Home air conditioning in Europe – how much energy would we use if we became more like American households?

George Henderson
Independent consultant
25 Ringway Road
Park Street, St Albans
Herts., UK AL2 2RE
george.henderson@ntlworld.com

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Abstract
Relatively few homes in Europe currently have air conditioning, which accounts for a small proportion of household electricity use by European households. In the United States of America, however, the 2001 Residential Energy Consumption (RECS) survey showed that three-quarters of all American households use electric air-conditioning and that it accounted for 16% of all household electricity use in the survey year. Much of the difference between Europe and North America may be attributed to climate but it is clear that other factors, including expectations of thermal comfort, also play a large part.

The information gathered by RECS includes the number of households with central and room air conditioning, conditioned floor area, average energy consumption per household and cooling degree days. Results are given separately for each of the 9 Census Divisions of the USA and the four most populated states: California, Florida, New York and Texas. This enables the use of air conditioning to be related to cooling degree days (CDD) and floor area. Despite relating to large areas that individually encompass substantial climatic diversity, the data show a strong correlation between energy use and degree-days. Other research used data from 39 American cities to establish the relationship between degree days and uptake of home air-conditioning systems.

This paper uses the relationships derived from American household data to estimate how much energy might be used at various locations in Europe if American uptake and usage patterns were to be followed. The results are compared with the projections made as part of the SAVE project on the Energy Efficiency of Room Air Conditioners (EERAC).

Introduction
The unusually warm spell experienced by Northern Europe in August 2003 raised questions about the need for cooling in both work places and homes, even in areas with summers cool enough to send their residents south for summer holidays. The impact of the warm spell was not confined to discomfort; based on retrospective analysis of the impact of the 2003 heat wave on mortality and emergency hospital admissions in England and Wales, it was concluded (Johnson et al, 2004) that there were around 16% excess deaths for the period 4th to 13th August, mostly among the elderly. Many more deaths were reported in other European countries. The recognition that the modest levels of heat experienced in the UK could be life threatening prompted speculation about the future uptake of air conditioning and its possible impact on electricity use. This was often based on comparisons with the United States, in some cases failing to take account of great differences in climate. The first aim of the research re-

1. The word “uptake” is used throughout this paper to mean the proportion of households using a service, in this case air conditioning. It is preferred to “ownership”, which is often used in the same context, but which seems inappropriate when used for households in rented accommodation.

ported in this paper is to provide a concise summary of available information about air conditioning in American dwellings, particularly how energy use and uptake of air conditioning systems are related to climate. The second is to use that information to estimate how much energy might be used by European households if they were to assume American ownership and usage patterns.

Information available from the USA

Information about the uptake and use of air conditioning by households is much more readily available for the USA than for Europe. The Energy Information Administration, a statistical agency of the U.S. Department of Energy, periodically carries out the Residential Energy Consumption Survey (RECS), a national statistical survey that collects energy related data for housing units. The most recent RECS for which results are available was conducted in 2001, collecting data from a sample of 4 822 households in housing units statistically selected to represent the 107.0 million housing units in the United States. Tabulated results from RECS are accessible from the EIA website. (EIA, 2004); all data attributed to RECS in this paper are from the 2001 survey tables unless otherwise stated.

The RECS 2001 tables contain data for both energy consumption and expenditure for air conditioning, broken down by type of air conditioning (central or room), climate zone, year of construction, household income, type of housing and region. They also show relationships between consumption and household characteristics, floor area and reported usage of systems.

TOTAL ENERGY USE AND EXPENDITURE

Table 1 shows key data relating to the uptake and use of air conditioning by US households in 2001. Although air conditioning accounts for only 6% of all energy used by households, it accounts for 16% of electricity used and 13% of household energy expenditure. The percentage figures may seem relatively modest but should be viewed in the light of the very heavy overall use of electricity by US households; the average consumption of 2 263 kWh per year for air conditioning is well over half of all electricity use by an average European household.

UPTAKE OF SYSTEMS

The 76% of households using air conditioning comprise 54% with central systems and 22% with room air-conditioners. Around a fifth of the central systems are shown to include a heat pump capability. Of those using room units, just

Table 1. Key data on the uptake and use of air conditioning by US households (from RECS 2001).

