Field assessment of the urban density of air conditioning use in the United Kingdom in non domestic buildings

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Abstract
Increasing sales of air conditioning (AC) will exacerbate future heat waves, paradoxically with positive feedback, since the resulting augmented emission of greenhouse effect gases will in turn contribute to global warming. According to a research study carried out in 2000 (Hitchin, E.R et al), the total air-conditioned UK building area, under both cooling and reverse systems, was estimated to have almost doubled over the previous decade and is projected to nearly double again by 2020. This has now become an urgent concern. However the estimated increase is based on sales data and the detailed patterns of increase in urban density of air conditioning use in service and retail sectors in the UK are largely unknown. Energy use information was collected from a major study carried out in the early 1990s. Since then there have been many changes in these sectors, with shifts in location patterns, and increased use of air conditioning in offices and shops. Unfortunately, AC unit sales figures may not indicate which stock is new, and which is sold as replacement. In this paper, the results of surveys of over 2000 retail premises and offices are presented. These are derived from ongoing surveys with the goal of a statistically representative picture of AC usage within the UK.

Introduction
Since the early 1970s UK energy consumption in the service sector, (i.e. commercial and public buildings), has increased by approximately 30 % compared to a 25 % increase in the domestic sector (DTI, 2005). Of the total UK energy consumption of 6,695 PJ in 2000, 880 PJ was used by the service sector[1], of which 160 PJ or 15 % was consumed by the retail sector (Pout et al, 2002). In office buildings, demand for air conditioning has grown rapidly alongside a dramatic increase in CO_2 emissions (Scrase, 2001).

In the EU as a whole, the growth in AC use by treated floor area has increased by almost 400 % since 1980 (Marchio, 2005). For the UK in 2000, total area air conditioned in all buildings, under both cooling and reverse systems, was estimated to have almost doubled (188 %) from over the previous decade to 204 Mm^2 and is projected to nearly double again (196 %) by 2020 to more than 400 Mm^2 (EECCAC, 2002). This corresponds to an increase in energy consumption from 8.5 PJ in 2000, to almost 16 PJ in 2020 and a rise from 826 kt to 1,540 kt in CO_2 emissions.

Detailed figures for UK energy consumption by sub-sector or by air conditioning system are sparse. However by the end of 1994, about 11 %, or approximately 10 Mm^2, of retail area was estimated as being air conditioned (Hitchin et al, 2000). By 2000 ventilation and cooling was calculated as accounting for about 8 PJ or 5 % of annual energy consumption in the retail sector, with rapid growth expected particularly for packaged rather than central air conditioning systems (EECCAC, 2002) (Hitchin et al, 2000). The UK has a temperate climate; however eight out of the ten warmest years recorded in England happened in the last 16 years. AC usage in the UK's retail sector is a

1. In UK service sector by convention includes all non domestic buildings except factories and similar industrial units.

relatively recent phenomenon but as the global climate warms, the sudden growth of AC usage is a cause for concern.

A low depth survey methodology was developed within the CaRB project to obtain sufficient premises to provide a statistically reliable estimate of the growth of AC use in the UK within the retail sector (Brown et al, 2006). Additionally to examining this growth, some energy efficiency data were collected These include air curtains, traditionally used in the UK to isolate a heated area from the outside in winter, now used in commercial refrigeration (Cui, Wang, 2004).

Methodology

Summer surveys were carried out in many cases by examination of installed air conditioning and energy efficiency measures from outside. When air conditioning use was unclear, the survey was extended by entering the retail premises, frequently interviewing shop staff. Towns were chosen primarily to view a reasonable range of sizes, and for accessibility, during 2005/2006.

External temperatures during the surveys varied in the range 18 – 23 °C. The cities chosen are located in two distinct climatic regions, Leicester, Chesterfield and Stamford, Swindon, having cooler summers when compared with London. The regional cooling degree-days for England's Midlands are usually below 50 whilst for the Thames Valley region varies between 50 to 100.

SHOP SURVEYS

The ratio of shops with and without air conditioning is shown in Figure 1. It is interesting to note that the proportion of AC use in London is much greater for other cities, Leicester and Chesterfield being approximately equal.

Figure 2 shows the proportions of AC configuration and installation from the dataset for shops which are not in shopping malls. Shopping malls were not included in the survey for three reasons. Firstly, the growth of packaged systems in the UK exceeds that of central systems. Secondly, cooling loss in UK shopping centres is controlled to a much greater extent, with shops venting to an enclosed space, often also treated. Thirdly, the use of large central air conditioning systems such as those found in shopping malls is already the topic of other researchers in the field, e.g. Canbay, C.S., A. Hepbasli, and G. Gokcen. A summary of these results is given in Table 1.

