CARBON AND COOLING IN UK OFFICE ENVIRONMENTS

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ABSTRACT
This paper discusses the latest results and development from an ongoing programme of research by the Welsh School of Architecture, studying the energy performance of air conditioning systems used in Offices in the UK. Over the past five years major field energy monitoring studies conducted in association with industry partners have established a considerable knowledge of the energy performance of air conditioning systems in practice.

Based on the expertise and extensive empirical air conditioning performance data already obtained further analysis is being undertaken to ascertain the effect of the building fabric on the loads experienced by the AC systems studied. This is the final piece of research needed to draw firm conclusions about what aspects of buildings, building services, their design and use have the greatest effect on air conditioning energy performance, and hence atmospheric carbon emissions, in the UK context. Many of the findings will have application at a worldwide level as the results can be used to validate existing or proposed design models and legislative control mechanisms.

The results obtained from this research are also contributing to the 'Field Benchmarking and Market Development for Audit methods in Air Conditioning' (AUDITAC) project, a Europe wide consortium project being undertaken on behalf of the European Commission.

INDEX TERMS
Air Conditioning, Energy Efficiency, Carbon Emissions, Monitoring, Modelling, Europe, UK.

INTRODUCTION
While the energy consumption and atmospheric carbon emissions from most building related services are falling, in the UK those associated with air conditioning (AC) are growing as more buildings become air conditioned (Pout 2002) due to increasing occupant expectations of thermal comfort. This growth in carbon emissions conflicts with national commitments to reduce greenhouse gas emissions, under the Kyoto protocol and the UK Government's additional goal to reduce emissions by 60% before 2050 (DTI 2003).

In practice, resolving this conflict is likely to involve the use of cleaner energy supplies, improved integration of building and services design and promoting the use of highly energy efficient AC systems. In order to achieve the latter, clear guidance on the appropriate use of AC and which systems are the most energy efficient in practice, is urgently required.

A series of field energy monitoring studies of AC systems undertaken by the Welsh School of Architecture over the past five years has started to answer many of the questions required to

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establish which AC systems are the most efficient in practice. This monitoring also established an extensive database of empirical AC energy performance data.

Building on this data the Welsh School of Architecture, in association with the Association of Building Engineers (UK), are undertaking further research to ascertain the effect of the building fabric loads on the performance of the AC systems studied. Combining this with the detailed energy performance data already collected will enable the research to draw firm conclusions on which aspects of buildings, building services, their design and use have the greatest effect on AC energy performance, and hence atmospheric carbon emissions, in the UK context.

This paper provides an overview of the findings from the field energy monitoring studies already undertaken and explores the methods likely to be employed as the work is further developed, as well as, the eventual outcomes from the research.

OVERVIEW OF FIELD MONITORING RESULTS

The field monitoring studies undertaken so far include a major independent study that monitored the energy consumption in over 30 comfort cooling systems 'as found' in actual UK office buildings, which monitored all cooling energy consumption at 15 minute intervals over a three year period, as well as, a more detailed monitoring study that studied a number of systems in greater detail. A number of papers on this research have been published to date by the authors (Knight 2005, Knight 2004, and Knight 2002).

The overall aims of this research were to answer the following major questions:

- How Carbon efficient is our current AC systems in real buildings?
- Are some AC systems inherently more carbon efficient than others in practice?
- By how much is it possible to improve the average carbon performance of AC systems in UK Offices using currently installed AC technology?

The cooling energy demand profiles obtained from this monitoring are presented in Figure 1, which shows the average week-day daily energy consumption taken over the two consecutive summers of 2001 and 2002 for each of the generic systems. These profiles are relatively consistent between systems, with all systems showing an early morning start up load and a peak afternoon load, though it is apparent that the Chilled Ceiling (red) systems consumed substantially less energy per m^2 to meet the comfort cooling loads encountered in the offices studied.