Total number of households using electric air conditioning	81 million
- percentage of all households	76 %
Total energy consumption by household air conditioners	183 TWh/year
- percentage of all household energy use	6 %
- percentage of all household electricity use	16 %
Average energy consumption per household using air conditioning	2 263 kWh/year
Total energy expenditure for air conditioning by households	$16 billion/year*
- percentage of all household energy expenditure	13%
Average energy expenditure per household using air conditioning	$197/year

(* the dollar was worth around 1.05 Euros during 2001)

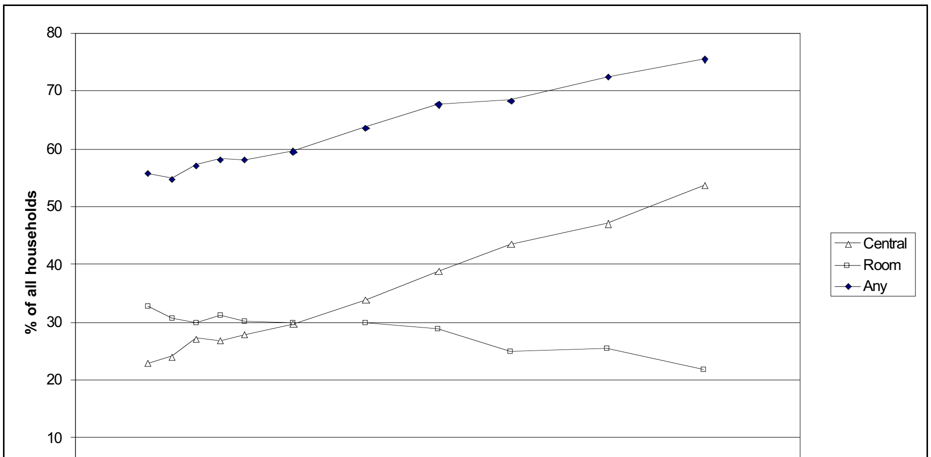

Figure 1. *Trends in the use of air conditioning by US households (Source EIA).*

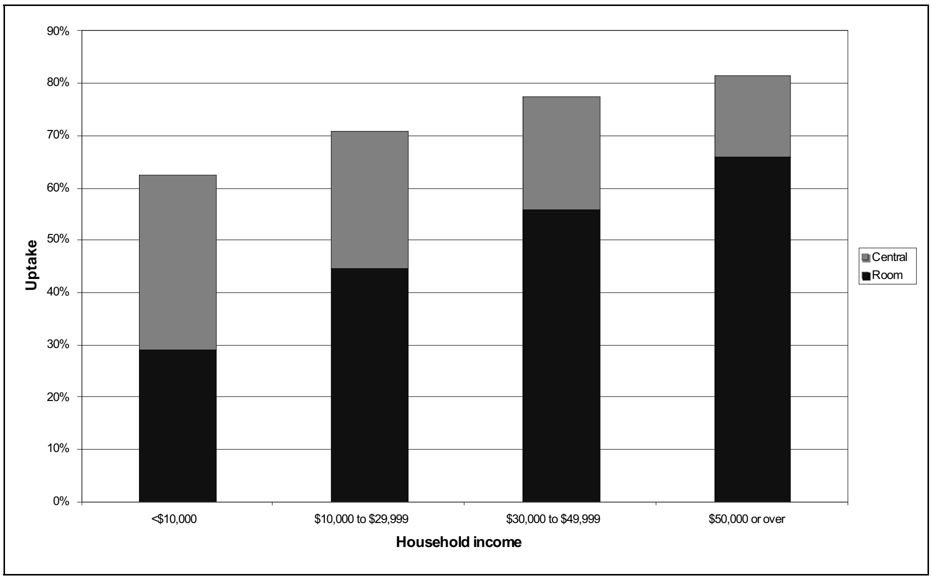

Figure 2. *Variation of uptake with household income (Source EIA).*

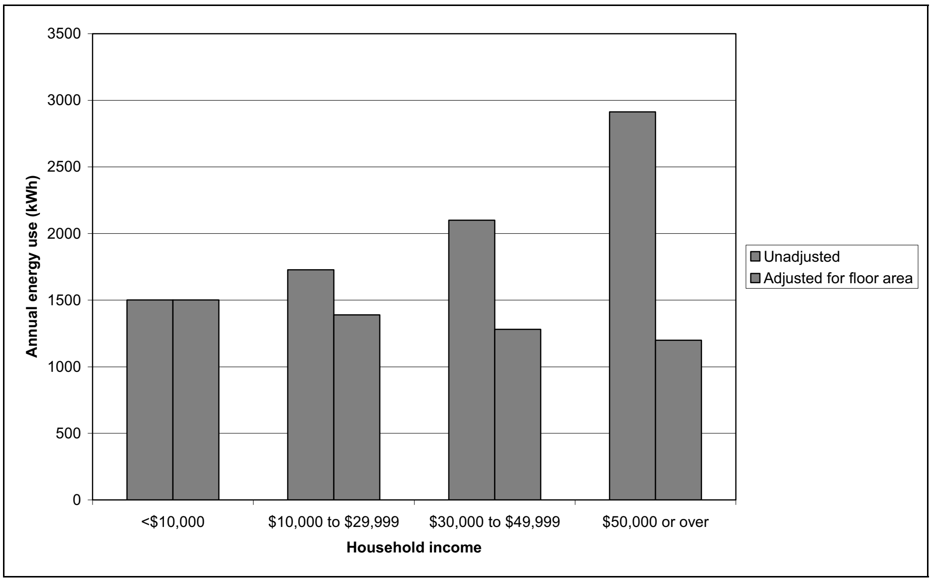

Figure 3. *Annual energy use by household income.*

over half have a single unit while an eighth have 3 or more units. Figure 1, which includes data from an earlier report (EIA, 2000), shows trends in the use of air conditioning by US households reported by RECS since 1979.

The overall percentage of households using air conditioning rose by just under 1 percentage point per year between 1977 and 2001. The uptake of central air conditioning grew more rapidly, doubling over the same period, partly through displacement of room units. There is no sign that saturation has been reached in the figures for the USA as a whole. The South census region, however, reached an overall uptake of 95% in 2001, including 78% with central systems.

VARIATIONS IN UPTAKE AND ENERGY USE WITH HOUSEHOLD INCOME

The RECS tables show uptake and energy use by household income. Figure 2 shows uptake to rise from 63% for the lowest income group to 81% for the highest. The difference is greater for central systems for which the uptake is more than twice as high for highest income group as for the lowest.

Figure 3 shows annual energy use by the highest income group to be almost twice that by the lowest income group. This appears to be largely related to floor area; when adjusted for floor area the relation appears to go in the opposite direction, possibly because the high income households are more likely to own better performing houses and systems.

REPORTED USE OF SYSTEMS

RECS reports of use of air conditioning systems by category: “only a few times”; “quite a bit”; and “all summer”. The results are summarised in Table 2, expressed as a percentage of all households using each type of system. Almost half of central systems are reported to be used “all summer” but the majority of room units are used "only a few times". In addition to those households covered by Table 2, a further 2% of all households with air conditioning report that they do not use it at all; such households are much more prevalent in the West Census Region, where they constitute 10% of households with air conditioning. Earlier RECS tables (EIA, 2000) show the number of households in the "all summer" category to have grown significantly, from only 33% of those with central systems in 1981. Usage is strongly climate related; the "all summer" category accounts for 68% of central systems in the South census region. However, the ratio of "all summer" to "only a few times" users does not seem to vary significantly across the income groups.