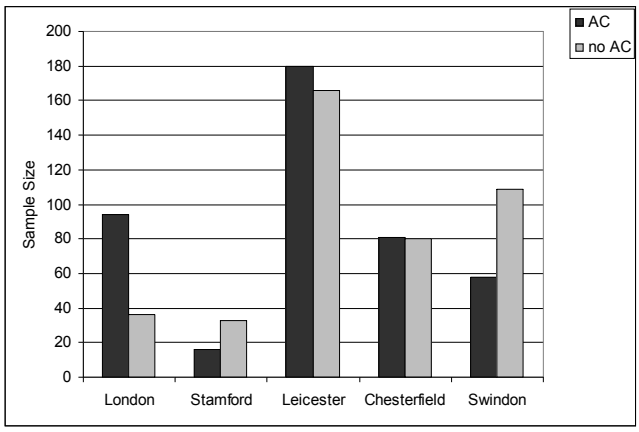

Figure 1. AC vs. no AC by town.

Figure 3, shows the door configurations within AC treated shops only. It can be seen that only around 40 % of shops with air conditioning employ any energy saving measures during the cooling season. The results show that the use of energy saving measures during the cooling season, such as closing external doors, or using air curtains, is minimal. The surprisingly high proportion of air conditioned shops with doors open or no air curtain in summer raises the question of how much cooled air is lost through doorways, and consequent energy loss. Estimation of energy losses using detailed field measurements; empirical mathematical models and computational fluid dynamics (CFD) show that in fact operating conditioned facilities with an open door increases the seasonal energy usage significantly (e.g. Lawton, E.B, 1995; Brown N. et al, 2006)

OFFICES SURVEYS

Office buildings have been estimated to represent nearly half of the total cooled floor area in the UK. Developers, building owners and tenants believe that air conditioned spaces result in more satisfied and more productive employees, and often higher rental values. There is concern that an increase in the frequency of spells of hot weather will be a driving force for an major growth in sales of AC systems to developers, owners and tenants, to whom uncooled space may well be seen as an increasingly risky commercial option.

In London where the heat island effect can add several degrees to ambient temperatures the intensive use of AC has already caused disruption of supply. Customers in borough of

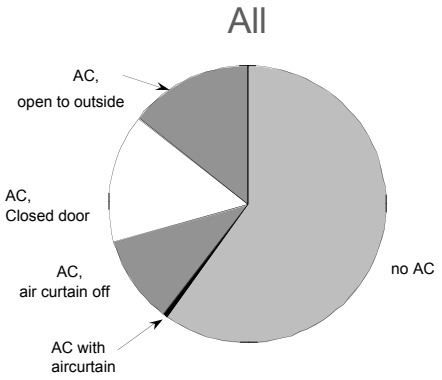

Figure 2. AC and door configurations.

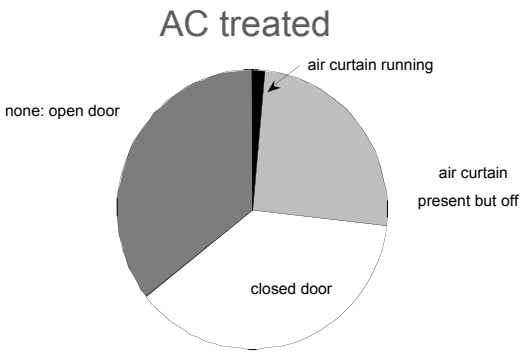

Figure 3. Door configurations for AC treated shops.

Table 1. Summary of AC and door configurations for the cooling season

AC configuration	Number of samples	% of total	% of AC treated only (Figure 3)
No AC	388	59.8	
AC, Air Curtain Off	66	10.2	25.3
AC, Air Curtain On	4	0.6	1.5
AC, Closed Door	98	15.1	37.5
AC, Open to Outside	93	14.3	35.6

Westminster, central London, with a very dense mix of retail premises and offices, were requested by the electricity utilities to refrain from using air conditioning after a succession of blackouts in the summer of 2006 caused business closures and financial losses in a large number of shops and restaurants.

Perhaps to offset the high costs and complexity of retrofitting businesses with packaged AC units, the market of portable units has been growing fast, as shown by the increase of sales. Most office premises are leased to different occupiers sharing the same building. It can thus be speculated that portable units will become increasingly popular among tenants as prices fall. These units can be easily controlled and moved around solving local overheating problems. However the type that only have a hot air discharge hose (Figure 4) that ejects air externally are not very efficient in cooling rooms. This is because the ejection of air creates a low pressure environment in the room, which will cause air to flow into the room from outside again, so this type of air conditioners is always replacing the cooled air with hot air. Cool air is also partially lost through windows kept open to let through the hot air exhaust tube or the outdoor unit.

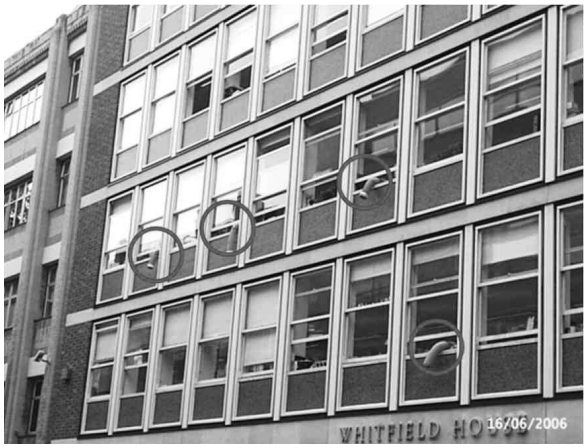

Figure 4. Hot air exhaust tubes or outdoor units.