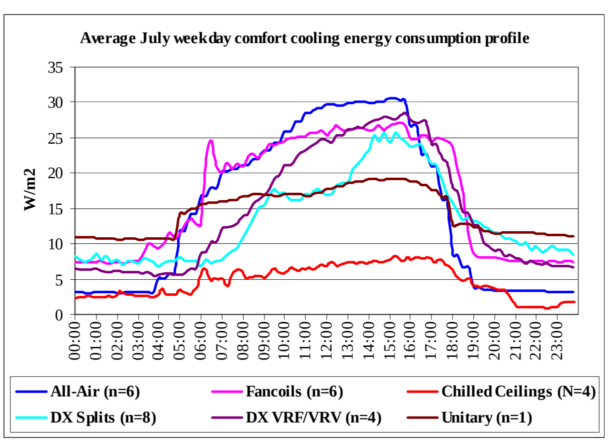

Figure 1. Average weekday cooling energy consumption profiles by system type

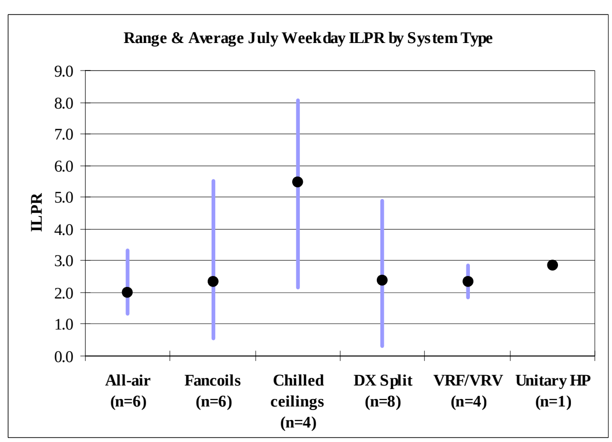

Figure 2. Average weekday cooling efficiency (ILPR) by system type

The data shown in figure 2 normalises the measured consumption for the internal heat gains encountered per m^2 in the offices monitored. The result is a dimensionless term we have chosen to call the Internal Load Performance Ratio (ILPR). The figure clearly shows that Chilled Ceiling type systems still consumed less than half the energy per m^2 of the next most efficient system type and this result is reflected in the annual energy consumption data shown in Figures 3 and 4, for the cooling-only and reverse-cycle systems respectively.

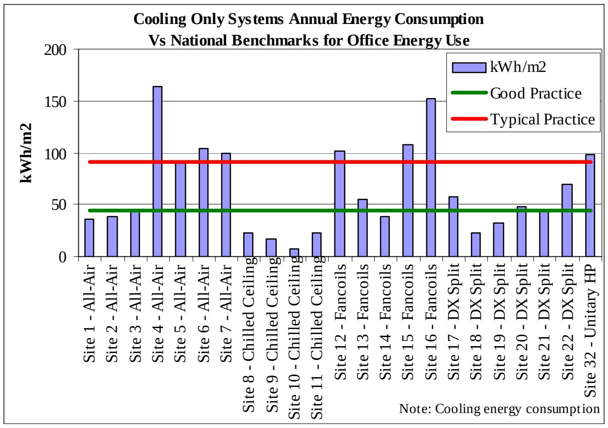

Figure 3. *Cooing-only systems measured annual energy consumption*

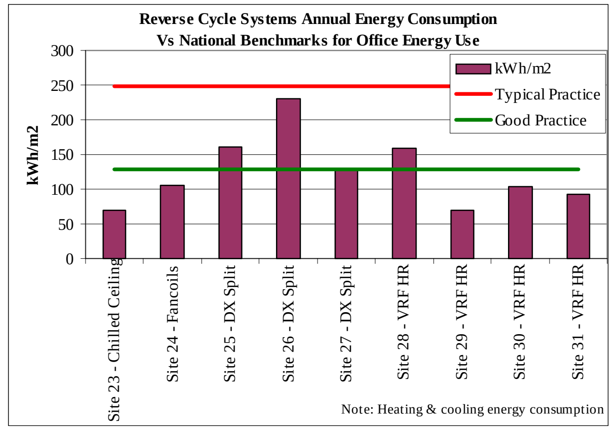

Figure 4. *Reverse-cycle systems measured annual energy consumption*

In the work undertaken so far, the effect of fabric and solar gains on the load imposed on each system have yet to be analysed, but it is the authors belief that even with these loads accounted for the Chilled Ceiling systems will still hold a clear efficiency advantage over the other systems tested. This belief has been reinforced by the modelling results of AC seasonal energy performance by other research (Dunn 2005).

One of the other important findings from the study is that control of the systems was patchy, as the run-hours of many systems, shown in Table 1, bore no relation to the times they were actually required. On average the monitored systems ran twice as long as conservative estimates of the occupancies served suggested they were needed. The data suggests that 50% energy and Carbon savings appear feasible from effective time control alone.

Analysis of chiller part-load profiles revealed that virtually all the systems were oversized for the loads they actually encountered in practice. An example chiller part load profile is shown in figure 5.

Table 1. Average annual run-hours by system type

System type	Cooling only	Reverse cycle
	(hours)	(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

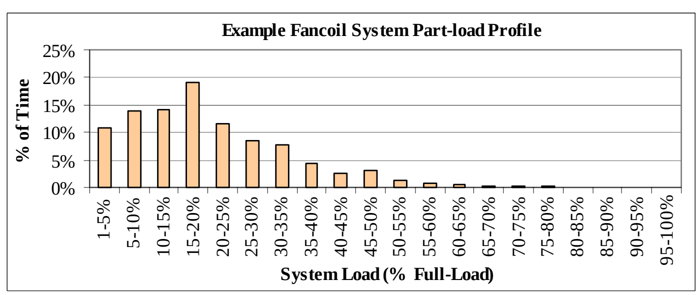

Figure 5. *Example measured part-load frequency profile*

Typically the systems studied 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 leading to reduced system efficiency as well as increased capital and running costs.