AGE AND EFFICIENCY OF EQUIPMENT

Table 3 summarises the age of equipment reported in RECS. Central systems are on average older than room units, reflecting greater longevity of the equipment. The numbers shown to be over 10 years old are surprisingly high in both cases: 37% of central systems and 27% of room units. Estimates are given (EIA, 2000) of the efficiency of average efficiency of central systems (SEER[2]) sold in various years; this rose from 7.34 in 1977 to 10.66 in 1997, in large part due to the introduction of standards.

REGIONAL VARIATIONS IN ENERGY USE

The RECS tables show results for 9 Census Divisions of the USA, giving the total number of households, the numbers owning and using central and room air conditioning, energy consumption per household and cooling degree days for each category. This enables the use of air conditioning to be related to cooling degree days[3] (CDD), albeit over relatively large areas that themselves encompass substantial climatic diversity. Similar information is also given for the four most populated states: California, Florida, New York and Texas. The key data shown in Table 4 are as reported in the RECS tables except that units have been converted to SI. Floor area has been converted from the original units of square feet to square metres. Cooling degree days are in Celsius, base 18.33 °C, converted from the original units of Fahrenheit, calculated relative to a base of 65°F using the standard American method. The energy use and floor area shown are for those households using air conditioning, not averaged over all households in the region. The degree days are also averaged over those households with air conditioning and apply to the year of the survey rather than the long term average. The final column shows annual energy used per square metre of floor area, which varies over a wide range between regions. Although they are included within their respective Census Divisions (e.g. California in the Pacific Division), the four most populated States are shown separately and cover an even greater range of conditions.

Figure 4 shows a very strong relationship between annual energy use and cooling degree days. The regression line shown on the graph is derived from the Census Division only but the most populated states appear to follow the same trend. The equation relating energy use to degree days is

$$Q = 0.0193CDD - 2.913 \text{ kWh/m}^2$$

It suggests that energy use would tend to zero for locations with less than around 150 cooling degree days. It may be observed that the base for the calculation is too low to correspond directly with cooling energy use, which would be the case if the intercept was zero. It is not possible to say precisely how much higher the base would need to be for

Table 2. Use of air conditioning systems by US households (from RECS 2001).