Figure 5. An office building with a high percentage of open windows.

Figure 6. Comparison between two buildings.

DESCRIPTION OF THE METHODOLOGY DEVISED FOR DATA COLLECTION

The rate at which air conditioning continues to penetrate the office building market, the air conditioning technology used, the types and ages of buildings in which it is installed, and the activities carried out in those buildings, remains poorly understood. In order to increase the amount of data available an efficient method of determining AC incidence in offices in urban areas was developed. This section reports on the new method devised and the preliminary results obtained. The data collected in future surveys will have an historical value as growth trends can also be detected.

The core of the method is based on the simple assumption that in a hot day occupiers of non air conditioned offices generally open their windows to benefit from natural ventilation. On the other hand, in air conditioned offices windows are kept closed to keep the cold in, avoid warm air infiltration and reduce noise entry. This assumption can be used to make an efficient statistical assessment of the density of AC use in urban areas. The method is illustrated by Figure 5 showing an office building with a high percentage of open windows, while the outdoor temperature was about 32 ^{0}C. Figure 6 shows two office buildings facing each other on opposite sides of the road. One has a high percentage of open windows, the other none. It was immediately clear that just one building was being mechanically cooled (which was confirmed by other visible signs of air conditioning). Similarly to the shops surveys, percentages of open windows and type of AC system installed were observed

from street level. One of major merits of this method is that it allows a survey team to cover large urban areas with minimal time expenditure which is a clear advantage over methods such as phone surveys that require contacting building occupants and/or observations carried out within the building. The method also requires no sophisticated equipment other than a digital camera.

In tandem other methods were also tested to identify rooftop condensing units of centralized air conditioning systems namely satellite photography.

Results

The method was used to survey about 140 central London office buildings in a typical part of central London containing a range of low and medium rise office buildings of various ages. The results obtained show that there is a strong correlation between the percentage of open windows and the use of AC. In buildings with up to 14.81 % of Open Windows (OW), central and packaged air conditioning systems were clearly identified. For buildings with over 37.5 % OW no air conditioning system could be seen. The collected data shows that in buildings with less than 15 % of OW the likelihood of it being air conditioned is 95 %. For buildings with more than 37.5 % of OW the likelihood of not being air conditioned is 100 %. There is however a band of uncertainty between these two limits as it was found that about 10 % of the total number of buildings surveyed were Centrally Air Conditioned (CAC) but simultaneously had a relatively high percentage of open windows. Figure 7 shows a more detailed breakdown of CAC and non air conditioned buildings distributed by percentage of OW. Figure 8 shows the proportion of office buildings in the surveyed area with CAC or with no AC of any type.

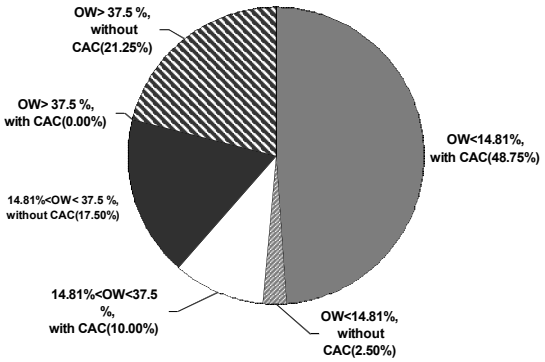

Figure 7. OW and central air conditioning distribution.

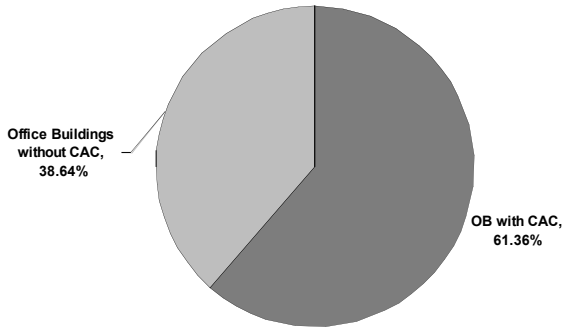

Figure 8. Distribution of centrally Air Conditioned and Non Air Conditioned building offices

Conclusions

The preliminary results of this study show that in London the use of AC in the retail sector is much more frequent than in other areas of the country. The reasons for this are unclear and further investigation is required to determine if it is related to the local climate, due to higher levels of occupancy, or other factors. Another important finding is that, in this survey area, the use of one important energy saving measure during the cooling season, namely closing external doors or using air curtains, is minimal.

The pilot study on office buildings AC incidence showed that the method developed is robust and can provide a good picture of the current AC incidence. In the survey area about 2/3 of all office buildings were air conditioned -. As with the shop surveys, the study is to be extended to other areas of London and of the UK.

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