Although further work is required to establish by how much oversizing affects the efficiency and costs of the systems, one conclusion must be that current load estimation and sizing methods are over estimating the loads actually encountered in UK practice and the data suggests that this is certainly the case as the research has shown that current design standards for UK offices do indeed appear to over estimate internal heat gains and only really apply at the highest occupant densities. (Dunn 2003)

NATIONAL CARBON EMISSIONS FROM COOLING

The implications of this research to the prediction of UK carbon emissions from air conditioning, is illustrated in figure 6, which shows predicted UK carbon emissions from air conditioning up to the year 2020 using current UK Government market growth and electricity carbon intensity estimates (DEFRA 2002). Three possible scenarios are presented:

- **Scenario 1:** assumes no major change to the way we currently use air conditioning
- **Scenario 2:** assumes all new systems from 2005 onwards are as efficient as the most efficient systems currently available
- **Scenario 3:** assumes all AC systems, both new and existing, are progressively replaced with the most efficient currently available

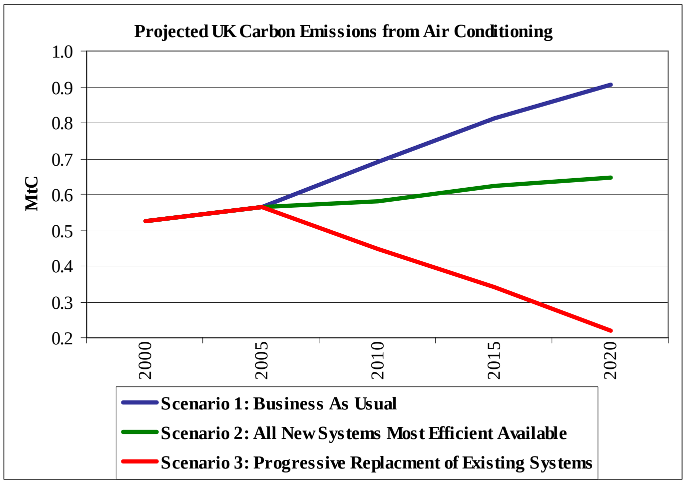

***Figure 6**. Projected UK carbon emissions from comfort cooling air conditioning*

Scenario 3 shows that, if all AC systems were able to perform to the level of the most efficient systems currently available then Carbon emissions from cooling could be reduced by 58% from 2000 levels, despite the projected increased use of AC over this period and without major change to the carbon intensity of national electricity supply.

FABRIC-SOLAR LOADS AND ENERGY PERFORMANCE

To refine the conclusions from the analysis already undertaken, the next stage of the study is to thermally model the buildings already monitored 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.

Therefore 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 7, where:

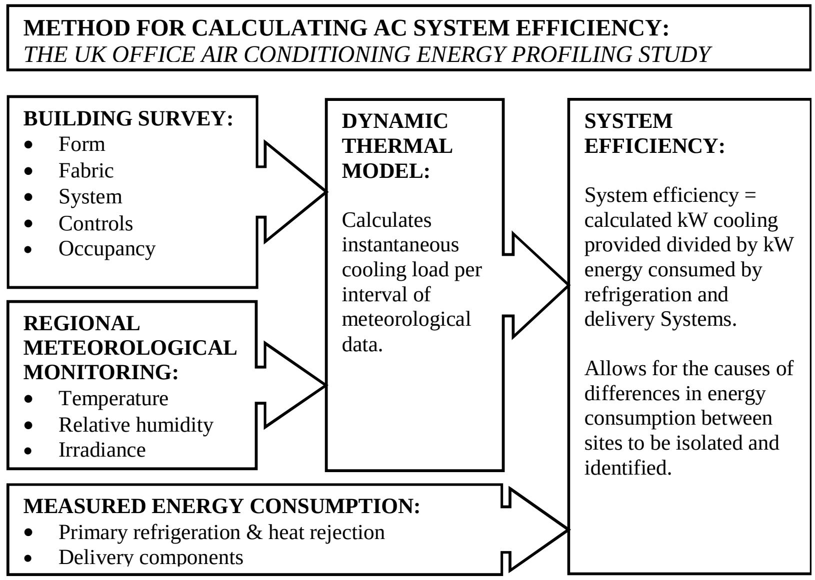

Figure 7. *Method for calculating AC system efficiency*

- 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 us to:
- 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.

These results will, therefore, 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.

EUROPEAN AUDITAC PROJECT

The results of all the research described are contributing to a two-year project funded by the European Commission’s Intelligent Energy Europe programme and 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.

CONCLUSIONS

This research has started to answer many of the questions regarding the relative performance of AC systems in practice and how we service our buildings, while also reducing Carbon emissions. Overall it is clear that AC systems as currently used in the UK show the potential for substantial improvements in system Carbon emissions performance, and significantly these improvements can be accomplished through existing technology.

The field energy monitoring undertaken shows that generic chilled ceiling systems are the most efficient way of delivering comfort cooling in UK offices, and to a lesser extent direct expansion (DX) systems also have the potential to be very efficient, but often fail to achieve their potential performance in practice due to poor operation and control. However, the work also illustrates good design, plant sizing, maintenance and control practice is equally important to achieve efficient cooling. Since the majority of systems monitored were oversized current design standards appear to be contributing to the oversizing by overestimating the loads served. Finally, a 50% saving in emissions appears possible from time controls alone.

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.

ACKNOWLEDGEMENTS

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