Reported use	Central systems	Room units
Only a few times	29%	58%
Quite a bit	21%	21%
All summer	49%	20%

(Note: columns do not add to 100% because of rounding.)

Table 3. Age of air conditioning systems used by US households (from RECS 2001).

Age	Central systems	Room units
Less than 2 years	11%	13%
2 to 4 years	18%	23%
5 to 9 years	28%	27%
10 to 19 years	27%	18%
Over 20 years	10%	9%
Don't know	6%	9%

2. Seasonal Energy Efficiency Ratio (SEER) is a measure of the average energy efficiency of a central air conditioner over a whole year of use, taking account of variations in load. SEER values quoted in the USA are expressed in units of BTU/hour per Watt and are therefore 3.413 times larger than a strict ratio of output to input when both are measured in the same units.

3. Cooling degree days provide a measure of accumulated temperature difference above a given base (or threshold) temperature, usually set at the level at which cooling might be required in a particular type of building. The degree days available from the US National Climatic Data Center and used in the RECS tables are calculated from daily mean temperatures. If the daily mean is greater than the base temperature of 65°F, the difference is the number of degree days for that day, if less than or equal to the base temperature then no degree days are counted. Other definitions and base temperatures are used, including some that take account of days when the maximum, but not the mean, temperaure rises above the base.

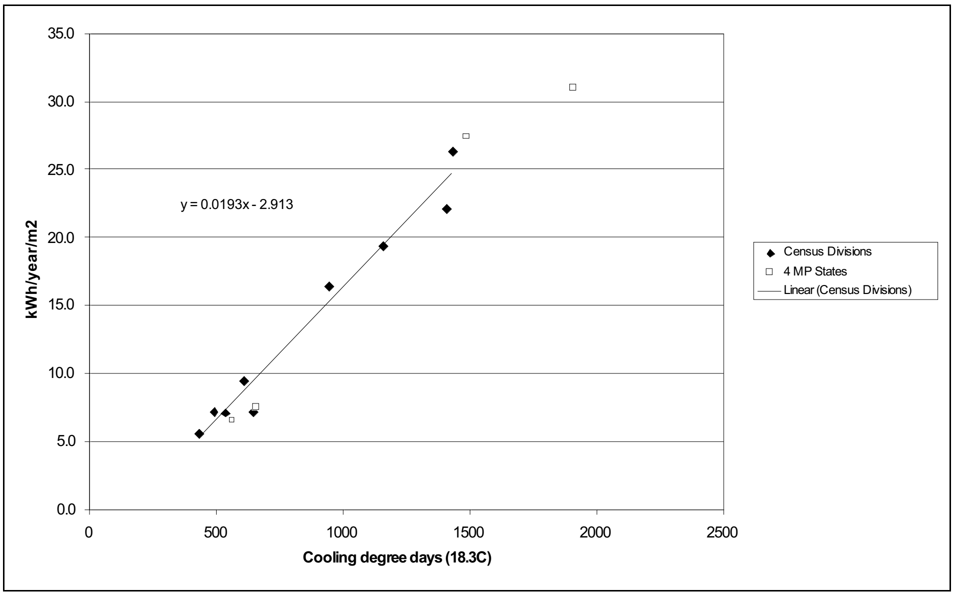

__Figure 4.__ Annual energy use for cooling against cooling degree days for regions of the USA.

Table 4. Regional variations in uptake and energy use.

Census Division	Number of households (millions)	Households with air conditioning (%)	Cooling degree days (base 18.3 C)	Average annual energy (kWh)	Average cooled floor area (m^2)	Energy per unit of floor area (kWh/m^2)
Mid Atlantic	14.8	75%	532	995	139	7.2
New England	5.4	59%	429	805	142	5.7
EN Central	17.1	78%	487	1 355	189	7.2
WN Central	7.4	91%	607	1 768	186	9.5
S Atlantic	20.3	94%	1156	3 137	161	19.4
ES Central	6.8	94%	943	2 888	176	16.4
WS Central	11.8	97%	1428	4 012	152	26.4
Mountain	6.7	48%	1404	2 850	128	22.2
Pacific	16.6	38%	642	938	130	7.2
Most populated States						
New York	7.1	66%	561	703	107	6.6
California	12.3	42%	657	967	128	7.6
Texas	7.7	96%	1 485	4 327	158	27.5
Florida	6.3	97%	1 908	4 855	156	31.1

the intercept term to become zero but it is of the order of few degrees, depending on the degree of variability of daily temperatures.

