring which may affect the energy consumption, include:

- Design issues such as choice of control strategy (local, centralised or BEMS control etc); location of thermostats; sizing of plant and components; ventilation type and configuration.
- Various controls issues including overrides leading to 24 hour 7 days a week operation; system interlocks leading to system conflicts; control algorithm errors leading to un-intended system operation.
- Commissioning issues such as improper grouping of internal units; calibration of sensors; improper installation of equipment.

However, assuming the majority of systems are serving similar loads, then the main drivers for energy consumption in the AC systems studied appear to be the design (including generic type selected) and control of the systems. At present differences in system component efficiencies appear less significant than these two factors.

FUTURE WORK

Future outputs from the work will include comparisons of the energy performance of the buildings monitored taking into account the loads placed on the systems using a dynamic thermal model.

Figure 6 shows a flow chart of the planned methodology for this study. This will allow comparison of how efficiently these systems have performed under real-world conditions, and identify which factors were most influential in determining the energy performance.

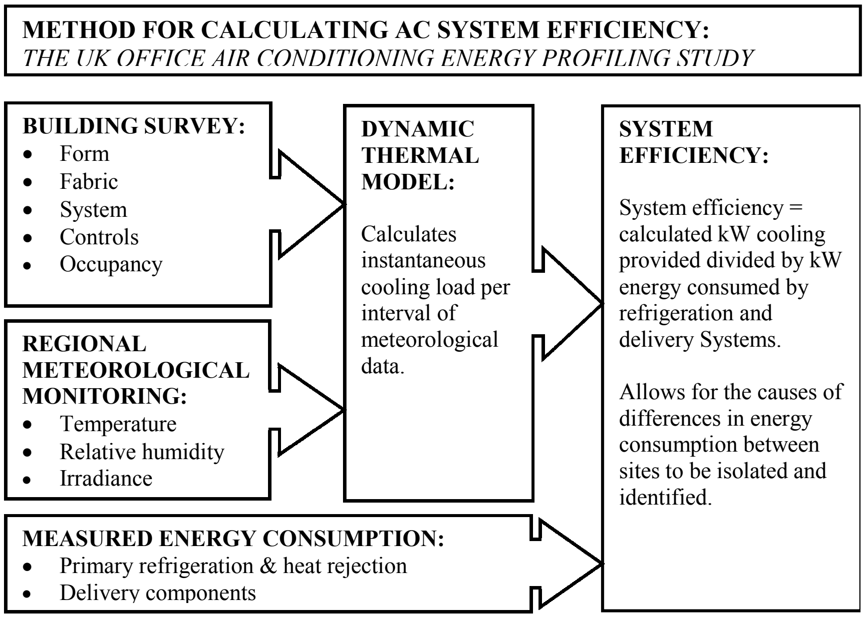

Figure 6. Method for calculating AC system efficiency

Further analysis of this data, intends to look at the "actual" energy performance of the systems as related to the effects of system sizing (i.e. part-load performance) and how efficiently reverse cycle systems deal with simultaneous demands for heating and cooling.

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