The relationship between the uptake of air conditioning systems and cooling degree days is shown in Figure 5, in this case using long term average degree days for the whole region weighted for population. In contrast to the close linear relationship observed for energy use, it is clearly non linear and two points deviate markedly from the general trend. The two errant points are the Mountain Division (Montana, Idaho, Wyoming, Utah, Nevada, Colorado, Arizona and New Mexico) and the Pacific Division (Washington, Oregon and California), which show much lower uptake than the trend. This may be due in part to the diversity of climate within those Divisions, each of which stretches from the Canadian border in the North to the Mexican border in the South. Another possible explanation lies in climatic factors other than degree days, particularly humidity, which is generally higher in the East than in the West of the USA.

Other research to establish the relationship between degree days and uptake of air condition by American households has been reported (Sailor and Pavlova, 2003). This work used data from 39 cities throughout the USA, which should overcome the problem with climatic diversity that was alluded to in the previous paragraph. It found a strong but highly non-linear relationship with climate for the up-

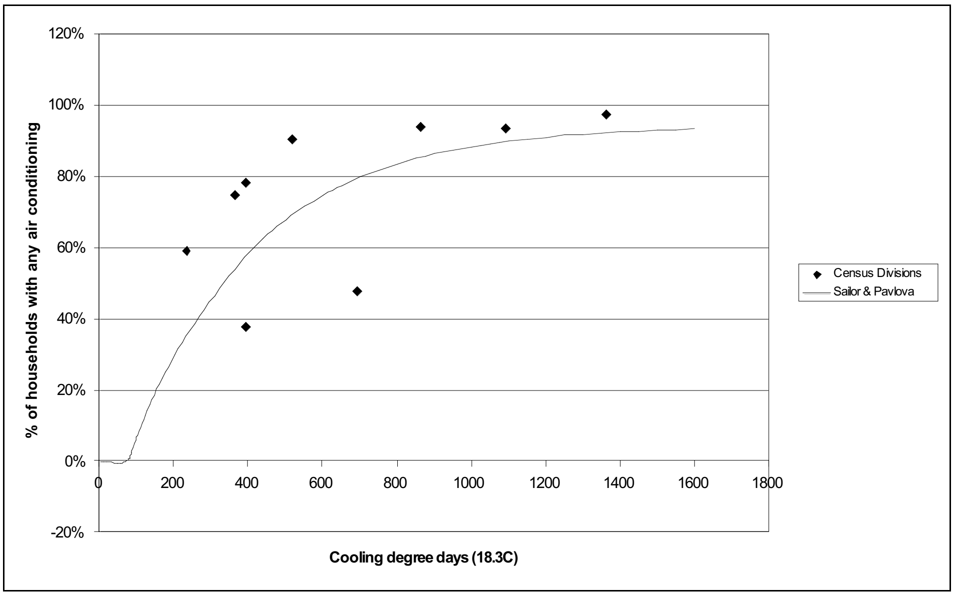

Figure 5. *Uptake against cooling degree days.*

take of both any type of air conditioning and central systems. Perhaps not surprisingly, the relationship for window (individual room) air conditioning was found to be much weaker, with highest uptake occurring where the number of degree days is relatively low. The best fit equation derived for the uptake of any air conditioning is:

$$U = 94.4 - 117\exp(-0.00298CDC) \qquad \%.$$

This shows the uptake of air conditioning rising steeply from a threshold near zero to around 90% at 1 100 cooling degree days. When added to Figure 5, it shows some similarity with the RECS data based on Census divisions. Differences may arise in part from the fact that two sources of data rely on different definitions of degree days. The EIA uses the standard American definition, which is calculated from daily mean temperature and counts no cooling requirement for days on which the mean is below the base temperature. The other work calculated degree days by aggregating hourly temperature differences and dividing by 24[4]. Thus any day on which the maximum temperature exceeds the base temperature will contribute something to the total by this method, with the result that a greater number of degree days is calculated. The results from the 39 cities also showed fairly high scatter and a conspicuous outlier in Honolulu, Hawaii, which has an uptake of only around 20% despite experiencing around 2 600 cooling degree days annually.

INSTALLED CAPACITY AND CONTRIBUTION TO PEAK ELECTRICAL LOAD

The RECS tables do not include information on the capacity of systems installed in dwellings or on the contribution they make to peak loads. It is widely recognised, however, that air conditioning systems (both residential and commercial) tend to contribute strongly to peak loads in summer and that summer peaks exceed winter peaks in many locations. The difficulties experienced in meeting peak loads in California have led to detailed analysis of electricity demand and exploration of options for better management of demand. A recent paper on demand responsive loads (Wilson et al, 2002) contained estimates of the contribution of both commercial and household air conditioning to the peaks experienced in 2002. Household air conditioning was estimated to account for 14% (7 000 MW) of the total peak load, exceeded only by commercial air conditioning at 15%. From the number of households in California (5.2 Million) using air conditioning reported by RECS, it is possible to estimate that each household contributes 1.35 kW to the total, i.e., the diversified peak load[5]. Other work, aimed at improving the efficiency of existing air conditioning systems in California, (Proctor Engineering, 2003) found average installed capacity of 2.92 tons[6], which is equivalent to an output of 10.2 kW and estimates an average energy efficiency ratio of 8 in American units[7], which is equivalent to 2.34 in standards SI units. This implies that average input power is 4.35 kW and the diversity factor is just over 0.3, which is much lower than the value of 0.7 quoted in the same report.

4. Established by private communication with David Sailor, 20th October 2003.
5. The diversity factor for a piece of equipment is defined as the probability that it will be in use at the time of the peak load. The peak diversified load is the average contribution made by a class of equipment to peak load and is the product of the average full load of the equipment and the diversity factor.
6. Air conditioning capacity in the USA is normally expressed in tons. A ton of air conditioning is equivalent to an output of 12 000 BTUs/hour or 3.517 kW.
7. Energy efficiency ratio (EER) is is a measure of the average energy efficiency basd on the ratio of output to input. As in the case of SEER, described earlier, in the USA it is expressed in units of BTU/hour per Watt.

Air conditioning by European households

SOURCES OF INFORMATION

In contrast to the situation in the USA, where household air conditioning has been widely used for several decades, it has only recently begun to spread in Europe and even now contributes little to electricity demand in most European countries. One consequence is that statistical information on both uptake and energy use is sparse, particularly at a pan-European level. This problem was addressed by two important collaborative projects supported by the European Commission: *Energy Efficiency of Room Air Conditioners (EERAC)* (European Commission, 1999); and *Energy Efficiency and Certification of Central Air Conditioners (EECCAC)* (European Commission, 2002). As described by their titles, the two projects focussed on the efficiency of room and central room air conditioners respectively, covering all sectors of the economy. Because most household air conditioning in Europe relies on room units, the EERAC project is the one more relevant to this paper.

CURRENT LEVELS OF UPTAKE AND ENERGY USE

The two European Commission projects referred to in the previous paragraph relied on market data provided by manufacturers to estimate stocks of appliances, using estimates of longevity to relate sales of new appliances to stock. The reports conclude that both the present stock and sales of central air conditioning systems to the household sector are effectively negligible and that household air conditioning is almost entirely by room units. Neither the number nor percentage of households with air conditioning is given for individual countries, except for Italy and Spain where it is given as around 10% and around 5% respectively for the base year of 1996. The overall percentage for the European Union is given as "no more than 2%". The European Union as it was composed in 1996 had a total of 150 million households, which implies that the total number of households with air conditioning was no more than 3 million, of which around half were in Italy. The overall consumption by households, obtained by modelling, is given as 2.46 TWh in 1996 (around 800 kWh per household), and estimated to rise to 11.5 TWh in 2020. If consumption per household were to remain constant, the estimated consumption implies uptake by around 14 million households or around 8% of the projected number of households in 2020.

The modelling undertaken for the EERAC project used 16 locations to represent the range of climatic conditions across Europe, although the report does not disclose the details of the methods used. It is of interest to use those same locations to make estimates of uptake and energy use based the relationships derived from American data and described earlier in this paper. This approach is beset with difficulties, however. The problem is that most locations in Europe have fewer cooling degree days than the lower end of the range covered by the US census regions and the expression derived for energy use may not hold.

Table 5 shows cooling degree days for a number of the locations used in the EERAC study, together with estimates of potential uptake of air conditioning and annual energy use based on USA data and described by the expressions given earlier in this paper for uptake and energy use. Degree days were calculated for each location by the two different methods to align with the different definitions used in the research reported from the USA. In each case the temperature data were obtained from the Swiss database Meteonorm (Meteotest, 2005), which can generate hourly data from monthly averages. The "US" definition, based on daily means, is needed for the expression for energy use derived from the RECS data while the "hourly" definition is needed for the expression for uptake reported by Sailor and Pavlova.

Table 5. Degree days and potential uptake and energy use for various European locations.

Location	CDD (US)	CDD (hourly)	Uptake	kWh/yr
Vienna	239	289	45%	136
Carpentras	315	422	61%	253
Athens	1 059	1 109	90%	1 403
Thessalonika	753	822	84%	930
Cagliari	687	767	82%	828
Milano	318	405	59%	258
Napoli	520	612	76%	570
Lisbon	443	531	70%	451
Murcia	765	902	86%	948

The most striking difference with the actual situation at present is the high levels of uptake implied. For example, Italy, which was estimated to have an uptake of around 10% at the time of the EERAC report, might be expected to have an uptake of over 70% by analogy with the USA. The annual energy use shown is based on average conditioned floor area of 80 m^2 and is relatively low for most locations, ranging from 136 kWh per household in Vienna to 1 403 kWh in Athens.

The information available about the modelling undertaken for EERAC is too sparse to allow detailed comparison or to attempt to scale the estimates from analogy with the USA to the whole of Europe. However, it is clear that much of Northern Europe would have low uptake and very low annual consumption. The author's own simple model, based on the same cities used by EERAC, suggests uptake would be by around one third of all European households and total energy use around 16 TWh, well over half of which would be in Italy, Greece and Spain. This compares with the EERAC projected consumption of 11.5 TWh for the year 2020. It seems, however, that the EERAC projection was based on uptake by a smaller number of households with a higher level of energy use.

EERAC also includes projections of peak load attributable to household air conditioning, including one of 24 GW for 2020. This is surprisingly large, compared to the current California peak load of 7 GW arising from 5.2 million households, including 3.9 million with central systems. This suggests that the EERAC estimate made a lower allowance for diversity than is implied by data from California.

The observations made above are simply based on climatic analogy and should not be mistaken for a forecast of what might happen in Europe. The low uptake of air conditioning by households in Europe cannot be attributed to being "behind" the USA in market development and expected to catch up in due course. In addition, degree days are a far from perfect descriptor of climate, particularly for relating to uptake. The USA itself shows a marked difference in this respect between East and West, with the latter having much lower uptake in locations with a given number of degree days. If Europe were to emulate California, rather than the USA as a whole, uptake would be much lower. As the relationship between energy use and climate in the USA seems to be much more robust than the one between uptake and climate, it is perhaps in that respect where comparison is most useful. It seems unlikely that European households will prefer more cooling than their American counterparts and American levels of consumption for a particular number of degree days might reasonably be taken as the upper limit for expected consumption. This suggests, for example, that households in Naples are unlikely to use more than 570 kWh per year on average and that consumption in many locations in Northern Europe is likely to be very low.

SENSITIVITY TO CLIMATE CHANGE

To gauge sensitivity to climate change, cooling degree days were recalculated for various locations in Europe after adding 2 degrees C to each hourly temperature in the Meteonorm files. The results are shown for selected locations in Table 6. The percentage increase is greatest for more Northerly locations, but is very significant in all cases. A 30% increase for Athens could cause a similar increase in consumption for those households who already have air conditioning, as well as adding pressure for greater uptake. The 108% increase for London is probably of lesser consequence, given that even energy use should remain low even after the increase, but it could trigger a significant increase in uptake. Overall, it must be concluded that household air conditioning could be very sensitive to even a modest increase in temperature and that climate change should be taken into account when estimating future energy demand.

Implications for energy policy in Europe

THE SIGNIFICANCE OF HOUSEHOLD AIR CONDITIONING

The EERAC study provides ample evidence of increasing uptake of air conditioning by households in Southern European households and analogy with the USA suggests that this trend has a long way to go before saturation is reached. This has implications for annual electricity use and carbon dioxide emissions but is particularly significant for its potential impact on peak demand for electricity. The impact on overall demand for electricity and carbon dioxide emissions should be kept in perspective – residential air conditioning is estimated to have accounted for just 6.4% of electricity use in the OECD countries in 2000. (Waide, 2004) The impact on peak demand is of greater consequence, however, and inherently more localised. As noted earlier, it was estimated that household air-conditioning contributed 14% of peak electrical demand in California in June 2000, only exceeded by commercial sector air conditioning with 15%. This suggests that policies should focus particularly on reducing peak loads.

Table 6. Effect on cooling degree days of a 2°C rise in temperature.

Location	Degree days with 2°C rise	Percentage increase
Athens	1 499	30%
Naples	903	47%
Milan	623	53%
Vienna	477	64%
Limoges	317	70%
London	206	108%

POSSIBLE POLICY INITIATIVES

Two broad classes of policy action may be distinguished: those directed at discouraging the uptake air conditioning by households; and those that seek to improve the efficiency and control of equipment and design of systems.

Policies to discourage uptake

It has frequently been observed that the perceived need for air conditioning depends on many factors and cannot be related precisely to an engineering definition of comfort. This suggests policies that promote the virtues of living without mechanical means of cooling, relying instead on adaptation of clothing and patterns of activity. It is clear, however, that the capacity to keep cool is strongly affected by building design, which may be more amenable to the usual forms of policy intervention. Vernacular architecture for warmer climates tends to incorporate features that are effective in limiting high temperatures in summer but are often ignored in recent buildings.

The tendency of modern housing to overheat in summer may be unwittingly exacerbated by building regulations aimed at saving energy, which concentrate on minimising the need for heating energy. The indoor temperature in well insulated buildings with low air leakage (required to minimise heating requirements) rises significantly in response to the gains arising from normal occupancy, including appliance use, metabolic gains and solar gains, which are exploited in passive solar design. The beneficial effect of gains in reducing heating requirements can be offset by causing discomfort in summer if measures are not taken to control solar gains and to provide additional ventilation when required. A possible solution lies in the use of comprehensive energy calculation methods, rather than insulation levels, for specifying energy performance for building regulations. The advantage of an overall assessment of the energy demand is clear but there are difficulties to be overcome before such calculations can be carried out routinely. Firstly, there is a requirement for a calculation method that is both capable of dealing with the complexity of the energy flows and simple enough to be used by the vast number of people involved in the design and construction of dwellings, many belonging to very small businesses without the resources to undertake complex modelling. Secondly, while indoor temperatures for assessing heating requirements for assessing heating are generally agreed, those for cooling are not; to set such temperatures might even tend to establish a "need" for cooling that is at present unspecified.

The Energy Performance of Buildings Directive (EPBD) sets out a general framework for assessing energy demand in buildings that requires inclusion of (among other aspects) "air-conditioning installation" and "passive solar systems and solar protection". Detailed work to provide harmonised calculation procedures is being undertaken by CEN (Bowie 2004), most particularly the revision of EN 13790 being carried out by Technical Committee 89. In the meantime, requirements aimed specifically at avoiding the need for cooling may be considered. For example, the current review of building regulations for England and Wales (ODPM, 2004) proposes a requirement to "demonstrate that the dwelling has appropriate passive control measures to prevent excessive solar overheating". This is to be achieved by a procedure based on the ratio of calculated gains to losses under summer condition, which takes account of the effect of window size, orientation and shading on solar gain, provisions for extra ventilation for cooling and thermal capacity.

Policies to improve the efficiency and control of equipment and design of systems

The success of labelling and minimum efficiency programmes for air conditioners in the USA and Japan provides strong encouragement for similar programmes in Europe. The EERAC study provided a sound basis for taking this forward and there is a clear case for doing so. Evidence from the USA that air-conditioners last for a long time suggests the importance of setting demanding standards at an early date.

There are many other technical options for reducing energy use, including those listed below.

- Regular inspection and assessment of the performance of air conditioning systems. This already is required by Article 5 of the EPBD for systems with an output of more than 12 kW.
- Load management procedures, in which consumers with real time meters agree to operate certain loads on a "demand responsive" basis. Programmes based on this type of control have proved to be successful in managing peak loads in the USA, including California. (Wilson et al, 2002)
- The use of desiccant and evaporative cooling instead of standard refrigeration cycles.
- Night ventilation strategies.
- Exploiting the synergy between the need for cooling and the availability of solar energy, for example through solar thermal assisted regeneration of desiccants. (Mavroudaki et al, 2002) This has previously been considered for non-residential buildings but could perhaps be exploited for apartment buildings.
- The use chilled beams/ceilings instead of air distribution systems.
- Ground coupling using boreholes or energy piles.
- Reflective surfaces and reflective barriers for roofs.
- All of the above have potential areas of application and could be encouraged through a research programme aimed at low energy cooling.

Conclusions

- Taking account of climatic differences, the emulation of American household patterns of air conditioning by European households would cause a very sharp rise in uptake but relatively modest increases in the overall demand for electricity. The most significant impact would be on peak electrical load in Mediterranean countries, although perhaps less severe than estimated by the EERAC study.
- American data show a very strong relationship between cooling degree days and electricity consumption for air conditioning by households. This suggests that large parts of Europe would have very low consumption even if they had air conditioning installed. The relationship between cooling degree days and uptake appears to be weaker, however, with some regions well below the general trend, including California, whose climate probably resembles that of Europe more closely than that of the East Coast. Degree days in Europe are very sensitive to climate change, suggesting that even a modest rise in summer temperatures could produce a very marked rise in uptake as well as a significant rise in energy use.
- European Union support for the EERAC and EECAC projects has been very valuable for providing both data on air conditioning use and a basis for labelling and standards, for which there is a strong rationale. The Energy Performance of Buildings Directive also contains a useful requirement to include consideration of air conditioning in energy calculations. There is a strong case, however, for more explicit action to ensure that building regulations include a requirement to minimise the need for cooling through passive means, including the provision of shading and additional ventilation in summer.

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